

## Research Article

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# A fuzzy reasoning approach to assess innovation risk in ecosystems

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**Abstract:** Currently, companies to be competitive must achieve high rates of innovation and respond quickly to market needs.

According to a number of managers and researches innovation is crucial for companies to stay “alive.” Taking into account several reports, the development of co-innovation networks based on a collaborative environment is the best strategy to support innovation projects. However, the absence of mechanisms to detect and even anticipate potential risks of innovation based on a collaborative approach is an obstacle to the proliferation of this way of working. To address this issue, this paper discusses an approach based on fuzzy reasoning for analyzing the level of risk in co-innovation projects. It is discussed how this approach can be applied to co-innovation projects within the context of a collaborative ecosystem. At last, it is discussed the benefits, and challenges found on experimental results from a Portuguese co-innovation network.

**Keywords:** Risk analysis; fuzzy logic; fuzzy reasoning; co-innovation; collaborative ecosystems

## 1 Introduction

Innovation is the main source of economic growth and new employment opportunities, providing potential benefits to society and the economy. In the face of competition from low-wage economies - such as China - the Western economies can only compete and survive through innova-

tion, that is, the discovery of new and better products and operational processes [1]. According to Afuah [2], innovation includes applying new knowledge to provide a new product or service desired by customers. Innovation refers to the economic application of a new idea. Process innovation involves a new or changed way of producing a product. Product innovation implies a new or altered product.

Innovations vary in nature, scale or degree of novelty. This implies that companies take risks associated with the development and launch of new products, quickly and successfully in the market. Thus, the ability to identify and control risk is considered of vital importance in innovative enterprises [3]. Companies to survive, must innovate at a pace unparalleled earlier, and in a larger context of uncertainty in the market. This means that the risk level of companies is increasing [4]. The risk is the probability of occurrence of a specified uncertain event and its consequence [5]. Any factor that affects the performance of a project can be a source of risk. The risk arises when this effect has an uncertain and significant impact on project performance [6].

In order to mitigate the risks associated with innovation, companies enter into collaborative agreements because they do not have all the necessary resources, including knowledge [7]. That is, there is a premise that the existence of a ‘healthy’ collaborative environment allows companies to operate more efficiently on cost / time / quality in the development of innovation processes and thereby be more competitive. Innovation network members “divide the value chain of innovation” into a variety of tasks where the assignment of these tasks to each partner is based on identifying the resources that have the lowest costs and the best skills and / or access to specific knowledge in order to maximize gains [8, 9].

However, it is reported by most small and medium-sized enterprises (SMEs) managers that the development of innovation processes in the context of a collaborative environment introduces additional risks. Do the potential benefits outweigh the additional risks? The publications on this subject seem to indicate that the answer is yes. However, it is still difficult to prove [10, 11]. The absence of management tools that are robust enough to detect and

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even anticipate potential risks associated with the development of an innovation project in a collaborative context is an obstacle to the proliferation of this way of working. According to several authors [12, 13], there are currently a number of tools that can be used to identify and analyze the risk where the most used are: Decision Trees, Brainstorming, Structured or Semi-structured Interviews, Delphi's Analysis, Risk Matrix, Cause-Effect Diagrams, Failure Modes and Effects Analysis (FMEA), and Bayes Networks.

In methodological terms, dispositional logic, as an important strand of fuzzy logic, deals with dispositions, that is, propositions that are preponderant, but not necessarily always true. The importance of dispositional logic stems from the fact that most common-sense knowledge can be seen as a set of dispositions. Thus, the development of inference rules of common-sense knowledge is the main concern of dispositional logic.

Fuzzy logic is directed to the formal principles of approximate reasoning, being the precise reasoning viewed as limiting. Unlike classical logic systems, fuzzy logic aims to model inaccurate modes of reasoning, which play an essential role in the ability to make rational decisions in environments of uncertainty and imprecision. This ability derives from an inferred response of personal knowledge that is inaccurate or incomplete [14].

In this paper, it will be discussed the advantages of applying fuzzy logic in the evaluation of risks with negative impact, that is, events of potential threat to the success of an innovation project in a collaborative context. Thus, section 2 describes the implementation of collaborative SMEs innovation agreements. Section 3 describes the types of risks in the processes of co-innovation. Section 4 describes the proposed model of innovation risk assessment in collaborative ecosystems. The robustness of the proposed approach is evaluated in Section 5 considering a case study. And, finally, section 6 provides some concluding remarks.

