A fuzzy multi-dimensional risk assessment framework for Integrated Management Systems (MIS)

Gionata Carmignani [1], Franco Failli [2] and Francesco Zammori [3]

[1] Dept. of Energy, Systems, Territory and Construction Engineering, University of Pisa,
Largo Lucio Lazzarino 561, 56122 Pisa, Italy
gionata.carmignani@unipi.it
[2] Dept. of Civil and Industrial Engineering, University of Pisa, Largo Lucio Lazzarino 561,
56122 Pisa, Italy
f.failli@ing.unipi.it
[3] Dept. of Industrial Engineering, University of Parma, Parco Area delle Scienze 181/A,
43124, Parma, Italy
francesco.zammori@unipr.it

Abstract

Quality, environmental and safety management systems are typically combined into an Integrated Management Systems (MIS), for easier management and improved performance. If, as usual, the MIS is developed in accordance to ISO standards, then *Process Control* becomes the key element regulating the functioning of the system. Indeed, to meet requirements in terms of quality, environment and safety, all processes must be known, standardized and, lastly, controlled. In this regard, risk management plays a critical role because, unless risks and criticality are known, it is not possible to make a process stable, repeatable and controllable.

The present paper focuses on the above mentioned topics and proposes a multi-dimensional risk assessment framework purposely developed for MIS. Due to the uncertain nature of the data needed for the analysis, the framework is based on fuzzy-logic rather than on probabilistic models. Specifically, for each process, a set of criteria (related to quality, environment and safety) are defined and their risk level is quantified using fuzzy linguistic variables. Criteria are then aggregated ad different levels of detail, up to a single indicator of global risk. Also, in order to take into account cause and effect relationships (among risk criteria) that cannot be easily measured, but that can only be judged by the experts, the aggregation is performed using a comprehensive set of If-Then rules combined using a Mamdani Fuzzy Inference System.

Lastly, a prototype application was coded in Matlab and many tests were performed; preliminary outcomes are encouraging as they indicate framework's robustness and stability.

Keywords: Integrated Management Systems, Fuzzy Logic, Risk Management.

1. Introduction

A Management System (MS) can be defined as «*an integrated set of policies, processes and procedures implemented to ensure, both the internal and the external customers, that all the objectives of a company can be achieved*». Typical examples are quality, environmental and safety management systems that enable companies to increase their standards and operating performance (in terms of product and process quality, environmental impact and workers' safety), through a continuous improvement process.

If, as usual, the management systems are developed in accordance to ISO standards, then *Process Control* and the well-known *Plan-Do-Check-Act* approach become the key elements regulating the functioning of the system. Indeed, to meet requirements in terms of quality, environment and safety, all processes must be known, standardized and, lastly, controlled. Also, due to their common intent and similarity, quite often, quality, environmental and safety management systems are combined into an Integrated Management Systems (MIS), for easier management and improved performance.

An important thing is that MSs cannot be considered as fixed entities, as they constantly evolve over time. Most of the times modifications proceed at a low rate, just to keep pace with the inevitable business changes, but periodically MSs undergo also revolutionary changes, due to upgrading of the underlying international standards. One of such revolution took place in 2015 when a new version of UNI EN ISO 9001 was released. Specifically, the new version of the ISO standard introduces many innovations, among which the most important one is, by sure, the massive introduction of the concept of risk management, defined as «*the identification, analysis, assessment, control, avoidance, minimization, or elimination of unacceptable adverse events*». More precisely, the risk of an adverse event is defined as the product of its damage and occurrence probability (Lein, 1992); thus a significant part of risk management, concerns the capability to estimate these two parameters, in a reliable and robust way. Obviously, apart from that, another fundamental area of risk management concerns both the design and the development of all the measures that are needed to transfer, to mitigate or, in the worst case, to face the occurrence of adverse events.

Certainly, the concepts of risk evaluation and risk control are widespread and well known in the engineering world, and this is not the very first time that the word "risk" appears in an ISO 9001 standard. However, in the past, apart from some specific regulations for the automotive and for the aerospace industry (i.e., ISO/TS 16949 and ISO/EN 9100) where risk management was mandatory, the requirements of the ISO 9001 were related, exclusively to the conformity of processes, products and services. The use of specific technique for risk management (such as Fault Tree Analysis and Failure Mode and Effect Analysis) were only indicated as possible support tools, but companies were free to decide whether to adopt them or not. Conversely, with the release of the new version, the implementation of a risk management system has become mandatory to obtain an ISO 9001 certification, in any business.

