# 2

# Applications of Fuzzy Logic in Risk Assessment – The RA_X Case

Isabel L. Nunes[1] and Mário Simões-Marques[2]
*[1]Centre of Technologies & Systems; and Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa,*
*[2]Portuguese Navy,*
*Portugal*

## 1. Introduction

Risk management for work accidents and occupational diseases is of utmost importance considering the high toll paid each year in human life, human suffering and the social and economical costs resulting from work accidents and work-related disorders. According to European Agency for Safety and Health at Work every year 5,720 people die in the European Union (EU) as a consequence of work-related accidents (EASHW, 2010). The same Agency points that the International Labour Organisation estimates that an additional 159,500 workers die every year from occupational diseases in the EU. Taking both figures into consideration, it is estimated that every three-and-a-half minutes somebody in the EU dies from work-related causes. EUROSTAT performed the Labour Force Survey 2007 regarding the situation on accidents at work and work-related health problems for the 27 EU Member States (EU-27). The main findings were (Eurostat, 2009):

- 3.2% of workers in the EU-27 had an accident at work during a one year period, which corresponds to almost 7 million workers;
- 8.6% of workers in the EU-27 experienced a work-related health problem in the past 12 months, which corresponds to 20 million persons;
- 40% of workers in the EU-27, i.e. 80 million workers, were exposed to factors that can adversely affect physical health; and
- 27% of workers, i.e. 56 million workers, were exposed to factors that can adversely affect mental well-being.

The same source notes that among workers who had an accident, 73% reported lost work days after the most recent accident, and 22% reported time off that lasted at least one month; hence, due to an accident at work, 0.7% of all workers in the EU-27 took sick leave for at least one month.

Within the context of their general obligations, employers have to take the necessary measures to prevent workers from exposure to occupational risks. This is a quite basic principle in the law of many countries. For instance, within the European Community, such principle was established by the Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work (Directive 89/391/EEC – the Framework Directive), and then adopted by Member States' national legislations.

For this purpose employers must perform risk assessment regarding safety and health at work, including those facing groups of workers exposed to particular risks, and decide on protective measures to take and, if necessary, on protective equipment to use. Risk assessment is according to (BSI, 2007), the process of evaluating the risk(s) arising from a hazard(s), taking into account the adequacy of any existing controls, and deciding whether or not the risk is acceptable. According to OSHA an acceptable risk is a risk that has been reduced to a level that can be tolerated by the organization having regard to its legal obligations and its own occupational health and safety (OHS) policy (BSI, 2007).

In a work situation a hazard is, according to (BSI, 2007), a source, situation or act with a potential for harm in terms of human injury or ill health or a combination of these, whereas risk is defined by the same standard as a combination of the likelihood of an occurrence of a hazardous event or exposure(s) and the severity of injury or ill health that can be caused by the event or exposure(s).

Risk assessment should be integrated in a more comprehensive approach, designated as risk management, which includes also the process of performing the reduction of risks to an acceptable level. This can be achieved through the implementation of safety measures or safety controls considering the following hierarchy: engineering controls to eliminate the risk, to substitute the source of risk or at least to diminish the risk; organizational/administrative controls to diminish the workers exposure time or to sign/warn risks to workers and; as a last measure, the implementation of personnel protective equipment usage. A key aspect in risk management is that it should be carried out with an active participation/involvement of the entire workforce.

## 2. Risk management

Risk management is an iterative and cyclic process whose main aim is to eliminate or at least to reduce the risks according to the ALARP (as low as reasonably practicable) principle. Following the methodology PDCA (Plan-Do-Check-Act) risk management is a systematic process that includes the examination of all characteristics of the work performed by the worker, namely, the workplace, the equipment/machines, materials, work methods/practices and work environment; aiming at identifying what could go wrong, i.e. finding what can cause injury or harm to workers; and deciding on proper safety control measures to prevent work accidents and occupational diseases and implement them (i.e. risk control).

Performing risk management entails several phases, which are illustrated in Figure 1. Considering a work system under analysis, the first phase is the collection of data, usually denoted as Risk Analysis, i.e identification of hazards present in the workplace and work environment as well as the exposed workers, and identification of potential consequences of the recognized hazards – risks, i.e. the potential causes of injury to workers, either a work accident or an occupational disease. This is followed by the Risk Assessment phase, which includes the risk evaluation, the ranking of the evaluated risks and their classification in acceptable or unacceptable. At the end of this phase the unacceptable safety and health risk situations are identified. The last phase is Risk Control that includes designing/planning safety control measures to eliminate or at least to reduce risks to ALARP, followed by the implementation of safety control measures. This should be done using the following hierarchy order, first prevention measures and after protection measures (NSW, 2011) (Harms-Ringdahl, L., 2001). The safety control measures to be implemented should be based on the current technical knowledge, and good practices. Part of the risks could be transferred to insurance companies. In EU is mandatory that employers have an insurance coverage for work accidents for each worker. This way part of the risk is transferred to the insurance companies. It is very important that employers know where the risks are in their organizations and control them to avoid putting at risk the employees, customers and the organization itself.

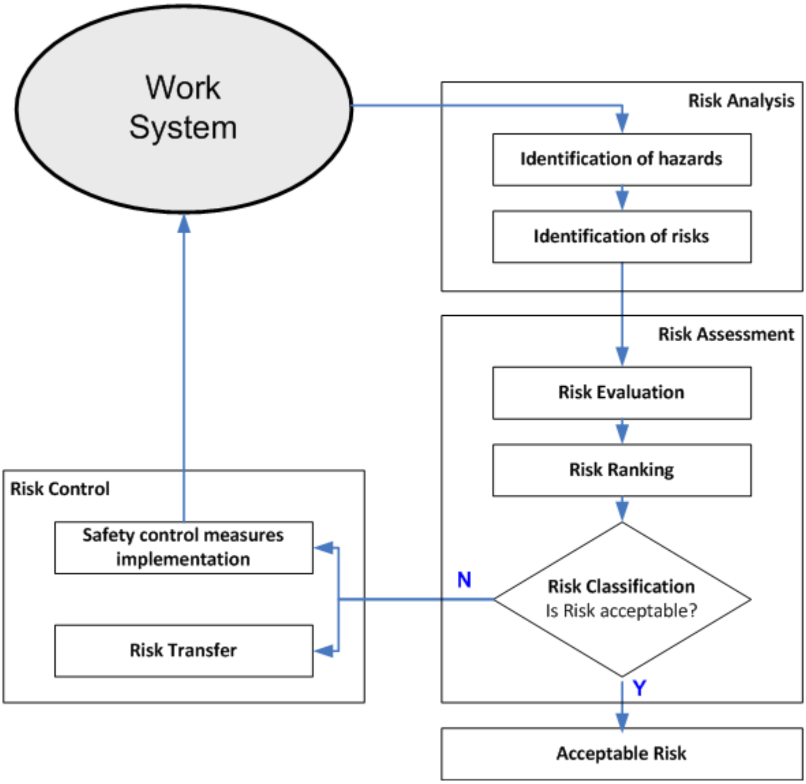



Fig. 1. Phases of the risk management process (Nunes, I. L., 2010b)

Further, in EU is a legal requirement that information and training courses are provided to workers, since workers must know the risks they are exposed to.

