ISSN No. 0976-5697

Volume 2, No. 5, Sept-Oct 2011

International Journal of Advanced Research in Computer Science

REVIEW ARTICLE

Available Online at www.ijarcs.info

Fuzzy Set Theory Applications in Software Projects: A Literature Survey

Zaiynab Salarian*
Department of Computer Engineering
Islamic Azad University, Qazvin Branch
Qazvin, Iran
salarian.shima@gmail.com

Hassan rashidi
Department of Computer Engineering
Islamic Azad University, Qazvin Branch
Qazvin, Iran
hrashi@gmail.com

Abstract: Despite various approaches that exist in software risk management, software projects have still some difficulties in achieving software engineering objectives. Moreover, managing software development becomes more difficult when the complexity and size of projects are increased. One of the newest approaches for risk management in software engineering is to use Fuzzy Set theory. This paper provides an overview of literature over fuzzy set theory applications in software project. In the literature, several works that incorporated software project risk management and classification, Fuzzy Sets, Analytical Hierarchical Process and Fault Tree are reviewed. After reviewing the process, the strengths and weaknesses of the different approaches are compared and contrasted, and finally some challenges in future are presented.

Keywords: Software Engineering, Risk Evaluation, Fuzzy Set Theory, Fault Tree, Analytical Hierarchical Process.

I. INTRODAUCTION

One of the most important factors in making decisions to accept or reject a software project is the risk consideration. According to a definition risk is a combination of probability or frequency of occurrence of an event and the severity or consequences of the hazard. Risk addresses the condition that is out of control of the project team and if it is not neutralized, it will cause adverse influence on the success of a project. Successful project managers try to solve the potential problems before they occur by using risk management tools [1].

In a more recent study, Raz et al [2] observe that project risk management practices are correlated with success in achieving time and budget goals, which is one of the most common risks encountered in most projects.

Because unanticipated risks or unmanaged risks are two of the main causes of project failure, organizations or project teams need to be prepared for project risks in order to attain the desired level of project success. This requires being aware of project risks and managing them. Risk management in projects has been practiced since the mid-1980s and is one of the nine main knowledge areas of the Project Management Institute's Project Management Body of Knowledge. Risk management is defined as the systematic process of identifying, analyzing, and responding to project risks [3]. Cooper and Chapman [4] and Chapman andWard [5] identify risk management as a multiphase "risk analysis" that covers identification, evaluation, control, and management of risks. Chapman [6] also suggests that a formal risk management process should be applied at all stages in the project life cycle and it should be a project in itself. Although there are different project risk management approaches in the literature, the aim of project risk management is the same, which is to increase the project performance and also to achieve the project objectives by identifying and evaluating the possible risks and developing appropriate responses to them.

This paper mainly focuses on the evaluation phase of the project risk management process, which is a certain common element in all approaches. Chapman and Ward [5] consider the evaluation phase as central in the risk management process.

Once the possible risks and their characteristics that may affect the project are identified, they must be evaluated. Risk evaluation is the process of assessing the impact and likelihood of identified risks. The aim of risk evaluation is determining the importance of risks and prioritizing them according to their effects on project objectives for further attention and action. Evaluation techniques can be mainly classified into two groups; these are qualitative methods and quantitative methods. Qualitative methods describe the characteristics of each risk in sufficient detail to allow them to be understood. Quantitative methods use mathematical models to simulate the effect of risks on project outcomes [7]. The most commonly used qualitative methods are the probability–impact risk rating matrix, which is constructed to assign risk ratings to risks or conditions based on combining probability and impact scales[65]and the use of a risk breakdown structure (RBS) to group risks by source[7]. Quantitative methods include Monte Carlo simulation, decision trees, and sensitivity analysis. These two kinds of methods, qualitative and quantitative, can be used separately or together.

Multicriteria decision-making methods are an important set of tools for addressing challenging business decisions because they allow the manager to better proceed in the face of uncertainty, complexity, and conflicting objectives [8].

Because risks are multidimensional [9], they should be evaluated with respect to more than one criterion to get more accurate and reliable results. The analytic hierarchy process (AHP) is one of the extensively used multicriteria decision-making methods. One of the main advantages of this method is the relative ease with which it handles multiple criteria. In addition to this, AHP is easier to understand and it can effectively handle both qualitative and quantitative data. Mustafa and Al-Bihar [10] introduce the approach of using AHP for project risk evaluation. They apply AHP in assessing the riskiness of a construction project in Bangladesh. The importance of their work is that it is the first on the utilization of AHP in risk evaluation. Dey [11] uses AHP and decision tree analysis as a quantitative approach to construction risk management. He uses the AHP for determining the probability of occurrence of various risk factors and displays the benefits of using it. Millet and Wedley [12] show how AHP can be used to model risk and uncertainty in a variety of ways by introducing prototypical case studies.

The risk level evaluation of project risks is a complex subject including uncertainty. The imprecise and vague terms will exist, because most project managers find it more practical and easier to evaluate risk in linguistic terms. Fuzzy sets theory introduced by Zadeh [13] is specially powerful when there is a need to take into consideration the ideas and judgments of people because of complexity and lack of proper information. Fuzzy sets provide representation of the knowledge of project managers in a better and more natural way. Because AHP does not take into account the uncertainty associated with the mapping of one's judgment to a number and also the subjective judgments, selection, and preference of decision makers exert a strong influence in the AHP [14] ; fuzzy sets theory can be used to overcome these shortcomings of AHP. In this paper, we propose the use of fuzzy AHP (FAHP) as a suitable and practical way of evaluating project risks based on the heuristic knowledge of project managers. Although fuzzy logic and AHP have been separately used in the evaluation of project risks, the significant contribution of this paper, as the first, is the suggestion of the use of FAHP in project risk evaluation.

Fuzzy set theory has been studied extensively over the past 46 years. Most of the early interest in fuzzy set theory pertained to representing uncertainty in human cognitive processes (see for example Zadeh (1965)). Fuzzy set theory is now applied to problems in engineering, business, medical and related health sciences, and the natural sciences [15].

Fuzzy set theory is being recognized as an important problem modeling and solution technique. Fuzzy linguistic multiple attribute decision making method is utilized to assess software project risk.

Fault tree analysis is an analytical technique in which an undesired state of the system is specified and the system is then analyzed in the context of its environment and operation to find all realistic ways in which the undesired event can occur [16].

Fault tree analysis is one kind of the probabilistic safety analysis method**.** After constructing a fault tree, many basic events which can happen theoretically have never occurred so far or have occurred so infrequently that their reasonable data are not available. However, the use of fuzzy probability can describe the failure probability and its uncertainty of each basic event, and then evaluate the probability that the top event occurs through certain mathematical operations [17]. Fuzzy fault tree analysis extends classic fault tree analysis, which is based on the assumption that there are sound and clear success and failure states in a system and that failures occur at random.

The organization of the paper is as follows. In Section II we introduce basic concept and their description and software project risk management process, classifying software risks, and fuzzy sets theory and risk evaluation, in section III, we describe in detailed, risk evaluation method under fuzziness and its representation, hierarchical structured risk management systems, fuzzy analytic hierarchy process, fuzzy fault tree analysis, a risk analysis method, fuzzy fault tree representation approaches and risk analysis, fuzzy fault tree analysis evaluation approaches and fuzzy fault tree analysis applications, and finally in section IV we give concluding remarks and suggestions.

II. BASIC CONCEPTS AND THEIR DESCRIPTION

This section makes the literature review in which software project risk management process, fuzzy set theory and software risk classification.

a. ***Software Project Risk Management (SPRM)*****:** it is an important aspect of project management. Risk Management is one of the nine knowledge areas defined in PMBOK (*A Guide to the Project Management Body of Knowledge* (*PMBOK Guide*)). Project Risk can be defined as unforeseen event or activity that can impact the project progress, result or outcome in a positive or negative way.
b. ***Fuzzy sets theory (FST)*****:** Fuzzy sets are sets whose elements have degrees of membership. Fuzzy sets were introduced simultaneously by Lotfi A. Zadeh and Dieter Klaua in 1965 as an extension of the classical notion of set. In classical set theory, the membership of elements in a set is assessed in binary terms according to a bivalent condition — an element either belongs or does not belong to the set.
c. ***Analytic Hierarchy (AHP) Process:*** it is a structured technique for organizing and analyzing complex decisions. Based on mathematics and psychology, it was developed by Thomas L. Saaty in the 1970s and has been extensively studied and refined since then. It has particular application in group decision making, and is used around the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.
d. ***Fault tree analysis (FTA):*** It is one of the most effective techniques for estimating the frequency of occurrence of hazardous events in probabilistic risk assessment study. It is a failure analysis in which an undesired state of a system is analyzed using boolean logic to combine a series of lower-level events. This analysis method is mainly used in the field of safety engineering to

quantitatively determine the probability of a safety hazard. FTA was originally developed in 1962 at Bell Laboratories by H.A. Watson, under a U.S. Air Force Ballistics Systems Division contract to evaluate the Minuteman I Intercontinental Ballistic Missile (ICBM) Launch Control System.

A. *Software Project Risk Management Process:*

The development of software projects exists various risks and some risks are even disastrous. Risk management is a kind of activity that can identify risks and develop risk plans, minimizing the impact of risk on projects. Software project risk management is intended for identifying, treating and eliminating the source of the risks before the threat of risks that may lead to the failure of the projects. Software project risk management process is made up of risk assessment and risk control. Risk assessment involves risk identification, risk analysis and risk plans and risk control is divided into risk tracking and risk response[18], and according to Boehm definition, risk assessment involves, risk identification, risk analysis and risk prioritization to provide data of developing risk response planning and controlling risk[19], and risk control involves risk management planning, risk resolution, that divide into risk avoidance and risk assumption, problem control, risk transfer, knowledge acquisition and risk monitoring. Software project risk management process is shown in Fig.1.