The growing trend to integrate in a MIS quality, environmental and safety management systems is another element that makes the implementation of a risk management system a more and more compelling issue. Indeed, for a MIS to properly work, risky events must be analyzed from different perspectives, so as to consider the domino effects they may have in different areas of the business in terms of quality, environment and safety.

The present paper focuses on the above mentioned topics and proposes a multi-dimensional risk assessment framework, purposely developed for risk management in MIS. Due to the complexity of the problem, which may even be increased by possible correlations among quality, environment and safety issues, collecting numerical data concerning the risk of adverse events is often impossible (Casal, 2008). Most of the times, one has to make do with vague and imprecise data, or with subjective evaluations given by the experts operating in the various fields of a company (Matsatsinis et al., 2003). For these reasons, the use of quantitative probabilistic models would be useless if not even misleading. Instead, we propose using a multi-criteria framework based on a Fuzzy Inference System (FIS), as the one proposed in the recent works by Lahsasna (2009) and Li et al. (2011), who used fuzzy rules in the context of classification analysis for business failures models. More precisely, rather than using precise values to quantify both the likelihood and the effect of a risk, different risk criteria are expressed as linguistic terms and combined using a comprehensive set of If-Then rules, operating according to a Mamdani-Type FIS (Cheng et al., 2006). This leads to robust conclusions as it encourages human reasoning (involving the cause-and-effect relationships between key factors as well as the exposure for each individual risk) in a consistent and well-documented way (Reveiz and Leon, 2009; Yu et al., 2009).

The rest of the paper is organized as follows. Section 2 introduces the conceptual model of the risk assessment framework. Specific details, concerning data gathering, experts' opinions and the architecture of the developed Mamdani-Type FIS model, are given in Section 3 and Section 4. Lastly, conclusions and future research directions are discussed in Section 5.

2. A conceptual model for fuzzy Risk Assessment

In a standard risk management system, risk estimation involves the identification of the hazardous events and, most of all, the precise assessment of the magnitude of both their consequences and frequency. Unfortunately, specifically in case of Quality, Environment and Safety (QES), this process is not as straightforward as one could imagine. For a thorough QES risk assessment, a great amount of data is required, but in many cases neither databases nor distributions are available. Thus, QES data tend to be vague and imprecise and, consequently, significant uncertainty is associated to any study related to them. In these circumstances, a fuzzy logic approach may be a precious alternative to the classical method where every proposition must either be true or false. Instead, fuzzy logic asserts that things can be simultaneously true and not true, with a certain membership degree. Thus, a risk assessment model based on fuzzy logic can provide consistency when analyzing risks with limited data and knowledge and may lead to an understandable approach for the decision makers (Cherubini and Lunga, 2001). In order to develop a proper fuzzy risk assessment system, we propose a framework based on the following main steps:

1. *Data Gathering*
    - ✓ *Expert team formation*

      In order to develop a consistent model, experts of quality, environment and safety must found and involved in the analysis.
    - ✓ *Processes identification*

      Processes that are potentially critical in terms of quality, environmental sustainability and safety are identified.
    - ✓ *Process Analysis*

      Standard mapping and analysis tools are used to analyze the process and to collect all data required for the subsequent steps.
    - ✓ *Definition of QES Risk Criteria*

      An adequate number of Risk Criteria for Quality, Environment and Risk is defined.
    - ✓ *Quantification of QES Risk Criteria*

      People involved in the selected processes and, mainly processes’ managers, are interviewed; opinions and evaluations are collected for each one of the QES risk assessment criteria. If more people are interviewed, opinions can be aggregated by means of consensus decision making approaches, such as the well-known Delphi or fuzzy Delphi method.
2. *Fuzzy Multivariate analysis*
    - ✓ *Fuzzy Inference model generation*

      In order to quantify the risk, a multi criteria FIS model is built. This implies: *(i)* the definition of appropriate linguistic variables for each one of the QES risk criteria, *(ii)* the definition of a set of If - Then rules to aggregate the linguistic variables in a single fuzzy score and *(iii)* the selection of a defuzzification procedure.
    - ✓ *Processing of QES Risk Criteria*

      QES risk criteria (preliminary defined at Step 1) are used as the main input of the FIS model. In this way, for each process, a risk score for quality, environment and safety is obtained.
    - ✓ *QES Criteria aggregation*

      Lastly, single Q, E and S scores can be aggregated in an overall risk level.
3. *Actions Definition*
    - ✓ *Risks prioritization*

      Processes are ranked depending on their single (or the aggregate) risk levels. Corrective and mitigation actions should be conceived and implemented for the most risky ones (i.e., unacceptable risks); conversely, for those risks classified as "conditionally acceptable" risk mitigation actions are generally sufficient. Corrective and mitigation actions are voluntary for all the acceptable risks.