The standard risk assessment approach, for different risks (e.g., falls, electrical shock, burn, burying due to trench collapse, crushing) is based in the evaluation of the risk level, which results from the combination of two estimated parameters. One is the likelihood or probability of an occurrence of a hazardous event or exposure(s); and the other is severity of injury or ill health that can be caused by such event or exposure(s). These estimations are based on data regarding the presence of the hazards or risk factors in the workplace and the adequacy of the control measures implemented (prevention and protection measures).

The estimations of these parameters usually involve imprecise or vague data, incomplete information or lack of historical data that can be used to produce statistics. This is the reason why the introduction of methodologies based on fuzzy logic concepts can improve risk assessment methods.

Another important aspect in risk management is that there is no single cause (or simple sequence), but rather an interaction of multiple causes that directly and indirectly contribute to an occupational accident, the so-called cumulative act effects (Reason, J., 1997). The Reason model for the study of accident causation lies on the fact that most accidents can be traced to one or more of four levels of failure: organizational influences, unsafe supervision, preconditions for unsafe acts, and the unsafe acts themselves. The organization's defenses against these failures are modelled as a series of barriers. The barriers could be physical or organizational. The model considers active failures (unsafe acts that can be directly linked to an accident) and latent failures (contributory factors in the work system that may have been hidden for days, weeks, or months until they finally contributed to the accident) (Reason, J., 1997).

Therefore, is important to include organizational and individual factors in the risk management process. This is also in accordance with more holistic views, recognized by several authors, that consider also a host of other factors (e.g., individual, psychosocial) that can contribute to the risk (EC, 2009), (EASHW, 2002).

## 3. The RA_X expert system

Construction industry is one of the activities more affected by work accidents. According to European Agency for Safety and Health at Work around 1,300 workers are killed each year, equivalent to 13 employees out of every 100,000 — more than twice the average of other sectors (EASHW, 2010). As a result of its particular characteristics (e.g., projects performed only once, poor working conditions, some tasks involve particular risks to the safety and health of workers, emigrant workers, low literacy, low safety culture) construction industry has special legislation concerning the workers protection, because temporary or mobile construction sites create conditions prone to expose workers to particularly high levels of risk. Temporary or mobile construction sites means any construction site at which building or civil engineering works are carried out, which include repair and maintenance activities. In Europe the Framework Directive is complemented by the Council Directive 92/57/EEC of 24 June 1992 that addresses minimum safety and health requirements at temporary or mobile construction sites designed to guarantee a better OHS standard for workers.

Despite a steady and steep decline in the accident rates in the construction industry they remain unacceptably high, both in Europe (EASHW, 2010) and in the US (NASC, 2008). One contribution for the lowering of such accident rates could be making available tools that support the risk management activities in a simple and easy way, since there is still a lack of practical tools to support these activities. This shortfall leads to the existence of a big gap between the available health and safety knowledge and the one that is applied. Using computer-based methods could be an interesting approach to support risk assessment. The possible reasons for the lack of computer aided support tools are twofold. On one hand, the conventional software programming, based on Boolean approaches, have trouble in dealing with the inherent complexity and vagueness of the data and knowledge used in the risk assessment processes. On the other hand there are no steady and Universal rules to use for the assessment (e.g., action and threshold limit values) and the advice (e.g., regulations). These challenges call for solutions that are innovative in terms of methodologies, flexible in terms of tailoring to a specific regional context, and adaptive to deal with new or emerging risks and regulations.

The motivation for the development of the Risk Analysis Expert System (RA_X) was to make use of some emergent instruments offered by the Artificial Intelligence toolbox, namely the use of fuzzy logics in the development of a fuzzy expert system. Fuzzy Logics has been used to handle uncertainty in human-centred systems (e.g., ergonomics, safety, occupational stress) analysis, as a way to deal with complex, imprecise, uncertain and vague data. The literature review performed by (Nunes, I. L., 2010a) characterizes and discusses some examples of such applications.

Expert Systems (ES), also called knowledge-based systems, are computer programs that aim to achieve the same level of accuracy as human experts when dealing with complex, ill-structured specific domain problems so that they can be used by non-experts to obtain answers, solve problems or get decision support within such domains (Turban, E. et al., 2004). The strength of these systems lies in their ability to put expert knowledge to practical use when an expert is not available. Expert systems make knowledge more widely available and help overcome the problem of translating knowledge into practical, useful results. ES architecture contains four basic components: (a) a specialized Knowledge Base that stores the relevant knowledge about the domain of expertise; (b) an Inference Engine, which is used to reason about specific problems, for example using production rules or multiple-attribute decision-making models; (c) a working memory, which records facts about the real world; and (d) an interface that allows user-system interaction, as depicted in Figure 2.

A Fuzzy Expert System is an ES that uses Fuzzy Logic in its reasoning/inference process and/or knowledge representation scheme. For more information about Expert Systems see, for instance, (Turban, E. et al., 2010), (Gupta, J. N. D. et al., 2006), (Turban, E. et al., 2004).

The main objective of RA_X is assisting the risk management process, which is key for the promotion of safety and health at work, by identifying, assessing and controlling occupational risks and advising on the application of corrective or preventive actions. One requirement for this system is the adoption of a flexible framework that can be easily customized to the particular needs and specificities of groups of users (e.g., particular fields of activity, different national/regional legislation and standards). The underlying concept was first presented in (Nunes, I. L., 2005) and the proof of concept for the risk assessment phase was presented in (Monteiro, T., 2006).