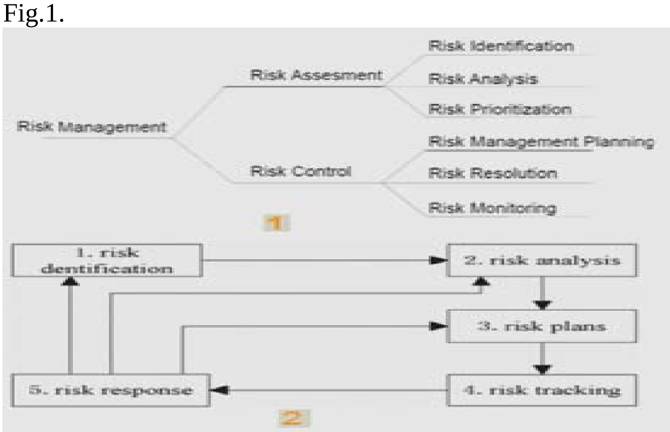

Figure 1. Software project risk management process: 1) "Software Risk Management" Boehm 1989 [20], 2) from [18], 2010

Risk assessment is the core and foundation of software project risk management, directly affecting other processes and even the success or failure of the software projects. Failing to understand and manage software project risk can lead to a variety of problems including cost and schedule overruns, unmet user requirements, and even the canceling of the project. So software project risk management plays an important role in completing software projects successfully [19].

Boehm defines four major reasons for implementing software risk management [20]:

i. Avoiding software project disasters, including run away budgets and schedules, defect-ridden software products, and operational failures.
ii. Avoiding rework caused by erroneous, missing, or ambiguous requirements, design or code, which typically consumes 40-50% of the total cost of software development.
iii. Avoiding overkill with detection and prevention techniques in areas of minimal or no risk.
iv. Stimulating a win-win software solution where the customer receives the product they need and the vendor makes the profits they expect.

There are basic risks that are generic to almost all software projects that classify in the next section [21]. Although there is a basic component of risk management inherent in good project management, risk management differs from project management in the following ways:

Table I. The comparison of project management and risk management

Project Management	Risk Management
Designed to address general or generic risks	Designed to focus on risks unique to each project
Looks at the big picture and plans for details	Looks at potential problems and plans for contingencies
Plans what should happen and looks for ways to make it happen	Evaluates what could happen and looks for ways to minimize the damage
Plans for success	Plans to manage and mitigate potential causes of failure

In [22] consider a conceptual view for the risk management model within GSRM, as shown by Fig. 2 that evaluates a goal-driven risk management model (GSRM) that is integrated into Requirement Engineering (RE) activities in order to manage risks of offshore outsourced software development (OOSD). The approach explicitly defines the relations between the goals relating to project success from offshore environment and the risk factors that obstruct the goals respecting technical as well as non-technical development components. In addition, it defines the control actions that enable the satisfaction of the goals. Therefore, GSRM assesses and manages risk that relate to the challenges of the offshore context right from the beginning of a project.

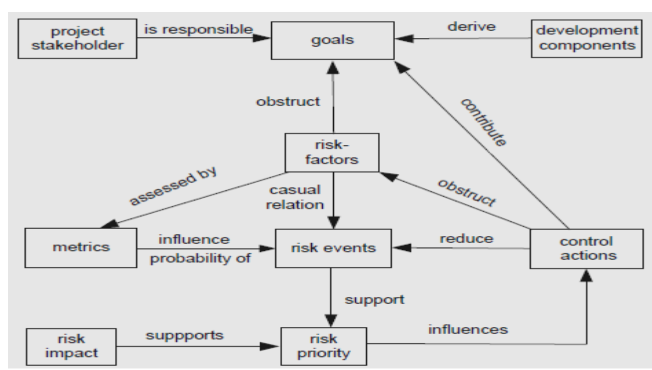

Figure 2. Conceptual view for the risk management model

Goals are derived from the development components by considering the factors relating to project success. Project Stakeholders are responsible to these goals. Risk factors certainly obstruct these goals and support casual relationships to the risk event. Likelihood of risk events along with the risk impact supports to prioritize the risks.

Finally, control actions are implemented to reduce the risk event and contribute for the goal satisfaction.

In [23] presents a new approach for offshore risk analysis that is capable of dealing with linguistic probabilities in Bayesian Networks (BNs). Linguistic probabilities are used to describe occurrence likelihood of hazardous events that may cause possible accidents in offshore operations. In order to use fuzzy information, a f-weighted valuation function is proposed to transform linguistic judgments into crisp probability distributions which can be easily put into a BN to model causal relationships among risk factors. In comparison with [22] the use of linguistic variables makes it easier for human experts to express their knowledge, and the transformation of linguistic judgments into crisp probabilities can significantly save the cost of computation, modifying and maintaining a BN model. The flexibility of the method allows for multiple forms of information to be used to quantify model relationships, including formally assessed expert opinion when quantitative data are lacking, or when only qualitative or vague statements can be made. The model is a modular representation of uncertain knowledge caused due to randomness, vagueness and ignorance. This makes the risk analysis of offshore engineering systems more functional and easier in many assessment contexts. Advantage and disadvantage of effective risk management behavior is as follows in Table II [24].

Table II. Dysfunctional vs. effective risk management behavior

Disadvantage of effective risk management behavior(Dysfunctional behavior (observed))	**Dvantage of effective risk management behavior(Functional behavior(goal))**
View each person’s decision-making capability as invariant	Manage risk as an asset
View uncertainty as a negative	Treat decision making as a skill
Don’t ask for risk information	Create a pull for risk information
Don’t bring forward risks or problems without solutions	Seek diversity in perspectives and information sources
Ignore the soft stuff	Minimize uncertainty in time, control, and information
Be risk averse	Recognize and minimize bias in perceiving risk
Make decisions based on emotion, rather than logic	Plan for multiple futures
Make commitments without determining the probability of success	Be proactive
Be reactive	Make timely, well-informed decisions and commitments
Reward heroes	Reward those who identify and manage risks early, even if the risks become problems

B. Classifying Software Risks:

Classification is fundamental to the insurance business. On the one hand, risks need to be properly classified and segregated for pricing purposes; while on the other hand, classification is basic to the underwriting of potential coverage. As indicated before, the main aim of risk evaluation is to determine the relative significance of different sources of risk on the overall project. In other words, it is for determining which risk events warrant response [3]. This is because every project has different risks and, indeed, different levels of risk [25]. Chapman andWard [5] suggest the approach of evaluating and assessing the risk as groups, and then determining the impact on the project in a cumulative manner [25]. There are different classifications of risk groups in the literature. Elkington and Small man [25] classify project risks in four groups, which are business risks, procurement risks, management risks, and technical risks. Miller and Lessard [9] classify project risks in a more general way as market-related risks, technical risks, and institutional risks. Mustafa and Al-Bahar [10] classify different sources of risk in construction projects as acts-of-God risks, physical risks, financial and economic risks, and job-site-related risks.

Kerzner [26] gives a more detailed classification of risks, which are cost, funding, schedule, contract relationship, political, technical, production, and support risks.

These classifications are important and can especially be used in the identification phase of risk factors. Because every project is different from another, not every risk factor valid for a certain project will be valid for others. Risk factors for a project should be considered as specific to that project.

The primary purpose of classifying risk is to get a collective viewpoint on a group of factors, which will help the managers to identify the group that contributes the maximum risk. A scientific way of approaching risks is to classify them based on risk attributes. Risk classification is an economical way of analyzing risks and their causes by grouping similar risks together into classes.

Software project risks can affect requirements, scheduling, cost, quality and business. Therefore, classification on the basis of these groups can be done [27]. Table III represent a classification of software project risk. These risks are gotten through studies and experiences in projects.

Table III. Software projects Risks classification

Classifying Software Risks	**Some instance of risk factor**
SOFTWARE REQUIREMENT RISKS	*Lack of report for requirements *Ambiguity of requirements *Poor definition of requirements
SOFTWARE COST RISKS	*Lack of good estimation in projects *Large size of architecture *Unrealistic schedule
SOFTWARE SCHEDULING RISKS	*Inadequate budget *Difficulty of implementation *Lack of good estimation in projects
SOFTWARE QUALITY RISKS	* Inadequate documentation * Inadequate knowledge about programming language * Lack of stability between personnel
SOFTWARE BUSINESS RISKS	* The products that no one want them * The products that are not suitable with total strategy * Failure in total budget

C. Fuzzy Sets theory and Risk Evaluation:

The most important factors contributing to the risk of failure for any type of organization or system are related to poor performance, time pressure, low quality and high cost.

The major problem associated with the estimation of risks is that the input data are imprecise by nature and it is difficult to represent them with crisp numbers.

To deal with vagueness of human thought, Zadeh [13] (1965) first introduced the fuzzy set theory, which was based on the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague knowledge. The theory also allows mathematical operators and programming to apply to the fuzzy domain [28] (2006).

Usually the risk analyst prefers to estimate in linguistic terms such as High or Low rather than in exact probabilistic terminology. To this end, the application of Fuzzy Set Theory (FST) to risk analysis seems appropriate, as such analysis can handle inexact and vague information[29] (2010).