- ✓ *Definition of means of prevention and protection*

  If possible risks should be avoided or at least decreased through prevention. To this aim Business Process Reengineering actions, safety programs, training, and other similar activities should be planned and implemented. Also, protections, standard procedure, alarms, etc., should be implemented so as to limit accidents, incidents, injury, or occupational diseases.

- ✓ *Definition of plans for crisis management*

  The occurrence probability can never be zero, so an important part of risk management concerns the definition of emergency procedure to minimize losses and or impact of an adverse event.

Detailed information concerning Steps 1 and 2 will be given in the following Sections; conversely, Step 3 is standard and so it will not be addressed in further details.

3. Data Gathering, selecting proper QES features

Processes that must be analyzed are case specific and so, we will not propose a list of processes on which one should focus attention, as this would be pretentious if not even misleading. However, in this Section we will give some operating advices concerning the definition and the quantification (through interviews) of the QES risk criteria.

Specifically, we propose using a list of QES evaluation criteria and three quantification tables (for quality, environment and safety, respectively) that can be used as a guideline (i.e., a checklist) during the process analysis steps.

In this study the QES evaluation criteria were defined combining the ideas of both academic and industrial experts with a literature review and with the analysis of ISO 9001, ISO 14001, OHSAS 18001 management standards. We also note that both QES criteria and quantification tables were defined in a generic and flexible way, so that they can be applied in any industry (both manufacturing and services) with little changes.

3.1 Quality

In order to assess the risks of process failures in terms of quality requirements, we proposed to schematize it using the Deming's PDCA cycle. In other words, the analyst is guided through the following steps:

- ✓ *Plan* - The process has been properly planned.

  A process has been properly planned if its inputs, outputs, constraints and mechanisms/instruments/people have been defined and are known. So, in order to check it, six questions must be answered:

  - ▪ *Who?* - Has been a process owner defined? Have been people involved in the process identified? Are the responsibilities defined? Has been the work-flow defined?
  - ▪ *What?* - Are input and output known? Have been process activities standardized?
  - ▪ *When?* - Are cycle times known? (peculiar of manufacturing industrial processes). Have been correlations among processes defined? If so, have been the way used to synchronize the processes defined?
  - ▪ *Where?* - Have been work place and machines/equipment to be used defined and identified? Are they adequate? Have been alternative routings identified?
  - ▪ *Why?* - Have been the reasons to use a certain process clarified? Is this the sole option? Is it the most efficient one? Is it also the most effective one?

    - *How?* Have been operating and managerial procedures defined? Are they fit for use? Are the necessary KPIs defined (together the way they will be gathered/evaluated/calculated)? Production cycles are updated? (peculiar of manufacturing industrial processes)

- ✓ *Do* - The process is both efficient and effective.
  A process is said to be efficient if it is "wastes free", and it is said to be effective if it is capable to achieve its goals. Both these issues could be subjectively evaluated by the experts; however the use of Key Performance Indicators (if available) is preferable. In this respect, especially for an industrial process and accordingly to lean thinking, a proper KPI describing the efficiency of a process could be the ratio between the planned cycle time (i.e., operating time) and the lead time or total throughput time (i.e., operating and waiting time). Concerning effectiveness, quality related metrics (such as the quality rate) could be fine for internal processes, whereas customers' related metrics (such are number of complaints, returned items, etc.) seem more appropriate for outbound processes.
- ✓ *Check* - The process is under control;
  A process is said to be under control if outputs are acceptable and stable (i.e., there are no drifting phenomenon). Thus to check this issue we propose considering the trend (over time) of the KPI used at the previous step.
- ✓ *Act* - Countermeasures have been defined and successfully implemented.
  To check this issue, the analyst has to see witch countermeasures (due to quality problems) have been defined and if they have proved to be robust.

Lastly, depending on the answers, a score ranging from 0 (very low risk) to 1 (very high risk) can be assigned to each quality criteria (i.e., Plan-Do-Chek-Act), as shown in Table 1.
The overall effect in terms of quality depends on the possible combinations of the scores given to each P-D-C-A factor. This will be evaluated by means of a FIS module, as described in Section 4.