In (Nunes, I. L., 2005) it was described the Fuzzy Multiple Attribute Decision Making (FMADM) model developed by the author for the evaluation of risk factors. This model was applied in two different risk assessment contexts, for ergonomic analysis and for risk analysis for work accidents. The ergonomic analysis FMADM model was used in the ERGO_X fuzzy expert system prototype and in the subsequent implementation of the FAST ERGO_X fuzzy expert system. To learn more about ERGO_X and FAST ERGO_X see, for instance, (Nunes, I. L., 2006a, b, 2007, 2009). This article offers a view of the current state of evolution of the FMADM model for the risk analysis for work accidents that was introduced in (Nunes, I. L., 2005) used for the development of the RA_X fuzzy expert system and presents an example applied to the risk management in the construction industry.

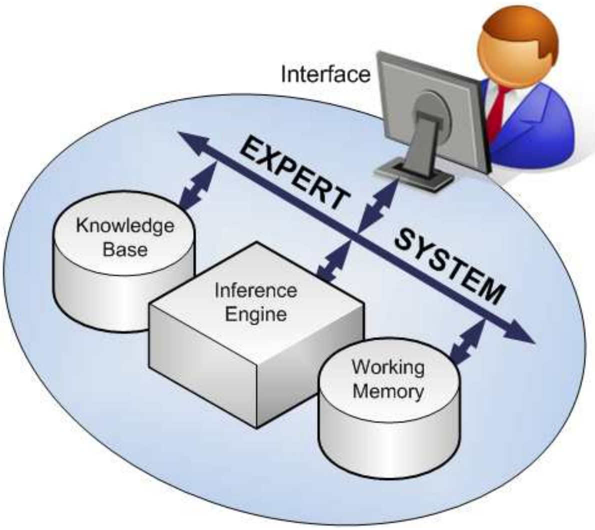



Fig. 2. Basic architecture of an Expert System

Considering the risk management context, as a very brief summary one can say that the FMADM model is used to compute the possibility of occurrence of Cases that are defined in the expert system. "Cases" are what, in classical Risk Analysis terminology, is referred as Risks (e.g., falls, electrical shock, burn, burying due to trench collapse, crushing). A given Case is assumed to be possible to occur based on the evaluation of a set of contributing "Factors". In the RA_X analysis model, three types of Factors are considered: "Hazard", "Safety Control Factors" and "Potentiating Factors". The main objective of the "Hazard" and the "Potentiating Factors" is to characterize the risk factors present on a specific work situation; and the "Safety Control Factors" purpose is to characterize the adequacy of the safety measures implemented in the workplace. Each Factor is evaluated based on a set of relevant "Attributes" that characterize in detail the work situation.

The concept and the analysis model was implemented in the RA_X, which is a fuzzy expert system prototype designed to support risk management for work accidents. This tool can facilitate the practical application of risk management at company level, targeting especially SMEs. The main objectives of the RA_X are the identification and assessment of exposure to occupational risks and the advice on measures to implement in order to control risks, i.e., to eliminate or, at least, to reduce the potential of the occupational risks for accident causation. The system also allows monitoring the evolution of risks over time, by performing trend analysis through the comparison of different risk assessment results regarding the same work situation.

### 3.1 General structure

RA_X lies in a FMADM model that calculates the risk level for each specific Case (i.e. Risk) based on three main factors: the Hazard itself, the effectiveness of the Safety Control measures set in the workplace, and the presence of a number of other factors, collectively referred as Potentiating Factors.

These main factors are assessed based on Attributes that characterize one particular work situation. Attribute's raw data can be of objective or subjective nature, depending if it is quantitative data obtained from measurements (e.g., height of a scaffold, depth of a trench, voltage of a power line) or qualitative data obtained from opinions of experts (e.g., adequacy, periodicity, acceptability). Figure 3 shows a schematic representation of the RA_X assessment model. The process depicted in the figure will be repeated as many times as the number of Cases to analyze (which may be the total number of cases in the Knowledge Base, or a user selected subset of those).

In this approach it is considered that the data collection phase (depicted inside the boxes in the left hand side of Figure 3) includes the gathering of raw data and their pre-processing (i.e., fuzzification and aggregation) in order to generate the fuzzy attributes that will be used as inputs in the subsequent phase (the risk assessment). Usually each risk results from a single specific hazard but its triggering is affected by different types of safety control measures and potentiating factors. Therefore, for each Case defined in the Knowledge Base the model considers one Hazard fuzzy attribute, and several Safety Control Factors and Potentiating Factors fuzzy attributes.

The risk assessment phase is depicted in the right hand side of Figure 3, illustrating the inference process that uses the attributes as criteria for the Fuzzy Rules that emulate the reasoning process used by human risk analysis experts (note that these fuzzy rules are translated into the FMADM model as discussed in subsection 3.3). The fuzzy evaluation result is defuzzified and presented in a more intelligible way to the users, for instance using sentences in natural language.

Figure 3 illustrates also the type of entities stored in the Knowledge Base (e.g., Fuzzy Sets, Fuzzy Rules) and their use in these two phases. The fuzzification of the raw data is done using continuous fuzzy sets (①) for the objective data, and linguistic variables or discrete fuzzy sets (②) for the subjective data. The objective and subjective attributes resulting from the fuzzification are aggregated using fuzzy aggregation operators (③) (e.g., fuzzy t-norm and fuzzy t-conorms) generating a unique fuzzy attribute that reflects both sources of data. The fuzzy attributes characterizing the hazards, the safety controls measures and the potentiating factors present in the workplace are aggregated according to fuzzy rules (④) that evaluate the risk. Finally the fuzzy result is defuzzified using linguistic variables (⑤) to generate conclusions expressed as natural language sentences. In addition, the conclusions can be explained to users.

The advice phase, also depicted in the right hand side of Figure 3, is performed after the conclusion of the risk assessment and is based on an inference process that uses rules (④) contained in the knowledge base, which identify potential risk control solutions and prioritize them according to the factors that were assessed as more critical in the previous phase.

Hence, building up the RA_X Knowledge Base according to the above described model required the elicitation and representation of knowledge in the risk management domain, which involved the following activities:

- Enumeration of Cases;
- Identification of the Factors that contribute to each specific Case;
- Identification of the Attributes to use in the assessment of each Factor;
- Identification of Measurements to use as data for an Objective Attribute (quantitative) related to an Attribute;
- Identification of Opinions to use as data for a Subjective Attribute (qualitative) related to an Attribute;
- Definition of continuous Fuzzy Sets used for the fuzzification of Objective Attributes;
- Definition of Linguistic Variables used for the fuzzification of Subjective Attributes;
- Definition of Generic Recommendations related to Cases;
- Definition of Specific Recommendations related with Attributes.