The basic idea of the fuzzy approach, which were developed by L.A. Zadeh in 1965, is to allow an element to belong to a set with degrees of membership ranging in the continuous real interval [0,1], rather than in the set[13]. A fuzzy number is a normal and convex fuzzy set with membership function$\mu_A(x)$,which both satisfies normality,$\mu_A(x)=1$, for at least one x□R, and convexity, $\mu_A(x') \geq \mu_A(x_1)$□$\mu_A(x_2)$, where $\mu_A(x) \in [0,1]$, and $\forall x' \in [x_1,x_2]$."□" stands for the minimization operator.

A tilde will be placed above a symbol if the symbol represents a fuzzy set. A fuzzy number is a special fuzzy subset of the real numbers. The membership function of a triangular fuzzy number (TFN), M′, is defined by

$$\mu(x|\tilde{M}) = (m_1, f_1(y|\tilde{M})/m_2, m_2/f_2(y|\tilde{M}), m_3) \quad (1)$$

Where $m_1 < m_2 < m_3$, $f_1(y|M')$ is a continuous monotone increasing function of y for $0 \leq y \leq 1$, with $f_1(0|M') = m_1$, and $f_1(1|M') = m_2$, and $f_2(y|M')$, is a continuous monotone decreasing function of y for $0 \leq y \leq 1$ with $f_2(1|M') = m_2$,and $f_2(1|M') = m_3$.$\mu_A(x|M')$ is denoted simply as $(m1/m_2, m_2/m_3)$; Fig. 3 presents a TFN [28]. The extended operations of fuzzy numbers can be found in [30].

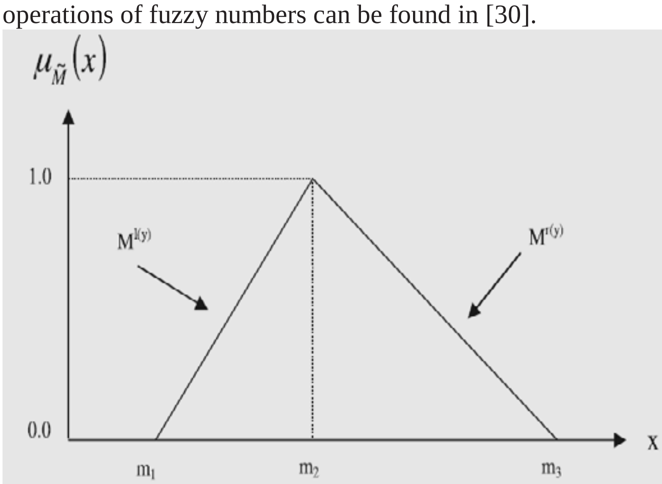

Figure 3. A Triangular fuzzy number

Research in risk analysis and management exploiting fuzzy logic has produced several different models in the recent years.

The fuzzy logic built on the fuzzy promotion of the binary logic is close to people's way of imaginal thinking, which is very suitable for qualitative analysis and reasoning, and at the same time, it has a strong ability to deal with natural language. Zadeh introduced the concept of fuzzy sets in order to quantitatively describe fuzzy concepts and fuzzy phenomenon [31] (2010).

In [32] (2005) the authors summarize the application areas where risk analysis is done applying fuzzy logic concepts. In [33] (1984) there was the first attempt to have a computerized risk analysis model based on fuzzy logic. Afterwards, there were several attempts to have a risk analyzer based on fuzzy logic like in [34] [35] (1996) (2001).

Kuchta [36] (2001) puts forward a fuzzy way of measuring the criticality of project activities and of the whole project. The criticality measure serves as a measure of risk and helps in making the decision whether to accept or to reject the project. In this approach, the decision makers expresses what he/she understands by “very critical,” “a little critical,” and so forth in the form of a fuzzy number.

Bonvicini et al [37] (1998) provide an application of fuzzy logic to the risk assessment of the transport of hazardous materials by road and pipeline in order to evaluate the uncertainties affecting both individual and societal risk estimates. In evaluating uncertainty by fuzzy logic, the uncertain input parameters are described by fuzzy numbers, and calculations are performed using fuzzy arithmetic. A connection between the “degree of membership” and the “probability of occurrence” is established by means of an objective transformation that turns a probability measure into a degree of membership. Carr and Tah [38] (2001) present a fuzzy risk analysis model in which a hierarchical risk breakdown structure is described to represent a formal model for qualitative risk assessment. The relationship between risk factors, risks, and their consequences are represented on cause and effect diagrams. Risk descriptions and their consequences are defined using descriptive linguistic variables. They use fuzzy approximation and composition to identify and quantify the relationship between risk sources and the consequences on project performance measures. The main objective of their model is to evaluate the risk exposures considering consequences in terms of time, cost, quality, and safety performance measures of the entire project based on fuzzy estimates of the risk components.

Cho et al [39] (2002) propose a methodology for incorporating uncertainties using fuzzy concepts into conventional risk assessment frameworks. They introduce some forms of fuzzy membership curves that are designed to consider the uncertainty range that represents the degree of uncertainties involved in both probabilistic parameter estimates and subjective judgments. They use linguistic variables such as “Close to any value” or “Higher/Lower than analyzed value” and so forth that include some quantification with giving specific value or scale. Three types of membership functions proposed for the statements "Close to," "Lower than," and "Higher than" curves are defined.

Huang[40] (2002) uses the interior-outer-set model to calculate the risk of crop flood and rank farming alternatives for Huarong County, China, where only a small sample of eight observations is available. The risk calculated by the suggested model is a particular case among imprecise probabilities, called possibility– probability distribution. He discusses in detail how to order alternatives based on a possibility–probability distribution and shows that the ordering based on a calculated fuzzy risk is better than one based on a histogram estimate. Huang and Moraga [41] (2002) develop a matrix algorithm for the same model because the model involves combination calculus that is very difficult to follow. This matrix algorithm consists of a moving sub algorithm and an index sub algorithm. A moving sub algorithm works out leaving and joining matrices and an index sub algorithm is a combination algorithm to get index sets. They also present an example of how to calculate a risk of a strong earthquake with the algorithm.

Lee et al [42] (2003) present a new and flexible algorithm to evaluate the rate of aggregative risk in fuzzy circumstances by fuzzy sets theory during any phase of the software development life cycle. In this algorithm, each individual risk item is ranked using two fuzzy sets with triangular membership functions, grade of risk and grade of importance. Then the rate of each individual risk item is evaluated by multiplication by the centroid method.

Chen and Chen [43] (2003) present a method for fuzzy risk analysis based on similarity measures of generalized fuzzy numbers. They propose a method named the simple center of gravity method (SCGM) to calculate the center-of-gravity (COG) points of generalized fuzzy numbers and then use the SCGM to measure the degree of similarity between generalized fuzzy numbers. Their method takes into consideration the degrees of confidence of decision makers' opinions.

III. RISK EVALUATION METHOD UNDER FUZZINESS AND ITS EPRESENTATION

Risk management as a decision making challenge is basically a complex structure with non-crisp input factors. Based on the strength of those attributes it is a reasonable way for fast and human-like decision to group the factors, and to use the fuzzy approach in the risk management modeling. The additional advantage of this model-structure is the possibility to gain the different factor-group's impact in the system [44].

All software development processes include steps where several alternatives induce a choice, a decision-making. Sometimes, methodologies offer a way to make decisions. However, in a lot of cases, the arguments to carry out the decision are very poor and the choice is made in an intuitive and hazardous way. We want to consider a scientifically founded way to guide the engineer through tactical choices with the application of multicriteria methods in software development processes [45].

Generally, a decision-making (DM) problem is defined by the presence of alternatives. The traditional approach consists in using only one criterion in order to select alternatives. The usual example is the selection of the projects according to the net present value. However, using a single criterion is not sufficient when the consequences of the alternatives to be analyzed are important. The goal of the Multicriteria (MC) DM methods consist in defining priorities between alternatives (actions, scenarios, projects) according to multiple criteria. In contrast to a monocriterion approach, MC methods allow a more in-depth analysis of the problem because they consider various aspects. However, their application has proved more difficult.

MCDM methods have shown their qualities for over 30 years and they currently dominate in the field of decision-making. They appeared at the beginning of the Sixties, and their number and application contexts increase continually. For example, these methods are employed for requirements prioritization, to choose evolution scenario, or to make operational decisions.

Five families of MC methods can be considered: MAUT, AHP, outranking methods, weighting methods, and fuzzy methods. These methods will be detailed in the following. We propose in this work to improve any development process with the use of multicriteria methods as a way to choose the most adapted alternative to each situation, and among them we consider AHP method in detailed. Process of integration of MC method into software development methodologies shows in Fig. 4.

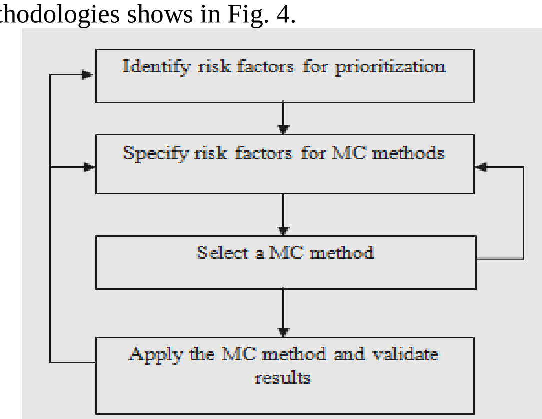

Figure 4. Process of integration of MC method into software development methodologies.