QUALITY				
SCORE	**PLAN** 5W 1H	**DO** KPIs	**CHECK** KPIs Trend	**ACT** Positive Results
Low risk **0 - 0.25**	More than 75%-80% of the answer are Yes. Excellent or very good planning.	KPIs are outstanding. Effective and efficient process.	All KPIs are improving. Process is under control.	Countermeasures assure excellent results.
Acceptable Risk **0.25 - 0.5**	Most answers are Yes.	KPIs are acceptable.	All KPI are stable.	Countermeasures are fine.
High Risk **0.5 - 0.75**	Most answers are No.	Some KPIs are Low.	Some KPI are getting worse.	Countermeasures exist, but they are flawed.
Unacceptable risk **0.75 - 1**	More than 75%-80% of the answer are No. Too poor or absent planning.	All KPIs are low. Inefficient and ineffective process.	All KPI are getting worse. The process is out of control.	There are no countermeasures.

Table 1. Quality assessment.

3.2 Environment

In order to assess the environmental risks of a process, there is the need to quantify: *(i)* its inputs (especially in terms of row materials) and outputs, *(ii)* its energy requirements and sources (i.e., electricity, fossil fuel, etc.) and *(iii)* all wastes and/or polluting substances released into different environmental compartments (i.e., water, soil/landfill and air). Pollutants identification can be performed checking pre-defined legal limits (such as air and water standards) and/or consulting environmental database that list all substances that may have negative effects on the environment (Wathern, 1988). In doing so it is also advisable to perform the analysis considering all the process's lifecycle, i.e., one should identify all pollutants that could be released as a consequence of implementation, utilization and dismantling of the process.

ENVIRONMENT				
SCORE	**LARGE SCALE**	**HUMAN HEALTH**	**ECOSYSTEM**	**RESOURCES**
Low risk **0 - 0.25**	There are no potentially dangerous substances or emissions.	There are no potentially dangerous substances or emissions.	There are no potentially dangerous substances or emissions.	Renewable resources. Strong or mild saving actions are implemented
Acceptable Risk **0.25 - 0.5**	Effects are negligible.	All legal limits are fully respected.	Effects are negligible.	Non-renewable resources. Strong saving actions are implemented
High Risk **0.5 - 0.75**	There are some large scale effects	There are situations close to legal limits.	There are some local scale effects.	Non-renewable resources. Mild saving actions are implemented
Unacceptable risk **0.75 - 1**	Effects are unacceptable (e.g. one or more legal limits are trespassed).	Effects are unacceptable: one or more legal limits are trespassed.	Effects are unacceptable (e.g. one or more legal limits are trespassed).	Non-renewable resources. No saving actions are implemented

Table 2. Environment assessment.

Once pollutants have been identified, their impact can be assessed using the following four macro classes.

- ✓ *Environmental Large Scale Effects*

  These effects refer to a change in an environmental parameter, over a specified period and within a defined area, resulting from a particular activity compared with the situation which would have occurred if the activity had not been initiated. Large scale factors such as eutrophication, climate change, ozone layer depletion, acid rains, etc. should be considered in this class. In order to quantify the effect it may be useful to consider, also, the extent and the duration of the environmental damage, its reversibility and social and political acceptance.
- ✓ *Effects on Human Health*

  Known effects on human health (both in the short and long term) should be carefully evaluated. The assessment can rely on existing quality standards (i.e., concentration of pollutants in the air or noise level) or on case-by-case evaluations. More specifically, according to Edwards-Jones et al. (2000), the following issues should be considered:
  - The existence of pre-defined legal limits;

  - The frequency and the duration of the exposure;
  - The possibility of mitigation;
  - The gravity of the illness;
  - The recoverability of the illness.
- ✓ *Effect on ecosystem*
  These effects refer to regional effects that have a direct impact on the local flora and fauna. Effects such as disappearance/reduction/introduction of plant and animal species should be considered in this class.
- ✓ *Effects on non-renewable resources*
  The last environmental class refers to the use of non-renewable resources, non-recyclable materials and water. Also the introduction of saving or control actions to minimize the resource consumption should be considered. Typical example of saving action is the use of top class equipment. This last class should encourage business to understand the full spectrum of their environmental costs and integrate these costs into decision process.

Depending on the answers, a score ranging from 0 to 1 can be assigned to each one of the environmental criteria, as shown in Table 2.