The knowledge acquisition is a manual process based on data available on literature, on information collected from experts and on legislation. The initial knowledge acquisition activities for the RA_X were mainly focused on the Construction industry.

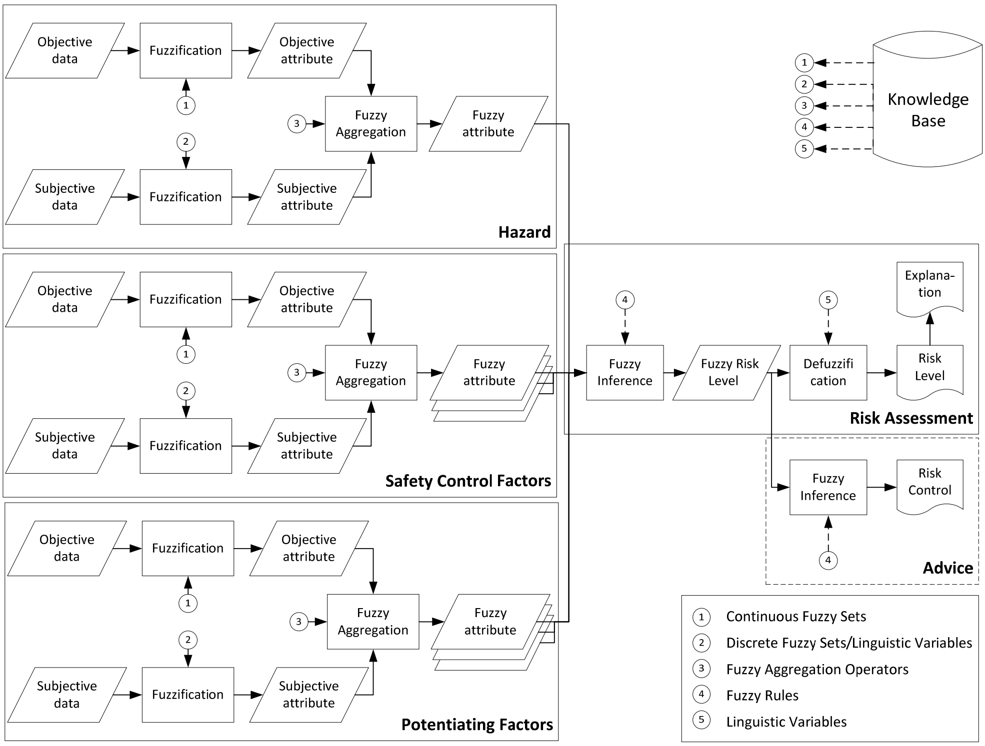



Fig. 3. Schematic representation of the risk assessment model for a Case

### 3.2 Data collection phase

The data collection is the phase of the process where the risk analysis raw data is gathered and pre-processed (i.e., fuzzified and aggregated) in order to generate the fuzzy attributes that will be used as inputs in the subsequent phase (the risk assessment).

As mentioned before, on a specific risk assessment situation the fuzzy attributes characterizing the three main factors of a particular Case can result from the combination of objective and subjective attributes that relate, respectively, to objective and subjective data. Objective data is typically a quantitative value that can be measured (e.g., the height in meters at which a worker operates), therefore in this model it will be designated as "measurement". Subjective data is a qualitative estimate made by an analyst (e.g., "very high", "high", "and low") and therefore in this model it will be designated as "opinion".

Using the FST principles it is possible to evaluate the degree of membership to some high-level concept based on observed data. Consider, for example, the evaluation of the risk of injury associated with falls from height based on the continuous membership function presented in Figure 4, where the input is a measured height. A low degree of membership to the "falls from height" risk concept (i.e., values close to 0) means the height is safe; while a high degree of membership (i.e., values close to 1) means the risk is unacceptable.

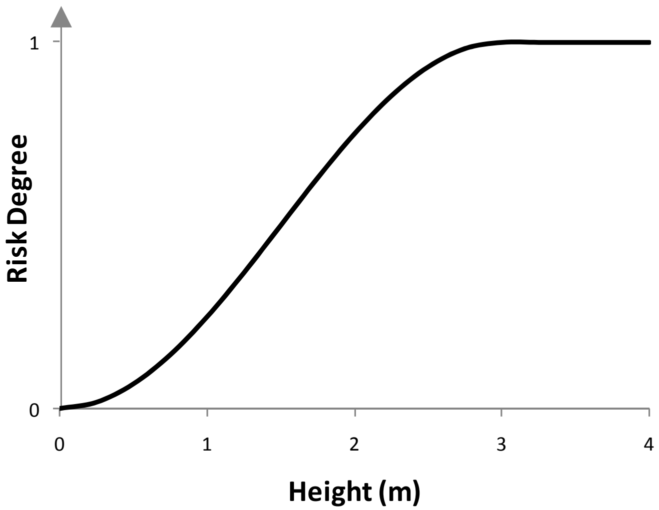



Fig. 4. Fuzzy set for the evaluation of the *risk of falls from height*

The representation of continuous fuzzy sets in the Knowledge Base is done using a parametric method that was discussed in (Nunes, I. L., 2007).

The fuzzification of opinions can use Linguistic Variables (LV). In this approach, due to considerations regarding the numerical efficiency of the computational process, the LV terms were assumed as discrete fuzzy sets. Consider, as an example, the LV "inadequacy" presented in Figure 5, which can be used to evaluate the inadequacy of the protection provided in a workplace, by the Safety Control measures implemented (Nunes, I. L., 2007). An effective protection can be classified using the term "very adequate" (i.e., a membership degree of 0), while an inexistent protection can be classified as "very inadequate" (i.e., membership degree of 1).

The result of the aggregation of the existing objective and subjective attributes is a fuzzy value assigned to the corresponding attribute. In the present model the aggregation of opinions and measurements is done using the OWA operator (Yager, R. R., 1988). With this operator it is possible to assign weights to the different input data sources. This is particularly useful when the sources of information have different levels of reliability. In this case the inputs from more reliable sources have a bigger weight than the ones coming from less reliable sources.