The integration process includes four steps: 1) Identify risk factors for prioritization, 2) Specify risk factors for MC methods, 3) Select a MC method, and 4) Apply the MC method and validate results. This IP includes both direct steps and flashbacks. The former indicate the normal integration process (IP) development, and the latter enable returns to the previous steps if necessary [45].

A. Hierarchical Structured Risk Management Systems:

Statistical methods-based reasoning models in crisis situations need long-time experiments and enough reliable data elaborated by experts. Additionally, they are time- and computing-demanding. The problems to be solved are full of uncertainties, and complexity of the systems increases the runtime factor of the decision process [44]. Considering all those conditions fuzzy set theory helps manage complexity and uncertainties, and represents the inputs and outputs of the model in an emphatic form. The relationship between risk factors, risks and their consequences are represented in different forms, but in a well-structured solution, suitable for the fuzzy approach is given. A risk management system can be built up as a hierarchical system of the risk factors (inputs), risk management actions (decision making system) and direction or directions for the next level of risk situation solving algorithm. A possible preliminary system construction of the risk management principle can be given based on this structured risk factor classification and on the fact, that some risk factor groups, risk factors or management actions have a weighted role in the system operation. The system parameters are represented with the fuzzy sets, and the grouped risk factors' values give intermediate result. Considering some system input parameters, which determine the risk factors' role in the decision making system, intermediate results can be weighted and forwarded to the next level of the reasoning process.

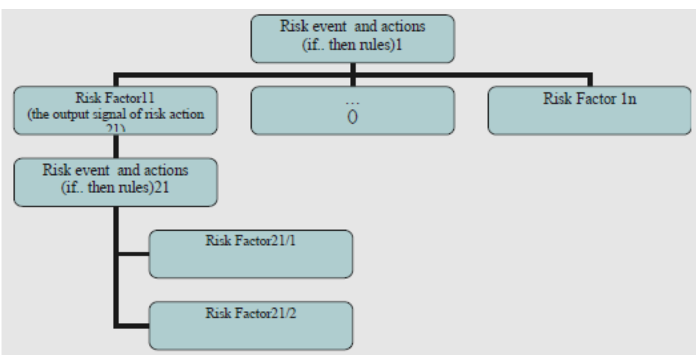

Figure 5. The hierarchical risk management construction

B. *fuzzy Analytic Hierarchy Proces:*

Projects are critical to the realization of performing organization's strategies. Each project contains some degree of risk and it is required to be aware of these risks and to develop the necessary responses to get the desired level of project success. Because projects' risks are multidimensional, they must be evaluated by using multi-attribute decision-making methods. In [28] by Tüysüz, Kahraman (2006), provide an analytic tool to evaluate the project risks under incomplete and vague information. The fuzzy analytic hierarchy process (AHP) as a suitable and practical way of evaluating project risks based on the heuristic knowledge of experts is used to evaluate the riskiness of an information technology (IT) project of a Turkish firm. The means of the triangular fuzzy numbers produced by the IT experts for each comparison are successfully used in the pairwise comparison matrices.

There are many fuzzy AHP methods proposed by various authors. These methods are systematic approaches to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis [28].

In [46] by Braglia(2000) develop a new tool for reliability and failure mode analysis by integrating the conventional aspects of the popular failure/risk mode and criticality analysis (FMECA) procedure with economic considerations that called MAFMA: multi-attribute failure mode analysis. Here FMECA is approached as a multicriteria decision making technique which integrates four different factors: chance of failure, chance of non-detection, severity, and expected cost. To aid the analyst to formulate an efficient and effective priority ranking of the possible causes of failure, the analytic hierarchy process technique is adopted. With this technique, factors and alternative causes of failure are arranged in a hierarchic structure and evaluated only through the use of a series of pairwise judgments. With this new approach to failure investigation, the critical FMECA problem concerning the (direct) evaluation of failure factors is also by-passed. The principles of the theory and an actual application in an Italian refrigerator manufacturing company are reported in the paper.

Decision makers usually find that it is more certain to give interval judgments than fixed value judgments. This is because usually he/she is unable to be explicit about his/her preferences due to the fuzzy nature of the comparison process. The work in fuzzy AHP appeared in [47] by Laarhoven and Pedrycz (1983), which compared fuzzy ratios described by triangular membership functions. In [48] by Buckley (1985) determines fuzzy priorities of comparison ratios whose membership functions are trapezoidal. Stam (1996) et al [49] explore how recently developed artificial intelligence techniques can be used to determine or approximate the preference ratings in AHP. They conclude that the feed-forward neural network formulation appears to be a powerful tool for analyzing discrete alternative multicriteria decision problems with imprecise or fuzzy ratio-scale preference judgments. By Chang (1996) in [50] introduces a new approach for handling fuzzy AHP, with the use of triangular fuzzy numbers for pairwise comparison scale of fuzzy AHP, and the use of the extent analysis method for the synthetic extent values of the pairwise comparisons. By Cheng (1997) in [51] proposes a new algorithm for evaluating naval tactical missile systems by the fuzzy analytical hierarchy process based on grade value of the membership function. Weck (1997) et al [52] present a method to evaluate different production cycle alternatives adding the mathematics of fuzzy logic to the classical AHP. Any production cycle evaluated in this manner yields a fuzzy set. The outcome of the analysis can finally be defuzzified by forming the surface center of gravity of any fuzzy set, and the alternative production cycles investigated can be ranked in order in terms of the main objective set. Kahraman (1998) et al [53] use a fuzzy objective and subjective method obtaining the weights from AHP and make a fuzzy weighted evaluation. In [54] Deng (1999) presents a fuzzy approach for tackling qualitative multicriteria analysis problems in a simple and straightforward manner. Lee et al [55] review the basic ideas behind the AHP. Based on these ideas, they introduce the concept of a comparison interval and propose a methodology based on stochastic optimization to achieve global consistency and to accommodate the fuzzy nature of the comparison process.

Cheng (1999) et al [56] propose a new method for evaluating weapons systems by an analytical hierarchy process based on linguistic variable weight. In [57] by Zhu (1999) discuss the extent analysis method and applications of fuzzy AHP. Chan (2000) in [58] present a technology selection algorithm to quantify both tangible and intangible benefits in a fuzzy environment. They describe an application of the theory of fuzzy sets to hierarchical structural analysis and economic evaluations. By aggregating the hierarchy, the preferential weight of each alternative technology is found, which is called fuzzy appropriate index. The fuzzy appropriate indices of different technologies are then ranked and preferential ranking orders of technologies are found. From the economic evaluation perspective, a fuzzy cash flow analysis is employed. Another work in [59] by Chan (2000) report an integrated approach for the automatic design of flexible manufacturing systems (FMS), which uses simulation and multicriteria decision-making techniques. The design process consists of the construction and testing of alternative designs using simulation methods. The selection of the most suitable design (based on AHP) is employed to analyze the output from the FMS simulation models. Intelligent tools (such as expert systems, fuzzy systems, and neural networks) are developed for supporting the FMS design process. The active X technique is used for the actual integration of the FMS automatic design process and the intelligent decision support process [28].

Leung and Cao (2000) [60] propose a fuzzy consistency definition with consideration of a tolerance deviation. Essentially, the fuzzy ratios of relative importance, allowing certain tolerance deviation, are formulated as constraints on the membership values of the local priorities. The fuzzy local and global weights are determined via the extension principle. The alternatives are ranked on the basis of the global weights by application of maximum–minimum set ranking method. In [61] by Kuo (2002) develop a decision support system for locating a new convenience store. The first component of the proposed system is the hierarchical structure development for the fuzzy analytic process. Wang and Lin (2003) [62] use a fuzzy multicriteria group decision-making approach to select configuration for software development. Bozdag˘(2003) et al[63] Kahraman (2003,2004) in [64][65][66] Buyukozkan (2004) in [67] and Kulak and Kahraman[68] use Chang's(1996) [50]fuzzy AHP for various decision-making problems. Sheu (2004) [69] presents a hybrid fuzzy-based method that integrates fuzzy-AHP and fuzzy multi-attribute decision making (MADM) approaches for identifying global logistics strategies when corresponding supply and demand environments are complicated and uncertain [28]. In [70] Takacs and Laufer (2010), conclude that, Risk management applications are complex, multicriteria and usually multilevel decision systems, and require to manage the uncertainties. Fuzzy environment is able to represent the ambiguous risk factors and rules in an acceptable form, where the risk factors are grouped based on their role in the decision making system. The system parameters' interaction is not on irrelevant moment in the modeling process that is why the pair wise comparison matrix can be added to the risk management system model. If one builds up a fuzzy based model with the grouped risk factors on the input, a fuzzy AHP model for the multilevel, hierarchically structured risk management system can be constructed, with further open problems and possibility to fine tuning in the reasoning process. Maintaining the Integrity of the Specifications. The comparison of different fuzzy AHP methods is in Table IV.

C. *Fuzzy Fault tree Analysis, a risk Analysis Method:*

Fault tree analysis was developed in 1962 at Bell Telephone Laboratories. Risk or fault tree analysis and assessment can simply be described as an analytical technique. It is a graphical model of various combinations of risks that result in the occurrence of the predefined undesired event. To analyze using risk tree, it is necessary to specify the undesired state of the system. This state may be the failure of the system or of a subsystem. Then a list is made of all the possible ways in which these events can occur. Each of the possible ways is then examined independently to find out how it can occur [17] [27]. Fault tree analysis is a commonly used tool to determine the cause(s) of system failure. The fault tree is constructed as a tree of sub-events, spreading into bottom events, procreating the fault and finally heading to the top [or main] event. A fault tree is a graphical representation of an event structure that clearly envisions the entire system and each level of each event within it. This structure enables one to identify particular sub-events that have a high impact on the main event.