3.3 Safety

Concerning safety, for each process, there is the need to identify all physical injuries that may occur (to avoid double counting, illness due to pollutants included In the Human Health class should be avoided). Next, once possible injuries have been identified, we propose to quantify the risk in terms of four classes readapted from a previous analysis proposed by the Italian National Institute for Insurance against Accidents at Work (INAIL) (Luzzi et. al. 2009). These are:

- ✓ *The Frequency of the injury* - expressed as number of injuries per year
- ✓ *The Time of the Exposure* - expressed as hour per day. Note that this element must be evaluated only in case of recurrent dangerous working condition (such as vibrations, low illumination, noise pollution, magnetic fields, etc.);
- ✓ *The Severity of the injury* - expressed as average number of day offs from work;
- ✓ *The adequacy of the existing systems of protection* - To be subjectively evaluated by experts in the field.

Depending on the answers, a score ranging from 0 to 1 can be assigned to each one of the safety criteria, as shown in Table 3.

SAFETY				
SCORE	**FREQUENCY**	**EXPOSURE TIME**	**SEVERITY**	**PROTECTIONS**
Low risk **0 - 0.25**	The injury has never happen before	There are no recurrent dangerous conditions	No day off	State of the art protections
Acceptable Risk **0.25 - 0.5**	The injury has occurred rarely	Exposure time are far below the limit	Less than 2 weeks	Good protections
High Risk **0.5 - 0.75**	The injury can happen	Exposure time are close to legal limits.	More than 2 weeks	Old protections
Unacceptable risk **0.75 - 1**	The injury is recurrent.	Some legal limits are trespassed.	Permanent handicap.	Inadequate protections

Table 3. Safety assessment.

4. The Fuzzy Inference System

In order to combine the above mentioned risk criteria into a composite output indicator, three Mamdani Fuzzy Inference Systems (one for Quality Q-FIS, one for Environment E-FIS and one for Safety S-FIS) were developed using the Matlab Fuzzy Logic Toolbox.

For the sake of clarity, a basic introduction to FIS is given in Subsection 4.1, specificities of the developed QES FISs are postponed to Subsection 4.2.

4.1 Mandami Fuzzy Inference Systems

As shown in Figure 2, a Mamdani FIS is composed of three main blocks that are, respectively: *(i)* the Fuzzification Block, *(ii)* the Inference Engine and *(iii)* the Defuzzification stage.

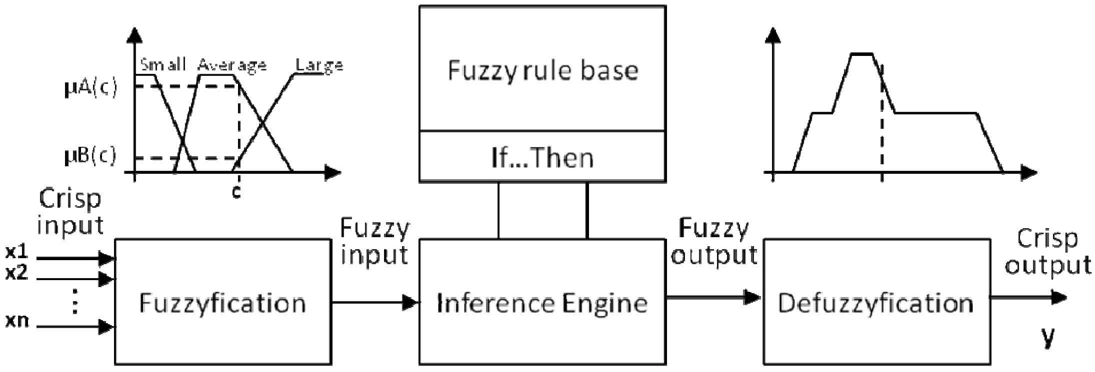

Figure 2. A Mamdani FIS.

The core is the inference engine that contains *m* fuzzy rules used to aggregate *n* crisp inputs: all the *m* rules are evaluated in parallel and a single crisp output is obtained.

In their basic forms, the IF-THEN rules are written as:

(IF *a* IS *A*) THEN *C*

where *a* is a crisp input, *A* and *C* are fuzzy sets.

It is important to note that both *A* and *C* are characterized by a membership function μ_A and μ_C that weight, appropriately, the linguistic characteristics (such as Low Medium, Average) that are attributed to the input and to the output, respectively. For instance if *A* is the fuzzy set representing the concept of *High* (with respect to the input *a*) and *C* is the fuzzy set representing the concept of *Unacceptable* (with respect to the output variable), the above mentioned rule can be read as «*IF a is High THEN the output IS Unacceptable*».