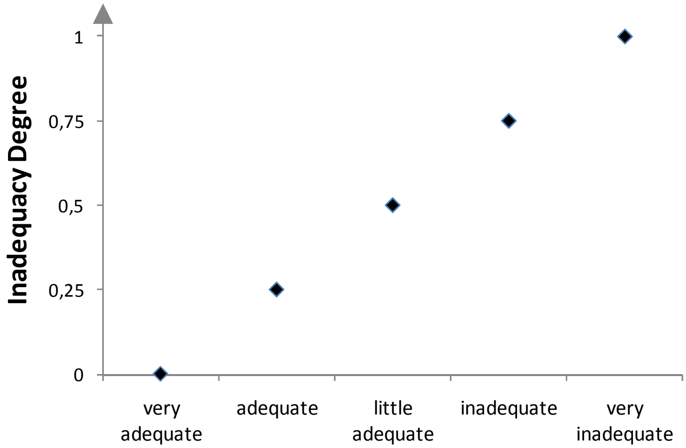



Fig. 5. Linguistic variable "inadequacy" used to evaluate "protection inadequacy"

### 3.3 Risk assessment phase

#### 3.3.1 Fuzzy inference process

The risk assessment is the phase where the fuzzy attributes related to a Case are processed according to fuzzy rules evaluating the degree of risk present in the workplace. At the end of this phase the fuzzy evaluation result is defuzzified to produce the output to present to the users. The reasoning process used is discussed in this section as well as its FMADM mathematical counterpart.

The main assumption of this fuzzy risk assessment model is that if a hazard is present in a workplace and there is a lack of adequate safety control measures and there are some potentiating factors then there is risk for accident. This can be expressed by the following generic rule:

**IF** hazard exists **AND**
safety control is inadequate AND (R1)
potentiating factors exist
**THEN** risk exists

The fuzzy approach allows the use of fuzzy operators to numerically aggregate the different fuzzy attributes that characterize the criteria of the rule and assess the degree of truth of the conclusion. Considering the variety of fuzzy operators the ANDs expressed in the rule can be formulated using different intersection operators, according to desired aggregation behaviour. Therefore, rule [R1] can be translated into a mathematical formula such as:

$$\mu_r = (\mu_h \ \alpha \ \mu_p) * \mu_{pf} \tag{E1}$$

Where:

$\mu_r$ is the Fuzzy membership degree that reflects the risk level;
$\mu_h$ is the Fuzzy membership degree that reflects the hazard level for a specific risk;
$\mu_p$ is the Fuzzy membership degree that reflects the inadequacy level of the safety control measures set in place to prevent a specific risk;
$\mu_{pf}$ is the Fuzzy membership degree that reflects the level of the potentiating factors for a specific risk;
$\alpha$ represents a Fuzzy Intersection aggregation operator that produces a normalized fuzzy value, i.e., in the interval [0, 1]
$*$ represents a Fuzzy Intersection aggregation operator that produces a normalized fuzzy value, i.e., in the interval [0, 1]

Each criteria of the rule (the left side terms of the IF-THEN) can be the result of previous rules of an inference chain. For instance, considering that the protection provided by the safety control measures can be achieved through collective and personnel protection means the evaluation of the criteria "safety control is inadequate" can result from the use of the following rule:

**IF** collective protection is inadequate **AND**
personnel protection is inadequate (R2)
**THEN** safety control is inadequate

As before this rule can be translated into a mathematical formula, such as:

$$\mu_p = \mu_{cp} \wedge \mu_{ip} \tag{E2}$$

Where:

$\mu_p$ is the Fuzzy membership degree that reflects the inadequacy of the safety control measures set in place to prevent a specific risk;
$\mu_{cp}$ is the Fuzzy membership degree that reflects the inadequacy of the collective protection measures set in place to protect a specific risk;
$\mu_{ip}$ is the Fuzzy membership degree that reflects the inadequacy of the personnel protection measures set in place to protect a specific risk;
$\wedge$ represents a Fuzzy Intersection aggregation operator that produces a normalized fuzzy value, i.e., in the interval [0, 1]

Another example relates with the evaluation of the potentiating factors. These factors (e.g., work activity, and environmental, psychosocial and individual factors) do not represent risk by themselves but potentiate and may intensify the negative impact of a hazard. In this case the evaluation of the criteria "potentiating factors exist" can result from the use of the following rule:

**IF** work activity is inadequate **OR**
environmental factors are inadequate **OR**
psychosocial factors are inadequate OR (R3)
individual factors are inadequate
**THEN** potentiating factors exist

Naturally such inference chains can have multiple layers that address the information regarding a specific concept with difference levels of detail (i.e., complexity, vagueness and relevance). An example of the next level of the inference chain rules is the evaluation of the criteria "work activity is inadequate". One should note that this evaluation is risk dependent. Considering, for instance, the criteria to assess the "work activity" potentiating factor regarding the risk of "falls from height", the following rule could be used:

**IF** type of floor/tidiness is inadequate **OR**
manual materials handling exists **OR**
use of tools exists **OR** (R4)
handling of suspended loads exists
**THEN** work activity is inadequate

This type of rule can be assessed numerically considering the respective membership degrees using a generic assessment formula such as:

$$\mu_{pf_i} = \cup_{j=1}^{n} \mu_{f_{ij}} \tag{E3}$$

Where:

$\mu_{pf_i}$ is the Fuzzy membership degree that reflects the inadequacy level of $i^{th}$ potentiating factor for a specific risk;
$\mu_{f_{ij}}$ is the Fuzzy membership degree that reflects the inadequacy level of the $j^{th}$ factor contributing to the $i^{th}$ potentiating factor for a specific risk;
U represents a Fuzzy Union aggregation operator that produces a normalized fuzzy value, i.e., in the interval [0, 1]

### 3.3.2 Fuzzy operators selection

The selection of the aggregation operators was based on the eight selection criteria proposed by (Zimmermann, H.-J., 2001) mentioned above. Table 1 synthesizes the main fuzzy operators used in the RA_X, and also the value of the parameters adopted for the parametric operators.

| Equation # | Fuzzy Operator | | | Parameter |
|---|---|---|---|---|
| E1 | α | Dubois and Prade Intersection | $\mu_{A\alpha B} = \frac{\mu_A \mu_B}{\max(\mu_A, \mu_B, \alpha)}, \alpha \epsilon [0,1]$ | α = 0.9 |
| E1 | * | Algebraic product | $\mu_{A.B} = \mu_A . \mu_B$ | - |
| E2 | ^ | Min | $\mu_{A \cap B} = \min(\mu_A, \mu_B)$ | - |
| E3 | ∪ | Dubois and Prade Union | $\mu_{A\alpha\acute{}B} = \frac{\mu_A + \mu_B - \mu_A \mu_B - \min(1-\alpha', \mu_A, \mu_B)}{\max(1-\mu_A, 1-\mu_B, \alpha')}, \alpha' \epsilon [0,1]$ | α' = 0.6 |

Table 1. Fuzzy operators adopted in the RA_X model

The Dubois and Prade Intersection operator is an operator with compensation which is controlled by the α parameter. This operator was selected to aggregate two main factors, Hazard and lack of adequate Safety Control. The result of this aggregation reflects the extension of the Hazard that is not mitigated by the Safety Control (Prevention and Protection) measures implemented.