The difference between a general hierarchical model and a fault tree is that while the former simply display the order of events that lead to the main failure event, the latter defines logical relationships between sub-events. Traditional fault tree analysis requires the assignment of crisp probabilities between events and the assumption of 'independence' between risk events. These two requirements carry inherent shortcomings. Firstly, one rarely knows 'precise' probabilities of causal relationships between events, and secondly, the required assumption of independence is often unrealistic [72].

Risk tree possesses many events. The lowest level events are called primary events. In the middle, intermediate events exist and the highest level event is called the top event. Also, all the events are connected in a tree by gates that show the relationship between successive levels of the tree.

The most common symbols and basic components used for risk tree construction and analysis are shown in Fig.6 [16].

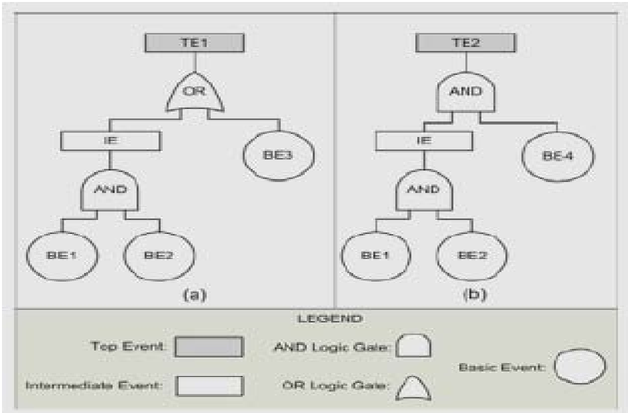

Figure 6. Fault tree structures with typical components

Traditionally, quantitative analysis evaluates the probability of the occurrence of the top event in which case the probability of each basic event is already known. Fault tree analysis of above figure can be described by the following relationship:

In TE1: $(BE1 \cap BE2) \cup BE3$ (2)

If P_{xi} denotes the probability of occurrence of the event , the top event probability would then be: $PTE1=1-\{(1-P_{AND})(1-P_{BE\#})\}$, $PAND=P_{BE1}.P_{BE2}$ (3)

It is then easy to estimate the probability of the top event if the probability of each basic event is known as a crisp value. However, in most cases, some basic events have never or rarely occurred before, providing insufficient statistical estimation of probabilities. To overcome this disadvantage, fuzzy probability was first suggested by Tanaka [73] to describe the vague, imprecise phenomena for the failure rates of the basic events.

However, current fault tree analysis still cannot be performed functionally without facing imprecise failure input data and improper modeling problems. Hence, fuzzy sets can help to overcome this situation [17].

Table IV. The comparison of different fuzzy AHP methods

Fuzzy analytic hierarchy Process methods	**The main characteristics of the method**	**Strengths**	**Weaknesses**
fuzzy extension of Saaty's priority theory By Laarhoven, Pedrycz (1983) in[47]	• Direct extension of Saaty's AHP method with triangular fuzzy numbers • Lootsma's logarithmic least square method is used to derive fuzzy weights and fuzzy performance scores	• The opinions of multiple decision makers can be modeled in the reciprocal matrix	• There is not always a solution to the linear equations • The computational requirement is tremendous, even for a small problem. • It allows only triangular fuzzy numbers to be used.
Fuzzy hierarchical analysis By Buckley(1985) in [48]	• Extension of Saaty's AHP method with trapezoidal fuzzy numbers • Uses the geometric mean method to derive fuzzy weights and performance scores	• It is easy to extend to the fuzzy case. • It guarantees a unique solution to the reciprocal comparison matrix.	• The computational requirement is tremendous.
Multicriteria decision analysis with fuzzy pairwise Comparison By Boender, Grann, Lootsma(1989) in[71]	• Modifies van Laarhoven and Pedrycz's Method • Presents a more robust approach to the normalization of the local priorities	• The opinions of multiple decision makers can be modeled	• The computational requirement is tremendous
Extent analysis method on fuzzy AHP By Chang (1996) in[50]	• Synthetical degree values • Layer simple sequencing • Composite total sequencing	• The computational requirement is relatively low. • It follows the steps of crisp AHP. It does not involve additional operations.	• It allows only triangular fuzzy numbers to be used.
Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function By Cheng (1997) in [51]	• Builds fuzzy standards • Represents performance scores by membership Functions • Uses entropy concepts to calculate aggregate weights	• The computational requirement is not tremendous	• Entropy is used when probability distribution is known. The method is based on both probability and possibility measures.
The AHP Extended Fuzzy Based Risk Management By Takacs, Laufer(2010) in[70]	• It is a multi-parametrical, multi-criteria decision process • Represents a hierarchical, multilevel risk management model in fuzzy environment	• Risk factors are grouped based on theirs role in the decision making system	• The decision-makers usually give some or all pair-to-pair comparison values with an uncertainty degree rather than precise ratings because this model use a pair wise comparison matrix

Experts utilize fuzzy sets to subjectively describe the uncertainties of each given event failure rate, and then perform mathematical operation to evaluate system reliability[17][74] In fuzzy Fault Tree Analysis, Thus, if $Pos(E_1)$, $Pos(E_2)$, … $Pos(E_n)$ are the failure possibilities of the basic events, and the corresponding components of the system are independent, then the output possibilities of the

AND – OR gates can be calculated with the following formulas:

$Pos_{AND}=Pos(E_1)\otimes Pos(E_2)\otimes\ldots\otimes Pos(E_n)$(4),$Pos_{OR}=$

$1\ominus(1\ominus Pos(E_1))\otimes(1\ominus Pos(E_2))\otimes\ldots.\otimes(1\ominus Pos(E_n))$(5)

The system uses the above formulas to calculate the possibilities of intermediate events and top events fuzzy fault trees. Referring to Fig.6 for example, it is possible to calculate the possibilities of the IE, TE1 and TE2 using fuzzy subtraction and multiplication as follows:

$Pos(IE)=Pos(BE_1)\otimes Pos(BE_2)$(6),$Pos(TE1)=$

$1\ominus(1\ominus Pos(IE))\otimes(1\ominus Pos(BE_3))$ (7) ,$Pos(TE2)= Pos(BE_4)\otimes Pos(IE)$ (8) that is, failure possibilities of the fault trees shown in Fig. 6.

In [17] shows that evidence theory can perform the fault tree analysis by the 3-valued logic and shows that the lower/upper bound intervals obtained from evidence theory can be used to calculate the failure probability interval of the top event directly, i.e. without needing to transform into 3-valued forms. Although some portion of the intervals may seen more confident than others, different kinds of membership functions may be used to describe subjective opinions while mathematical operation can be performed to calculate the fault tree quantitative analysis.

D. *Fuzzy Fault Tree Representation Approaches and Risk Analysis:*

In this section we want to describe the initial results of an ongoing investigation into representation issues for a known risk and reliability analysis technique, called Fuzzy Fault Tree Analysis (FFTA). In this work we compare frame-based and constraint-based techniques for modeling FFTAs. This paper presents the representation models for each alternative, using a typical fault tree structure, together with the results of an initial comparison. We want to work on the comparison of these forms of knowledge representation in the context of risk analysis.

As mentioned above, risk analysis methods define a systematic process for acquiring, identifying and codifying events, or different stages of the system components, together with their relations to a set of system failures. A number of risk analysis techniques have been used to acquire and encode domain specific knowledge about causes, failures and their relations in a system. Such techniques have been employed to develop AI systems, including expert systems, and decision support systems, for use in this field.

As such, these methods can be viewed as “risk oriented” knowledge acquisition techniques. It is not clear; however, which knowledge representation techniques are most useful for mapping the results of a risk analysis method into the knowledge base of an intelligent system [16].

In particular in safety-critical systems, models, methods and techniques from a wide range of areas like risk and barrier analysis, cognitive task analysis, psychology, ergonomics, computer-human interaction, etc. are used to help engineers understand the complicated picture of events that may act as triggering mechanisms for operational problems, incidents, and accidents. The objective of these techniques such as FFTA, is to design safe engineering facilities and to define their proper operating procedures, the number of accidents and harmful-contact incidents is minimized.

FFTA can be applied when:

a. There are no clear boundaries between failure and success states of the system, or when it is not clear that the performance of the system fulfils its specifications.
b. The probability of system failure cannot be calculated precisely due to the lack of sufficient data and/or the existence of “noise” in the data set.
c. There is a subjective evaluation of the reliability, which is made with natural language expressions.

In the context of FFTA, given a fault tree structure it is possible to calculate the subjective reliability of the corresponding system from information about the reliability of the system components given in linguistic terms. These terms are translated into fuzzy sets. Fuzzy sets express the subjective possibility of failure (i.e. the subjective unreliability) of the system. This is done by mapping each linguistic value to a range of subjective failure possibilities through a fuzzy set membership function. The subjective failure possibility is defined on an interval between 0 and 1 [16]. Fig.7 shows the linguistic terms that translated into fuzzy sets, together with their corresponding membership functions.