The if-part of the rule is called the *antecedent* or *premise*, while the then-part of the rule is called the *consequent* or *conclusion*. In the above example (If *a* IS *A*) is the antecedent and (Then *C*) is the conclusions. Clearly, complex rules may have antecedents with more than one part combined with classical logical operators as, for example: IF ((*a* IS *A*) AND (*b* IS *B*)) OR (*d* IS *D*).

Anyhow, when the fuzzy rule is evaluated, the antecedent is considered first, and the implication is considered next.

Evaluating the antecedent corresponds to the fuzzyfication step of Figure 2, a step that is typically performed using the following common operators:

- ✓ IS - (*a* is *A*) is quantified by the membership degree of *a* to the fuzzy set *A* i.e., $\mu_A(a)$;
- ✓ AND - the most common operators for the conjunction operator are *minimum* and *product* i.e., IF (*a* IS *A*) AND (*b* IS B) is quantified as $\min\{\mu_A(a), \mu_B(b)\}$ or as $\mu_A(a)\cdot\mu_B(b)$;
- ✓ OR - the most common operators for the disjunction are *maximum*, and the probabilistic OR method *probor*. The probabilistic OR method (also known as the algebraic sum) is calculated as: $probor(a, b) = a + b - ab$.

The value of the antecedent - a single number - determines the *firing strength* of the rule, which measures the degree to which the rule matches the inputs. This value is used as input for the implication process of the rule. As we have said, the consequent *C* is a fuzzy set represented by a membership function μ_C, which weights appropriately the linguistic characteristics that are attributed to it. When the rule is executed, the consequent *C* is reshaped to properly take into account the firing strength with which the rule has been activated. To this aims two methods are generally supported: *(i) minimum*, which truncates the output fuzzy set *C* and *(ii) product* which rescale the output fuzzy set *C*. In both cases, the input for the implication process is a single number given by the antecedent, and the output is a fuzzy set.

Since decisions are based on all the *m* rules of the inference engine, all the activated rules (i.e., that having a firing strength greater than zero), the rules must be combined in some manner in order to make a decision. Aggregation is the process by which the truncated fuzzy sets that represent the outputs of each rule are combined into a single fuzzy set. Three common methods to aggregate the truncated fuzzy sets can be used. These are *maximum*, the *probor* operator or *sum* (simply the fuzzy sum of each rule's output set).

Since the output of the aggregation step is still a fuzzy number, a defuzzyfication step is needed to convert the output into a crisp number. Many defuzzyfication methods exists and, among these the most common ones are: centroid, bisector, middle of maximum (the average of the maximum value of the output set), largest of maximum, and smallest of maximum.

4.2 QES FIS specificities

As shown by Figure 3, the Q-FIS (the other ones operate in a similar way) is based on three main parts: *(i)* Input Linguistic Variables (in yellow), *(ii)* Quality Risk Evaluation Model (in gray) and *(iii)* Output Linguistic Variables (in light blue).

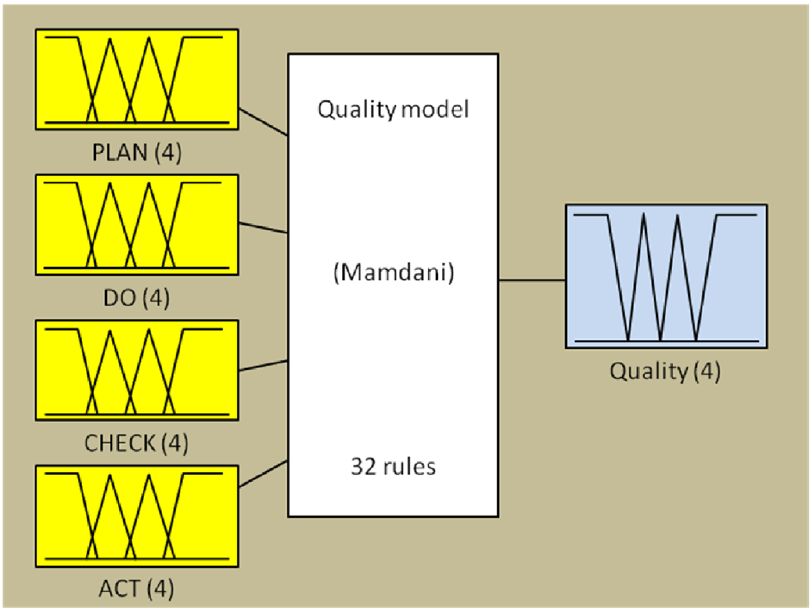

Figure 3. Q-FIS based on 4 input and 32 rules.