The Algebraic Product was selected to combine the result of the above aggregation with the Potentiating factors. The rationale behind this selection is that there is an identical contribution of both terms to the risk level.

The Min operator is used in the aggregation of data regarding the levels of Collective and Personnel Protection. This operator was selected because it reflects the lack of protection that is still present in the workplace after combining all the types of protective measures set in place.

The Dubois and Prade Union operator is an operator with compensation which is controlled by the α' parameter. This operator is used twice. It is used first to aggregate the Attributes that characterize each Potentiating factor, and a second time to aggregate the results of all individual Potentiating factors, producing a global result. The use of this operator allows the simulation of the synergistic effect resulting from the simultaneous presence of several Potentiating factors.

### 3.3.3 Defuzzification process

The risk assessment results are presented as crisp risk levels which are obtained through a defuzzification process that uses a VL like the one presented in Figure 6. Note that the definition of the defuzzification fuzzy sets has to consider the relationship between the results distribution in the [0, 1] domain and the linguistic evaluation categories. Since the evaluation process uses product operators and the terms in the interval [0, 1], the evaluation results tend to be shifted to zero; therefore, the width of the fuzzy sets that reflect each linguistic term varies to accommodate this characteristic of the evaluation process. For a

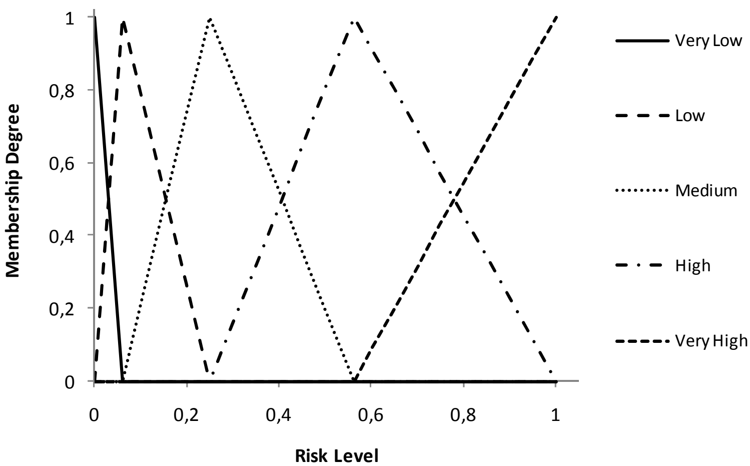



Fig. 6. Linguistic variable "risk level" used to defuzzify the risk assessment results

given fuzzy risk level the linguistic term is selected from the fuzzy set with higher membership degree. For instance, a risk level of 0.5 has a membership degree of 0.2 to "Medium" and 0.8 to "High", consequently the qualifier to use will be "High".

The selected qualifier is used for building a sentence in natural language that presents the result to the user, using the generic format:

*The risk of [descriptor of risk] is [qualifier]*

For instance, a result from a risk assessment can be "The risk of electrical shock is very high".

### 3.3.4 Explanation process

The system can also offer explanations about the results presented. This is done using a backward chain inference process that identifies, ranks and presents the attributes that have high values (above a specified threshold) and that more significantly contributed to the computed level of risk. The explanations use the following generic format:

"*The risk of [descriptor of risk] is [qualifier] because*:
The [*attribute*$_1$] is [*qualifier*] (fuzzy value)
The [*attribute*$_2$] is [*qualifier*] (fuzzy value)
…
The [*attribute*$_n$] is [*qualifier*] (fuzzy value)"

Where the detailed explanations are sorted in decreasing order of the respective attributes fuzzy value.

### 3.3.5 Advice phase

The advice phase is performed after the conclusion of the risk assessment, and offers recommendations about safety measures adequate to control the risk for situations where the risk level is Medium or higher. The recommendations can be generic and specific. Generic recommendations refer to advice (i.e., legislation, guidelines, best practice) relating to a type of risk in general (e.g., risk of falls from height); while specific recommendations refer to advice that addresses a specific type of attribute that contributes to the risk (e.g., collective protection installed in site).

The generic recommendations use the following format:

*"Regarding the risk of [descriptor of risk] consider the following advice*
*Generic Recommendation*$_1$
…
*Generic Recommendation*$_n$"

The selection of the specific recommendations is performed using a backward chaining inference process based on the risk assessment fuzzy rules. This process identifies and ranks the key attributes that contributed to the risk assessment result (i.e., the attributes with high membership values), and provides recommendations in this order.

The specific recommendations use the following format:

*"Regarding the [attribute1] of the risk of [descriptor of risk] consider the following advice*
*Specific Recommendation1*
*…*
*Specific Recommendationn"*

## 4. Application example

In this section it will be demonstrated the use of the RA_X fuzzy model in support of risk management. The example presented analyzes a construction work activity, which is pouring concrete into the forms of the structure of a building. Since the activity is performed on a platform located several meters in the air, the risk analysis presented regards the risk of "falls from height".

| Risk | Hazard | Attributes | |
|---|---|---|---|
| **Falls from height** | • Work at height | • Height | |
| | **Safety Control Factors** | **Attributes** | |
| | • Collective Protection (Physical) | • Safety barriers | • Safe Access |
| | • Collective Protection (Organizational) | • Supervision<br>• Security Signs/ Warnings | • Techniques and Procedures |
| | • Personnel Protection | • Harness/Lifeline | |
| | **Potentiating Factors** | **Attributes** | |
| | • Work Activity | • Type of floor/Tidiness<br>• Manual materials handling<br>• Use of power/heavy tools<br>• Handling suspended loads | • Interaction with other work activities |
| | • Environmental Factors | • Wind<br>• Rain<br>• Cold<br>• Noise | • Vibration<br>• Illumination<br>• Dust |
| | • Psychosocial Factors | • Work pace<br>• Extra Work | • Stress |
| | • Individual Factors | • Hearing<br>• Vision<br>• Alcohol consumption | • Safety behaviour<br>• Type of footwear<br>• Safety training |

Table 2. Example of main factors and attributes considered in the assessment of the risk "falls from height"

As explained before, the risk assessment is based on attributes related with three categories of main factors (hazard, safety control factors and potentiating factors). Table 2 illustrates the main factors and examples of corresponding attributes for assessing the risk of “falls from height”. For example, “Work at height” is the Hazard and “Height” is the attribute required for this analysis. The list of attributes is used during the data collection phase to ask for the relevant input data for the risk analysis. If the user doesn’t provide data to some attribute the model considers that this attribute is in such a state that is not contributing to the risk.