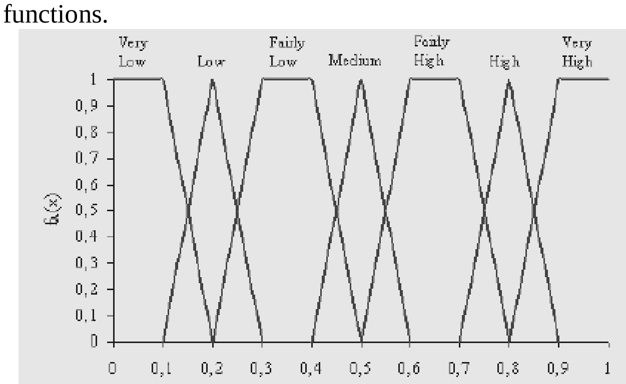

Figure 7. Fuzzy sets expressing linguistic values

i. *Representing FFTA With Constraint Programming(CP):*

Constraint programming has been successfully applied to many real-world problems, such as scheduling, planning, configuration, layout, resource allocation, and decision support, because these problems can be easily modeled in terms of constraints[75]. Constraint satisfaction techniques attempt to find solutions to Constraint Satisfaction Problems (CSPs). A CSP is defined by:

a) a set of variables $X=\{X_1,..., X_n\}$ where each variable X_i, has a range or finite set D_i of possible values, and

b) a set of constraints C, where each constraint $C_{<j>}$ is composed of a scope vars($C_{<j>}$) of the variables that participate in that constraint and a relation rel($C_{<j>}$) $\subseteq D_{j1} \times D_{j2} \times \ldots \times D_{jt}$, that specifies the values that variables in the scope can be assigned simultaneously. Arity is the number of variables involved in the scope.

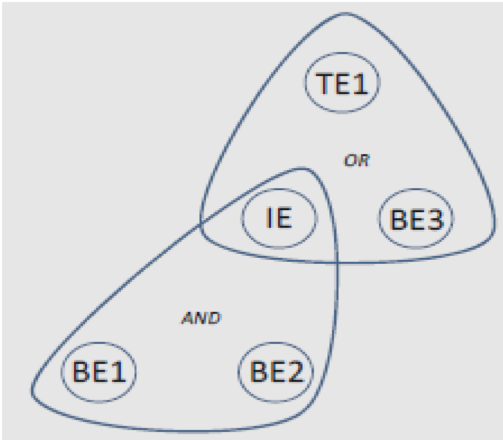

Figure 8. The CSP representation of FFTA in Figure 6- a

A solution to a CSP is the assignment of a value to every variable in such a way that all constraints are satisfied. To represent an FFT as a CSP, we represent the Top Events, Basic Events, and Intermediate Events as variables. AND and OR logic gates are represented as constraints with an arity of three or higher. The domain values of each variable are fuzzy sets. Graphical representation of CSPs that include constraints whose scope includes more than two variables is normally done with a constraint hyper graph, where the nodes represent the variables and a constraint is represented by a line drawn around the variables in its scope. Fig.8 shows how the Fault Tree in Fig.6a is represented using hyper graphs.

ii. Representing FFTA with Frames:

For representation of FFTA, can uses frame and constraint based approaches. Frames were introduced in 1974 by Minsky [76] as a basis for understanding and representing complex types of domain knowledge. A frame provides a structural representation of an object or class of objects. It contains slots that can be filled by entities which may themselves be frames, names, data or other identifiers. An instance of a frame inherits the slots and the default values of other frames (i.e. its parent's frames) according to its position in the frame hierarchy. In other words, the common properties are automatically inherited through the hierarchy. This avoids unnecessary duplication of information, simplifies code and provides a more readable and maintainable system [16]. Fig.9 shows how the Fault Tree is represented using frame.

The main concepts in the present frame representation of the FFTs are *Event*, *Top_event*, and *Basic_event*. These are shown in Fig.9, using the UML notation (assuming that the concepts of frames and instances can be represented in UML with classes and objects respectively). The frames *Top_event* and *Basic_event* are both kinds of *Events*, and thus they inherit the slots of the *Event* frame. Comparison between the tow approaches are as follows according table V.

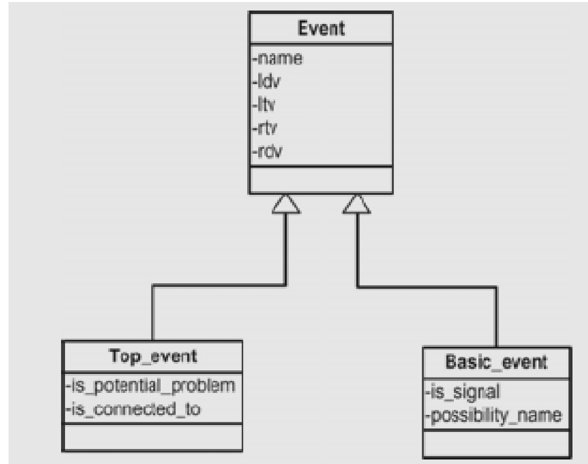

Figure 9. The Frame representation of FFTA

E. Fuzzy Fault Tree Analysis Evaluation Approaches:

a. Sampling Approach:

The procedure for the approach is as follows:
Fuzzy Representation of the probability is obtained for all the basic events of the fault tree. The membership grade function (μ) of each of these basic events is sampled with appropriate number of sampling points. Fuzzy number can be sampled (n). The extent of accuracy desired and the profile of μ depend upon the number of sampling points [18].

b. Fuzzy Simulation Approach:

An interval of confidence is one way of reducing the uncertainty using lower and upper bounds of failure probability value/information. It is a practical and logical process for treating uncertainty with the available information on failure data, which could be objective or subjective. Fuzzy arithmetic concept of interval of confidence and level of presumption is one way of modeling uncertainty, using lower and upper bounds. The concept of fuzzy number or uncertainty number in uncertainty modeling was, therefore, used [18].

F. Fuzzy Fault Tree Analysis Applications:

In this section we consider some fuzzy fault tree application. In [77] by Dunyak, Saad, and Wunsch, proposed (1999) a new extension of crisp probability theory. Their model is based on n independent inputs, each with a fuzzy probability. The elements of their sample space describe exactly which of the n input events did and did not occur. Their extension is complete since a fuzzy probability is assigned to every subset of the sample space. Their extension is also consistent with all calculations that can be arranged as a fault tree. Unfortunately, fuzzy fault trees do not provide a complete theory: many events of substantial practical interest cannot be described only by independent operations. Thus, the standard fuzzy extension (based on fuzzy fault trees) is not complete since not all events are assigned a fuzzy probability.

Table V. The comparison of different Representation approaches of Fuzzy Fault Tree

Fuzzy fault tree representation approaches	**The main characteristics of the approach**	**Strengths**	**Weaknesses**
Representing FFTA With Constraint Programming(CP) By Wallace(1996) in[75]	• has been successfully applied to many real-world problems, such as decision support • Constraint satisfaction techniques attempt to find solutions to Constraint Satisfaction Problems • system use identical user interaction sequences • system written in Prolog	• the CP representation appeared to be more concise than the frame based system • it simply calculates the equation upwards in the fault tree • there would not be any difficulty in representing mutual influences among Basic Events (on the same level of the fault tree). • when a user investigates a top event, and instantiates the shared basic event, this allows the constraint propagation functions to determine if any domain values in the neighbouring tree can be removed	• appears much difficulties to understand • real values limit choice of CP solver • representing the fuzzy sets as domain values for the event variables create a modelling challenge for the CP approach
Representing FFTA with Frames By Minsky(1974) in[76]	• a basis for nderstanding and representing complex types of domain knowledge • provides a structural representa-tion of an object or class of bjects • system use identical user interaction sequences • system written in Prolog	• the frame based representation ap-pears much easier to understand than CP representation • setting up test case tool using the frame based is easier • real values did not pose any difficulty for our Frame based approach • representing the fuzzy sets as domain values for the event variables is not an issue for the frame based approach	• updating the frame based system demanded more effort than was required for the CP representation • intermediate events are not represented directly, this has an obvious bearing on the complexity of updates and main-tainability.

Other complete extensions have been proposed, but these extensions are not consistent with the calculations from fuzzy fault trees**.** Their approach allows the reliability analyst to develop complete and consistent fuzzy reliability models from existing crisp reliability models. This allows a comprehensive analysis of the system.

Computational algorithms are provided both to extend existing models and develop new models. The technique is demonstrated on a reliability model of a three-stage industrial process.

Sharma, Sukavanam, Kumar and Kumar (2008) in [78], reliability analysis of complex robotic system have been studied using Petri nets and Fuzzy Lambda-tau methodology. The present work is based on amulti-robotic system, in which two robots are working independently with a conveyer unit. Petri net (PN) is applied to represent the asynchronous and concurrent processing of the system. To enhance the relevance of the reliability study, fuzzy numbers are developed from available data of the components using fuzzy possibility theory to define membership functions. Various reliability parameters (such as MTBF, ENOF, reliability, availability etc.), are computed using Fuzzy Lambda-tau methodology.

As the available data is imprecise, incomplete, vague and conflicting, the fuzzy methodology can deal easily with approximations. Finally, the results obtained by Fuzzy Lambda-tau methodology, are compared with those by fault tree.

A comparison between FTA and fuzzy lambda-tau methodology has been made with respect to reliability parameter and a structured framework has been developed that may help the maintenance engineers to analyze and predict the system behavior. The attempts have also been made (I) to deal with imprecise, uncertain dependent information related to system performance as the fuzzy methodology provides a better, consistent and mathematically sound method for handling uncertainties in data than conventional methods, such as fault tree analysis, (ii) to model and deal with highly complex robotic system using fuzzy sets as these sets can deal easily with approximations and (iii) various reliability parameters (such as failure rate, repair time, mean time between failures, availability, reliability and expected number of failures) were found to predict the system behavior in objective terms and it is concluded that in order to improve the availability and reliability aspects, it is necessary to enhance the maintainability requirement of the system.