Its basic functioning is as follows:

- ✓ The Q-FIS receives as inputs the [0, 1] crisp scores of the four risk criteria previously discussed i.e., Plan - Do - Check - Act;
- ✓ The crisp inputs are fuzzyfied by evaluating their membership degree to the fuzzy set representing the risk class to which they belong to. To this aim, fuzzy triangular numbers have been used to properly represent the following linguistic variables {Low

risk, Acceptable Risk, High Risk and Unacceptable Risk}. Note that, as shown in Figure 4, the support of each fuzzy number is wider than the intervals of the corresponding risk class of Table 1. For instance the interval [0.2, 0.5] is the support of the fuzzy number representing the linguistic term “Low Risk”, whereas in Table 1 the same risk goes from [0.25 to 0.5]. This generates a slight intersection between adjacent fuzzy sets, a technique that assures an excellent model development for non-linear process in which the rules were generated under fuzzy environment.

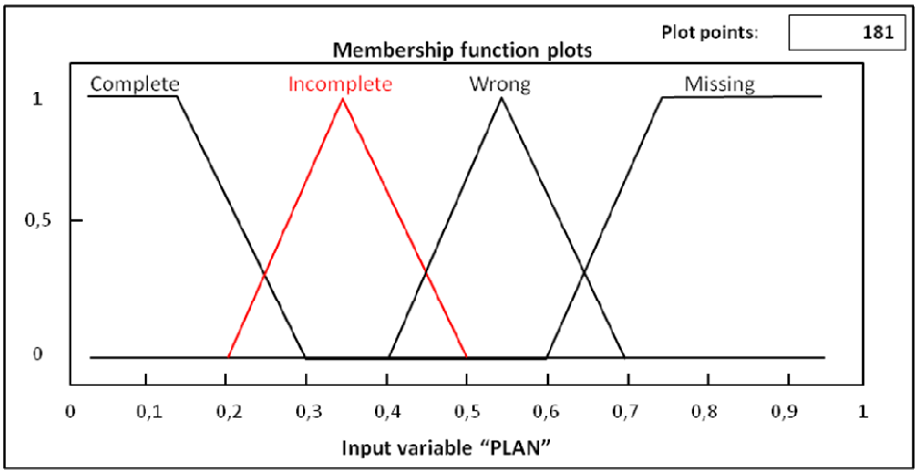

Figure 4. Linguistic Variables.

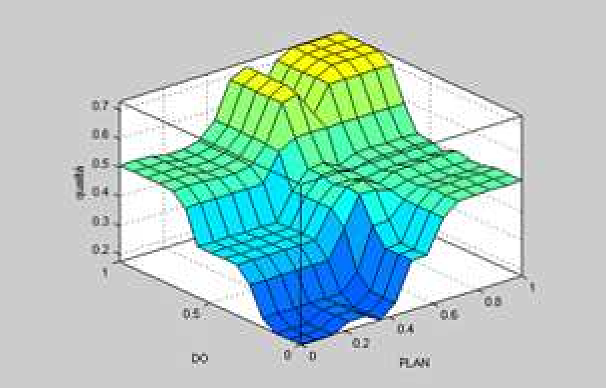

Figure 5. The Quality Risk surface.

- ✓ Inputs are combined using a set of If-Then Rules that have been defined after a detailed analysis of the literature and with the support of academics and industrial specialists. Also, knowing the non-linear behavior of QES risk parameters a total of 32 easy rules were defined for each FIS model, so as to ensure reliable and satisfactory results. An extract of the rules is listed below:
    - ▪ IF Plan IS Totally Developed AND KPIs are outstanding AND they are improving THEN Risk IS Low
    - ▪ IF Plan is Totally Developed AND KPIs ARE outstanding AND KPIs are getting worse THEN Risk IS Acceptable
    - ▪ …
    - ▪ IF Planning IS Absent AND (KPIs ARE Low OR KPIs are getting worse) AND Countermeasures ARE Absents THEN Risk IS Unacceptable
- ✓ The rules are evaluated in parallel and aggregated and, lastly, the obtained fuzzy output is defuzzyfied. In this way a composite output indicator in the range [0, 1] is finally obtained.