Table 3 synthesizes the application of the RA_X model. The collected input data is shown in column “Raw Data”.

<table>
<tr><th></th><th>Attribute</th><th>Raw Data</th><th>Fuzzy Attribute Value</th><th colspan="2">Aggregated Values</th><th>Fuzzy Risk Level (Crisp Risk Level)</th></tr>
<tr><td colspan="6">Hazard</td><td rowspan="12">0.72 (High)</td></tr>
<tr><td>Work at height</td><td>Height</td><td>4 m</td><td>1</td><td colspan="2">1</td></tr>
<tr><td colspan="6">Safety Control</td></tr>
<tr><td>Individual</td><td>Harness/Life line</td><td>Inadequate</td><td>0.75</td><td colspan="2" rowspan="2">0.75</td></tr>
<tr><td>Collective</td><td>Barrier</td><td>Inexistent</td><td>1</td></tr>
<tr><td colspan="6">Potentiating Factors</td></tr>
<tr><td rowspan="2">Work Activity</td><td>Type of floor/Tidiness</td><td>Inadequate</td><td>0.75</td><td rowspan="2">0.75</td><td rowspan="6">0.95</td></tr>
<tr><td>Use of power/heavy tools</td><td>Very adequate</td><td>0</td></tr>
<tr><td>Environmental Factors</td><td>Illumination</td><td>Adequate</td><td>0.25</td><td>0.25</td></tr>
<tr><td rowspan="3">Individual</td><td>Safety behaviour</td><td>Little adequate</td><td>0.5</td><td rowspan="3">0.83</td></tr>
<tr><td>Type of footwear</td><td>Very adequate</td><td>0</td></tr>
<tr><td>Safety training</td><td>Inadequate</td><td>0.75</td></tr>
</table>

Table 3. RA_X application example in the assessment of the risk “falls from height” for an activity of pouring concrete

In this case the Height was obtained by measurement and the other data are opinions. The fuzzification of the data was done using the membership function presented in Figure 4 for the Height, and the Linguistic Variable “inadequacy” (Figure 5) for the remaining subjective data (refer to subsection 3.2), and the results of the fuzzification process are presented in column “Fuzzy Attribute Value”. The results of the partial fuzzy inference processes are shown in column “Aggregated Values” (refer to subsection 3.3). Finally, the fuzzy risk level and the corresponding crisp level, obtained by defuzzification (see Figure 6) are presented in column “Fuzzy Risk Level (Crisp Risk Level)” (refer to subsection 3.3.3).

In short, the risk assessment based on the RA_X model is that there is a high risk of falls from height for an activity where the workers operate at a height of 4 m, the best protection offered is deemed as inadequate and the more relevant potentiating factors are the inadequate type of floor and safety training. The output of this assessment is done using a sentence in natural language, such as:

“The risk of falls from height is High”

As mentioned before the system can offer explanations about the results presented. The explanation regarding this risk assessment would adopt the following format:

“The risk of falls from height is High because:

The Height is very inadequate (1)
The Harness/Life line is inadequate (0.75)
The Type of floor/Tidiness is inadequate (0.75)
The Safety training is inadequate (0.75)”

Regarding advice the RA_X can offer generic and specific recommendations that can be customized to the regional specificity of the users. Generic recommendations to the risk of falls from height include multimedia documents or internet links to, for instance, regulations, guidelines, best practices or software tools (e.g., European Directive 2001/45/EC (EU, 2001), European norms for protection against falls from heights (CEN, 2008), OSHA’s Guidelines for the Prevention of Falls (OSHA, 1998), (OSHA, 2010c), OSHA Construction eTool (OSHA, 2010a), HSE’s Interactive Guide (HSE, 2010)). Specific recommendations include the same type of references, but addressing the individual issues that emerged as contributing significantly to the risk. In the present example, the recommendations would address themes like improving personnel protection (e.g., (BSI, 2005)), collective protection (e.g. (NASC, 2008)), type of working floor (e.g. (OSHA, 2010b)) or safety training (e.g. (HSE, 2008)).

## 5. Conclusion

Fuzzy Logics has been used to handle uncertainty in human-centred systems (e.g., ergonomics, safety, occupational stress) analysis, as a way to deal with complex, imprecise, uncertain and vague data.

This chapter presented the main features of the RA_X FMADM model, which was developed to implement a fuzzy expert system for supporting risk management activities. In the current stage a prototype was implemented for test and validation purposes. The support of a proactive risk management is achieved by assessing potential factors that contribute for occupational accident occurrence and by guiding on the adoption of safety measures.

The RA_X is meant to be a flexible and easy to use system, which can process both objective and subjective input data and provide risk assessment and advice for a broad variety of occupational activities. The results are offered using natural language. The system also provides means to perform trend analysis supporting the follow-up and monitoring of risks in work situations.

Following a quite simple Knowledge Engineering process, the Knowledge Base of the RA_X expert system can be updated to incorporate new risks, broadening the scope of application, and can be customized to different national realities accommodating, for instance, to different legal frameworks or level of action requirements, which affect the assessment process and/or the advice offered.

The advantages of this fuzzy system compared with traditional methodologies based on the estimation of two parameters (probability and severity) are obvious. First, the system is more thorough on the risk assessment, considering a wider range of factors, contributing to the implementation of a holistic approach to the assessment of risks, namely by including organizational and individual factors. Another important advantage is the fact that the methodology used allows the combination of objective and subjective data in a coherent way. Finally, it supports the full cycle of the risk management process (including hazard identification, risk assessment, advice on risk control and monitoring support), which is key for the promotion of safety and health at work.

The RA_X system is ongoing tests and evaluations by experts that are representative of the expected typical users of this new approach.

A future step is the web implementation of the RA_X system so that the most updated set of knowledge can be remotely accessed, which allows also exploiting the benefits offered by mobile devices, such as Tablets or iPads.