In [79] by Tsai, Wang and Hsu (2009) presented a two-stage fault-diagnosis method by integrating fuzzy with Bayesian evaluations. Fault diagnosis is a narrowing down procedure of identifying fault sources. It often is done largely depending on field knowledge and experience. Fault tree analysis is introduced to draw fault sources of a system. Fault patterns of faults in diagnosing are constructed by analyzing system information flows of functional block diagrams. Fuzzy sets are used to determine the upper events of faults for considering the ambiguous characteristics of symptoms in initial conditions. A structured process of fuzzy possibility score conversion is reported to give the correlations between the causes and the symptoms. The bottom events of faults are then judged by Bayesian method in cooperation with a tree structure of faults. An injection molding machine (IMM) is introduced which is used as an example to depict the method of fault diagnosis.

In another work [80] by Dokas, Karras and Panagiotakopoulos(2009), They argue that early warning systems for engineering facilities can be developed by combining and integrating existing technologies and theories. As example, they present an efficient integration of fuzzy expert systems, fault tree analysis and World Wide Web technologies to their application in the development of the Landfill Operation Management Advisor (LOMA), a novel early warning and emergency response system for solid waste landfill operations. The aim of LOMA is to provide assistance to landfill managers on their efforts in preventing accidents and operational problems and to help them to develop emergency response plans if these operational problems shall occur. When using LOMA, the user first describes the working conditions at the landfill. Then, based on this description, LOMA informs user about the potential operational problems. Afterwards, it analyzes the operational problems in more detail and it estimates the possibility of their occurrence. Finally, it provides advice on how to prevent them and on how to respond if any of them occurs.

In [81] by Batzias, Bountri, and Siontorou (2010), an algorithmic procedure, based on Fault Tree Analysis in its fuzzy version (to count for uncertainty), has been developed for solving river pollution problems. The main steps followed are: (a) determination of metrological requirements, necessary to maintain the present ecological status of the river, (b) combinatorial relaxation to obtain acceptable tolerance intervals for each ecological sub-system, (c) sensitivity analysis to quantify the impact of the parameter(s) values deviation from the normally expected values, (d) synthesis of the corresponding fault tree and assignment of weights, (e) FTA by using fuzzy input, (f) formation of representative alternatives by combining the most influential final events acting as ultimate causes that contribute to the occurrence of the ‘top event’, and fuzzy multicriteria ranking of them, and (g) sensitivity/robustness analysis, of the ranked first alternative and suggestions for corrective action. A case example is presented, where the top event is “high BOD at site G”, downstream of site F where wastewater is discharged into the river. The input independent/explanatory variables are given as fuzzy trapezoid numbers and the results (obtained as crisp numbers, after defuzzification) are discussed.

IV. CONCLUSIONS AND SUGGESTIONS

In this paper a short general review of the main characteristics of risk management applications is given, where a hierarchical, multilevel risk management method can be applied in a fuzzy decision making environment. The use of fuzzy sets to describe the risk factors and fuzzy-based decision techniques to help incorporate inherent imprecision, uncertainties and subjectivity of available data, as well as to propagate these attributes throughout the model, yield more realistic results. Fuzzy logic modeling techniques can also be used in risk management systems to assess risk levels in cases where the experts do not have enough reliable data to apply statistical approaches.

We suggest that using fuzzy theory contribute to manage uncertainty, specially in [17] by using of fuzzy fault tree analysis in Assessment Layer of GSRM framework or using an AHP method and other MCDM methods, can solve uncertainty that associated with lack of communication in offshore outsourced software development (OOSD) environment with applying linguistic variable and fuzzy theory. Also one can use from soft computing methods or other hybridizations of soft computing methods such as Neuro Fuzzy, fuzzy cognitive map, rough-neuro-fuzzy integration or other rough-fuzzy hybridizations for intelligent system design and rough-neuro-fuzzy-genetic framework, fuzzy-genetic integration and a roughneuro-genetic hybridization for extraction of knowledge about risk and environment, can contribute to resolve assessing risk factors in such environment and could be future research field. Risk management applications are complex, multi-criteria and usually multilevel decision systems, required managing uncertainties. The fuzzy environment is able to represent the ambiguous risk factors and rules in an acceptable form, where the risk factors are grouped based on their roles in the decision-making system.

V. REFERENCES

[1]. S.H.Iranmanesh, S.B.Khodadadi, Sh.Tahere, “Risk Assessment of Software Projects Using Fuzzy Inference System ", IEEE, pp1149-1154, 2009.

[2]. T. Raz, AJ. Shenhar, D .Dvir. Risk management, project success, and technological uncertainty. R&D Manage pp.101–109, 2002.

[3]. Project Management Institute. A guide to project management body of knowledge. Newton Square, PA: Project Management Institute, 2000.

[4]. D .Cooper, C .Chapman. Risk analysis for large projects. New York: John Wiley and Sons, 1987.

[5]. C.Chapman, S.Ward. Project risk management: Processes, techniques and insights. New York: John Wiley and Sons, 1997.

[6]. C .Chapman. Project risk analysis and management—PRAM, the generic process. Into J Proj Manage pp.273–281, 1997.

[7]. D. Hillson. Using a risk breakdown structure in project management. J Facil Manage pp.85–97, 2003.

[8]. ED.Hahn. Decision making with uncertain judgments: A stochastic formulation of the analytic hierarchy process. Decis Sci, pp.443– 466, 2003.

[9]. R .Miller, D .Lessard. Understanding and managing risks in large engineering projects. Int J Proj Manage, pp437– 443, 2001.

[10]. M.A .Mustafa, JF.Al-Bahar. Project risk assessment using the analytic hierarchy process.IEEE Trans Eng Manage, pp.46–52, 1991.

[11]. PK.Dey. Project risk management: A combined analytic hierarchy process and decision tree approach. Cost Eng, pp.13–26, 2002.

[12]. I .Millet, WC .Wedley. Modeling risk and uncertainty with the analytic hierarchy process. J Multi-Criteria Decius Anal, pp.97–107, 2002.

[13]. L. Zadeh, “Fuzzy Sets,” Information and Control, vol. 3, no. 8, pp. 338–353, 1965.

[14]. CH .Cheng, DL .Mon. Evaluating weapon systems by AHP based on fuzzy scale. Fuzzy Set Syst, pp.1–10, 1994.

[15]. A.L. Guiffrida, R.Nagi, " Fuzzy Set Theory Applications in Production Management Research: A Literature Survey ", Department of Industrial Engineering, State University of New York at Buffalo, 1997.

[16]. I.M. Dokas, T.E.Nordlander, R.J. Wallace, Fuzzy Fault Tree Representation and Maintenance based on Frames and Constraint Technologies: A Case Study, Copyright ACM2007.

[17]. Y.L.Cheng, "Uncertainties in Fault Tree Analysis ", Department of Information Management, Husan Chuang College, 2000.

[18]. A.Deshpande, Fuzzy fault tree analysis: revisited, The Society for Reliability Engineering, Quality and Operations Management (SREQOM), India and The Division of Operation and Maintenance, Lulea University of Technology, Sweden, springer, pp.3-13, 2011.

[19]. L.Yang, L.Nan, " Software Project Risk Assessment Based on Fuzzy Linguistic Multiple Attribute Decision Making ", International Conference on Grey Systems and Intelligent Services, November 10-12, pp1163-1166,2009.

[20]. B.W. Boehm, *Tutorial:* Software Risk Management, Les Alamitos, CA, IEEE Computer Society, 1989.

[21]. L.Westfall, Software Risk management, The Westfall Team, pp.1-8, 2001.

[22]. SH.Islam, S.H.Houmb, D.Mendez-Fernandez and Md. M.Alam Joarder, Offshore-Outsourced Software Development Risk Management Model, The work is partly supported by the German Academic Exchange Service (DAAD), Germany and the Institute of Information Technology (IIT), University of Dhaka, Bangladesh, 2010.

[23]. J.Ren, J.Wang, I.Jenkinson, Xu D.L., Yang J.B, A Bayesian Network Approach for Offshore Risk Analysis through Linguistic Variables, School of Engineering, Liverpool John Moores University, Liverpool,2007.

[24]. Y.H. Kwak, J. Stoddard, Project risk management: lessons learned from software development environment, Elsevier Science Ltd., pp. 915–920, 2004.

[25]. P. Elkington, C .Smallman. Managing project risks: A case study from the utilities sector. Into J Proj Manag, pp.49–57, 2002.

[26]. H.Kerzner. Project management: systems approach to planning, scheduling, and controlling, 7th Ed. New York: John Wiley and Sons, 2001.

[27]. H.Hoodat, .H. Rashidi, "Classification and Analysis of Risks in Software Engineering ", World Academy of Science, Engineering and Technology 56, pp 446-452, 2009.

[28]. F.Tüysüz, C.Kahraman," Project Risk Evaluation Using a Fuzzy Analytic Hierarchy Process: An Application to Information Technology Projects", International Journal of Intelligent Systems, VOL. 21, pp.559–584, 2006.

[29]. B.Lazzerini, L.Mkrtchyan, "Risk Analysis Using Extended Fuzzy Cognitive Maps ", International Conference on Intelligent Computing and Cognitive Informatics, IEEE, pp179-182, 2010.

[30]. H.J. Zimmermann. Fuzzy set theory and its applications, 2nd revised ed. Boston, MA: Kluwer Academic Publishers, 1994.