The obtained response surface, mapped by the 32 rules is shown in Figure 5.

By operating in this way, for each risky process, three distinct levels of risk (in terms of quality, environment and safety) can be obtained; thus processes can be ranked in terms of criticality and specific corrective actions can be initiated, on the basis of robust information.

Additionally, although if not strictly required, the three risk levels of can be easily joined in a synthetic metric using a simple weighted average:

$$\text{QES Risk} = (\alpha \cdot \text{Quality Risk} + \beta \cdot \text{Environment Risk} + \gamma \cdot \text{Safety Risk})$$

4.3 Limits and remarks

The rules and the operating parameters of each FIS were optimized by means of an extensive simulation activity: several combinations of the input variables were generate and obtained results were evaluated by a team of experts.

By operating in this way we observe that the following parameters led to the more stable and robust solutions:

- ✓ Linguistic variables are defined using Triangular fuzzy numbers;
- ✓ The *min* and *max* operators are used to evaluate conjunctions and disjunctions in the antecedent part of the IF-Then rules;
- ✓ The implication of the IF-Then rules is evaluated with the *min* operator i.e., the output fuzzy set is truncated;
- ✓ Rules are aggregated using the *sum* operator;
- ✓ Defuzzyfication is performed using the *centroid* method.

Obtained results have been judged reliable and robust, but, to be empirically validated, the model still needs to be practically implemented in some industrial settings. By such validation a better comprehension concerning the difficulties of implementation of the system will be achieved. In fact, the proposed system is quite complex, due to the number of data and decisions especially present in its first and second step. Also the choice of the weights necessary for the QES Risk evaluation is critical and needs of test and feedback from the field.

5. Conclusions and future research

The present paper proposed a multi-dimensional risk assessment framework purposely developed for MIS. Specifically, a set of relevant criteria (related to quality, environment and safety) are defined and their risk level is quantified using fuzzy linguistic variables.

The potential impact of the developed fuzzy decision support framework for assessment of quality, environment and safety risks is remarkable. While the main focus of classical approach is to start from the analysis of individual risk exposure, the fuzzy decision support framework starts from the analysis of the process and the opinion provided by the experts. This approach makes the fuzzy model extremely flexible, and it allows decision makers to use a broad range of linguistic variables and modifiers for a finer discrimination among QES performance categories. It is also an ideal system when the decision maker is faced with a series of sub-decisions where available data is based on vagueness, uncertainty, and opinion.

6. References

Casal, J., 2008. Evaluation of the effects and consequences of major accidents in industrial plants. Elsevier, Amsterdam.

Cheng, W.-Y., Ender S. Sheng-Jung L. A Financial Distress Prewarning Study by Fuzzy Regression Model of TSE-Listed Companies. *Asian Academy of Management Journal of Accounting and Finance* 2, no. 2: 75–93

Cherubini, U., Della Lunga G. 2001. Liquidity and Credit Risk *Applied Mathematical Finance* 8, no. 2: 79–95.

Edwards-Jones, G., Dvies, B., Hussain, S. 2000. *Ecological Economics. An introduction*. Cornwall: Blackwell Science.

Lein, J.-K., 1992. Expressing environmental risk using fuzzy variables: a preliminary examination, *Environ Prof* 14, 257.

Lahsasna, A. 2009. *Evaluation of Credit Risk Using Evolutionary-Fuzzy Logic Scheme*. Master's diss., Faculty of Computer Science and Information Technology, University of Malaya, 2009.

Matsatsinis, M., Kosmidou, K., Doumpos, M., Zopounidis, C., 2003. A Fuzzy Decision Aiding Method for the Assessment of Corporate Bankruptcy. *Fuzzy Economic Review* 3, no. 1: 13–23.

Li, A., Yong S., Jing H. Yanchun Z. 2001. A Fuzzy Linear Programming-Based Classification Method. *International Journal of Information Technology and Decision Making* 10, no. 6: 1161–74.

Wathern, P., 1988. An introductory guide to EIA. In: Wathern P., ed., *Environmental impact assessment. Theory and practice*. London: Unwin Hyman, 3-30

Luzzi, R., Fois, G., Murè, S., Palamara, F., Piccinini N., 2009 Metodi di data mining associati all'approccio fuzzy: metodologia integrata per l'analisi degli infortuni sul lavoro, *Proceedings of 6° Seminario di aggiornamento dei professionisti CONTARP - Sicurezza e Prevenzione: esperienze a confronto*, INAIL, 39–48.