## 6. References

BSI (2005). BS 8437:2005. Code of practice for selection, use and maintenance of personal fall protection systems and equipment for use in the workplace, British Standard Institutions.

BSI (2007). Occupational health and safety management systems – Requirements, BS OHSAS 18001: 2007, British Standard Institutions.

CEN (2008). EN 363: Personal fall protection equipment. Personal fall protection systems. European Committee for Standardization - CEN.

EASHW (2002). New trends in accident prevention due to the changing world of work European Agency for Safety and Health at Work. (http://osha.europa.eu/en/publications/reports/208).

EASHW (2010). Statistics European Agency for Safety and Health at Work. http://osha.europa.eu/en/statistics/index.stm .

EC (2009). Occupational Health and Safety Risks in the Healtcare Sector European Commision http://www.eurogip.fr/docs/Commission_europeenne_guide_secteur_sante_2009_EN.pdf .

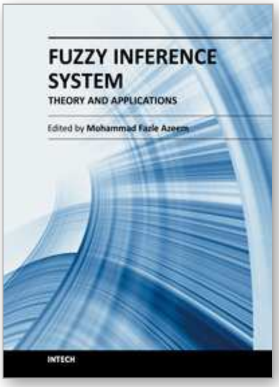
EU (2001). Directive 2001/45/EC of 27June 2001 concerning the minimum safety and health requirements for the use of work equipment by workers at work. Official Journal L 195 , 19/07/2001 P. 0046 - 0049 http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=CELEX:32001L0045:EN:HTML.

Eurostat (2009). Population and social conditions (http://epp.eurostat.ec.europa.eu/cache/ITY_OFFPUB/KS-SF-09-063/EN/KS-SF-09-063-EN.PDF). Eurostat. Statistics in focus 63.

Gupta, J. N. D., Forgionne, G. A.& M.T., M., Eds., 2006. Intelligent Decision-making Support Systems: Foundations, Applications and Challenges (Decision Engineering), Springer.

Harms-Ringdahl, L. (2001). Safety Analysis: Principles And Practice In Occupational Safety, Taylor & Francis.
HSE (2008). Health and safety training. What you need to know (INDG345). Available at http://www.hse.gov.uk/pubns/indg345.pdf Health and Safety Executive.
HSE (2010). Fallington (Interactive guide). Available at http://www.hse.gov.uk/falls/heightaware/flashindex.htm. Health and Safety Executive.
Monteiro, T. (2006). Análise de Riscos na Construção Civil. Construção e Validação de Base de Conhecimento de um Sistema Pericial. Lisboa. Lisboa-Portugal.
NASC (2008). SG4:05 Appendix A. Interim Guidance on Collective Fall Prevention Systems in Scaffolding. National Access & Scaffolding Confederation. http://v35.up1.universalpixel.com/ams/assets/NASC532147/SG4_05%20Appendix%20A_web.pdf. National Access & Scaffolding Confederation.
NSW. 2011. "Six steps to Occupational Health and Safety. Available at http://www.une.edu.au/od/files/OHSSixsteps.pdf."
Nunes, I. L. (2005). Fuzzy Multicriteria Model for Ergonomic workplace analysis and Risk analysis. Information Technology, Knowledge Management and Engineering for Enterprise Productivity and Quality of Working Life (International Conference: Computer-Aided Ergonomics and Safety - CAES'05), Kosice-Slovak Republic.
Nunes, I. L. (2006a). ERGO_X - The Model of a Fuzzy Expert System for Workstation Ergonomic Analysis. International Encyclopedia of Ergonomics and Human Factors. Karwowski, CRC Press: 3114-3121.
Nunes, I. L. (2006b). Quantitative Method for Processing Objective Data from Posture Analysis. International Encyclopedia of Ergonomics and Human Factors. Karwowski, CRC Press: 3306-3309.
Nunes, I. L. (2007). Knowledge Acquisition for the Development of an Upper- Body Work-Related Musculoskeletal Disorders Analysis Tool. Human Factors and Ergonomics in Manufacturing 17(2): 149-162.
Nunes, I. L. (2009). FAST ERGO_X – a tool for ergonomic auditing and work-related musculoskeletal disorders prevention. WORK: A Journal of Prevention, Assessment, & Rehabilitation 34(2): 133-148.
Nunes, I. L. (2010a). Handling Human-Centered Systems Uncertainty Using Fuzzy Logics – A Review. The Ergonomics Open Journal 3: 38-48.
Nunes, I. L. (2010b). Risk Analysis for Work Accidents based on a Fuzzy Logics Model. 5th International Conference of Working on Safety - On the road to vision zero?, Roros. Norway.
OSHA (1998). OSHA 3146 (Revised): Fall Protection in Construction. http://www.osha.gov/Publications/osha3146.pdf, U.S. Department of Labor. Occupational Safety and Health Administration.
OSHA (2010a). OSHA Construction eTool. http://63.234.227.130/SLTC/etools/construction/falls/mainpage.html (accessed in November 2010), U.S. Department of Labor. Occupational Safety and Health Administration.
OSHA (2010b). Standard 1910.23: Guarding floor and wall openings and holes. http://www.osha.gov/pls/oshaweb/owadisp.show_document?p_table=STAND

ARDS&p_id=9715. U.S. Department of Labor. Occupational Safety and Health Administration.
OSHA (2010c). Standard 1926.501: Duty to have fall protection. http://63.234.227.130/pls/oshaweb/owadisp.show_document?p_table=STANDARDS&p_id=10757 (accessed in November 2010). U.S. Department of Labor. Occupational Safety and Health Administration.
Reason, J. (1997). Managing the risks of organizational accidents, Ashgate Publishing Ltd,Aldershot Hants
Turban, E., Aronson, J.& Liang, T.-P. (2004). Decision Support Systems and Intelligent Systems.
Turban, E., Sharda, R.& Delen, D. (2010). Decision Support and Business Intelligence Systems, Prentice Hall.
Yager, R. R. (1988). On Ordered Weighted Averaging Aggregation Operators in Multicriteria Decison Making. IEEE Transactions on Systems, Man, and Cybernetics 18(1): 183-190.
Zimmermann, H.-J. (2001). Fuzzy Set Theory and Its Applications, Kluwer Academic Publishers.




**Fuzzy Inference System - Theory and Applications**
Edited by Dr. Mohammad Fazle Azeem

ISBN 978-953-51-0525-1
Hard cover, 504 pages
**Publisher** InTech
**Published online** 09, May, 2012
**Published in print edition** May, 2012