[31]. A.G.TANG, R.I.WANG, "Software Project Risk Assessment Model Based on Fuzzy Theory", International Conference on Computer and Communication Technologies in Agriculture Engineering IEEE, pp328-330, 2010.

[32]. E. W. T. Ngai and F. K. T. Watt, "Fuzzy dec. supp. System for risk analysis in e-commerce development," Decision Support Systems, vol. 99, no. 40, pp. 235–255, 2005.

[33]. K. J. Schmucker, Fuzzy Sets, Natural Lang. Comp. and Risk Analysis. Rockville, MD: Comp. Science Press, 1984.

[34]. V. Carr, J. Tah, "A fuzzy approach to const. proj. Risk assesses and analysis: const. proj. Risks manage. System, "Advances in Eng. Software, vol. 32, pp. 847–857, 2001.

[35]. W. G. de Ru and J. H. P. Eloff, "Risk analysis modeling with the use of fuzzy logic," Computers and Security, vol. 15, no. 3, pp. 239–248, 1996.

[36]. D. Kuchta. Use of fuzzy numbers in project risk (criticality) assessment. Into Proj Manage pp.305–310, 2001.

[37]. S.Bonvicini, P.Leonelli, G.Spadoni. Risk analysis of hazardous materials transportation: Evaluating uncertainty by means of fuzzy logic. J Hazard Mater, pp.59–74, 1998.

[38]. V.Carr, JHV.Tah.Afuzzy approach to construction risk assessment and analysis: Construction project risk management system. Adv Eng Software, pp.847–857, 2001.

[39]. H.N.Cho, H.H.Choi, Y.B.Kim. A risk assessment methodology for incorporating uncertainties using fuzzy concepts. Reliab Eng Syst Saf, pp.173–183, 2002.

[40]. C.Huang. An application of calculated fuzzy risk. Inform Sci, pp.37–56, 2002.

[41]. C. Huang, C .Moraga. A fuzzy risk model and its matrix algorithm. Into Uncertainty Fuzziness Know Base Syst, pp.347–362, 2002.

[42]. H.M .Lee, SY. Lee, TY. Lee, Chen JJ. A new algorithm for applying fuzzy set theory to evaluate the rate of aggregative risk in software development. Inform Sci, pp.177– 197, 2003.

[43]. S.J.Chen, SM. Chen. Fuzzy risk analysis based on similarity measures of generalized fuzzy numbers. IEEE Trans Fuzzy Syst, pp.45–56, 2003.

[44]. M.Takács, Hierarchical Risk Management Model with Gained Fuzzy Parameters, Óbuda University e-Bulletin, Vol. 1, No. 1, pp. 253-258, 2010.

[45]. E. Kornyshova, R.Deneckère, C.Salinesi, Improving Software Development Processes with Multicriteria Methods, Proceedings of MoDISE-EUS 2008.

[46]. M.Braglia, MAFMA: multi-attribute failure mode analysis, International Journal of Quality & Reliability Management, Vol. 17 No. 9, pp. 1017-1033, 2000.

[47]. PJM.van.Laarhoven, W.Pedrycz. A fuzzy extension of Saaty's priority theory. Fuzzy Set Syst, pp.229–241, 1983.

[48]. JJ.Buckley. Fuzzy hierarchical analysis. Fuzzy Set Syst, pp.233–247, 1985.

[49]. A.Stam, S.Minghe, M.Haines. Artificial neural network representations for hierarchical preference structures. Compute Oper Res, pp.1191–1201, 1996.

[50]. D.Y.Chang. Applications of the extent analysis method on fuzzy AHP. Eur J Oper Res, pp.649– 655, 1996.

[51]. C.H .Cheng. Evaluating naval tactical missile systems by fuzzy AHP based on the grade value of membership function. Eur J Oper Res, pp.343–350, 1997.

[52]. M.Weck, F.Klocke, HR.Schell, E.Rüenauver. Evaluating alternative production cycles using the extended fuzzy AHP method. Eur J Oper Res, pp.351–366, 1997.

[53]. C.Kahraman, Z.Ulukan, E.Tolga.A fuzzy weighted evaluation method using objective and subjective measures. In: Proc Into ICSC Symp on Engineering of Intelligent Systems (EIS '98), Vol. 1, University of La Laguna Tenerife, Spain; pp 57– 63,1998.

[54]. H.Deng. Multicriteria analysis with fuzzy pairwise comparison. Int J Approx Reason, pp.215–231, 1999.

[55]. M.Lee, H.Pham, X.Zhang.Amethodology for priority setting with application to software development process. Eur J Oper Res, pp.375–389, 1999.

[56]. C.H .Cheng, K-L.Yang, C.L.Hwang. Evaluating attack helicopters by AHP based on linguistic variable weight. Eur J Oper Res, pp.423– 435, 1999.

[57]. K.J.Zhu, Y.Jing, D-Y.Chang. A discussion of extent analysis method and applications of Fuzzy AHP. Eur J Oper Res, pp.450– 456, 1999.

[58]. FTS.Chan, MH.Chan, NKH.Tang. Evaluation methodologies for technology selection. J Mater Process Technol, pp.330–337, 2000.

[59]. FTS.Chan, B.Jiang, NKH.Tang. The development of intelligent decision support tools to aid the design of flexible manufacturing systems. Int J Prod Econ, pp.73–84, 2000.

[60]. LC.Leung, D.Cao, On consistency and ranking of alternatives in fuzzy AHP. Eur J Oper Res, pp.102–113, 2000.

[61]. R.j. Kuo, S.C.Chi, S.S.Kao. A decision support system for selecting convenience store location through integration of fuzzy AHP and artificial neural network. Comput Ind, pp.199–214, 2002.

[62]. J.Wang, Y.I.Lin. A fuzzy multicriteria group decision making approach to select configuration items for software development. Fuzzy Set Syst, pp.343–363, 2003.

[63]. CE.Bozdag˘, C.Kahraman, D.Ruan. Fuzzy group decision making for selection among computer integrated manufacturing systems. Comput Ind, pp.13–29, 2003.

[64]. C.Kahraman, U.Cebeci, Z.Ulukan. Multi-criteria supplier selection using fuzzyAHP. Logiest Inform Manage, pp.382–394, 2003.

[65]. C. Kahraman, D.Ruan, I. Dogan ˙. Fuzzy group decision making for facility location selection. Inform Sci, pp.135–153, 2003.

[66]. C.Kahraman, U.Cebeci, D.Ruan. Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. Int J Prod Econ, pp.171–184, 2004.

[67]. G. Buyukozkan, C .Kahraman, D .Ruan. A fuzzy multi-criteria decision approach for software development strategy selection. Int J Gen Syst, pp.259–280, 2004.

[68]. O.Kulak, C.Kahraman. Fuzzy multi-attribute selection among transportation companies using axiomatic design and analytic hierarchy process. Inform Sci, pp.190–210, 2005.

[69]. J.B.Sheu.Ahybrid fuzzy-based approach for identifying global logistics strategies. Transport Res E, pp.39– 61, 2004.

[70]. M.Takacs, T.Laufer Edit, The AHP Extended Fuzzy Based Risk Management, Recent Researches in Artificial Intelligence, Knowledge Engineering and Data Bases,pp.269-272,2010.

[71]. CGE. Boender, JG. de Grann, Lootsma FA. Multicriteria decision analysis with fuzzy pairwise comparison. Fuzzy Set Syst; pp.133–143, 1989.

[72]. R.Sadiq, E.Saint-Martin, and Y.Kleiner, Predicting risk of water quality failures in distribution networks under uncertainties using fault-tree analysis, institute for research in construction, pp. 1-35, 2008.

[73]. H .Tanaka., L. T .Fan., F. S .Lai. K .Toguchi, “Fault tree analysis by fuzzy probability,” IEEE Trans. Reliability, Vol.32, No.5, pp. 455-457, 1983.

[74]. C.H .Cheng. D.L. Mon., “Fuzzy system reliability analysis by interval of confidence,” *Fuzzy Sets and Systems*, Vol.56, pp. 29-35, 1993.

[75]. M.Wallace, Practical application of constraint programming, *Constraints*, Volume 1, Issue 1-2. pp. 139-168, 1996.

[76]. M.L Minsky, A framework for representing knowledge, in The psychology of Computer Vision, P. Winston, Editor, McGraw-Hill, New York, pp. 34-57,1974.

[77]. J.Dunyak, I.W. Saad, and D.Wunsch, A Theory of Independent Fuzzy Probability for System Reliability, IEEE Transactions on Fuzzy Systems, VOL. 7, NO. 2, pp.286-294, APRIL1999.

[78]. S.P. Sharma, N. Sukavanam, N.Kumar and A. Kumar, Performance Analysis of a Complex Robotic System Using Fault Tree and Fuzzy Methodology, XXXII National Systems Conference, NSC 2008, December 17-19,pp.874-878,2008.

[79]. Y. T. Tsai, K. S. Wang and Y. Y. Hsu, Applying Fuzzy and Bayesian Methods to Implement Fault-Diagnosis, The 10th International Conference on Automation Technology National Cheng Kung University (NCKU), Tainan, Taiwan ,June 27-29, pp.1-6,2009.

[80]. I.M.Dokas, D.A. Karras, D. C. Panagiotakopoulos, Fault tree analysis and fuzzy expert systems: Early warning and emergency response of landfill operations, Environmental Modelling & Software 24, pp.1-63, 2009.

[81]. F.Batzias, A.Bountri, CH.Siontorou, Solving River Pollution Problems by Means of Fuzzy Fault Tree Analysis, Advances in Biology, Bioengineering and Environment,pp.228-233,2010.