## 2 Collaborative Innovation Agreements

Global competition has led companies to share resources and the need for cooperation in their innovation processes. In addition to their own ideas, companies also intend to market external ideas. SMEs have fewer technological resources and less ability to access external resources than large enterprises [15]. However, they use the means of external innovation, in the form of alliances or through networks, as a way of expanding their techno-

logical skills [16]. According to Baum, Calabrese e Silverman [17], the companies involved in multiple types of collaborative ties in their competitive context are more innovative.

It should be noted that open innovation focuses more on the initial phases of innovation, addressing the supply of external technology and the network with technology suppliers and upstream companies (that is, firms that provide inputs needed for production). In this paper we have in mind the perspective of SMEs on the particularities of open innovation. Many SMEs haven't the resources and capacity to produce, distribute, market or finance research and development actions (R&D), which are fundamental for transforming inventions into processes and/or products. However, the specificity and flexibility of SMEs can be an advantage in accelerating innovation [16]. The increase in the complexity of technology means that it is no longer circumscribed to a single undertaking. Relevant knowledge becomes the domain of several companies, being the collaboration between SMEs considered as a determining factor for their competitive success [18].

The use of external resources enables SMEs to reduce the timeframe of the innovation process, reduce costs and risks associated with the innovation process and increase operational flexibility [19]. An inter-company collaboration is particularly important for SMEs with limited complementary resources that need to leverage their technology externally [20]. In the exploration phase, SMEs are more likely to use external partnerships to focus on the development of internal skills in a limited number of technology areas [15]. This happens at the level of supplier-client collaboration, outsourcing agreements, or strategic alliances with other SMEs in an attempt to create value [16].

Participation in a network can be another form of collaboration. In fact, the competitiveness of SMEs stems mainly from their ability to participate in external networks [21, 22]. Well-defined and managed networks can provide benefits to SMEs in terms of decoding and adequacy of information flows regarding technological change, technical assistance and market requirements to be met, thus helping to sustain their competitive advantage [23]. The network allows its members to efficiently develop products and services in the context of innovation processes. In addition, there is mutual influence among the members of the network through their intervention and experience [24]. This encourages learning for future innovation [25]. Since SMEs, in general, are specialize in a specific area of activity, their cooperation in a network can, for example, enable them to enter wider markets, the ac-

quisition of additional resources and increased core competences, thereby improving their competitiveness.

It should be noted that the inter-company collaboration can also generate new risks and threats as, for example, uncertainty of market acceptance of innovative products, possibility of imitation of technological innovation and additional innovation uselessness. SMEs still face obstacles in the development of innovation processes, such as: lack of specialized labour in the company, lack of technological information, lack of market information, difficulty in financing due to high risk due to technological uncertainty and due to high innovation and marketing costs, and lack of infrastructures.

Collaboration in the development of innovations is more likely to happen when innovation is new or complex, or when the market for innovation is still poorly defined.

There are several characteristics of innovative companies that we can consider as aspects related to the propensity of companies to establish collaborative agreements of innovation. In line with Tether [7], we can identify three strands that lead to collaborative innovation agreements.

## Reduce difficulties in the innovation process

In general, companies enter into collaborative innovation agreements because they require resources and aim to minimize the risk inherent in the innovation process.

The risk may be spread by the following factors: economic risk and/or financial, poor budget allocation and cost of financing for innovation, organizational rigidity and inadequate resources (e.g., lack of technical and skilled personnel), domain of standardized regulations and procedures, development of synergies with suppliers, customer receptivity and response to innovation, lack of information on technologies and markets, fulfilment of time goals and scope of innovation to confirm or not the desired result based on an initial idea.

The implementation of a collaborative innovation process can reduce these difficulties individually felt by a company.

## 2.1 Commitment of R&D for innovation

R&D carried out by companies aims, in part, to increase their absorption capacity, that is, their ability to learn from the knowledge of other economic actors [26].

A greater intensity of R&D activities may be related to the development of more complex innovations or with a high level of novelty (and consequently higher risk). This

desideratum requires the verification of close relations between the innovator and his suppliers and customers, as well as with other innovation partners [7].

## 2.2 The type of innovation to be developed

The introduction of new innovations in the market is not accidental but may result from collaborative actions. Not being a cause, reflect the strategic intent to innovate at a higher level [27], which requires unique features involving greater uncertainty and risk in the market [28]. While companies that introduce only process innovations may be more likely to develop collaborative agreements with suppliers. This implies a competitive orientation towards cost reduction, rather than betting on collaborative agreements for the creation of the “new”.

This study focuses on risk assessment inherent in an innovation project in the metal industry, in order to reduce difficulties in the innovation process at the design stage level in SMEs.

## 3 Types of risks in the processes of co-innovation

Most of the work done on the identification and characterization of innovation risks does not follow a standardized approach and the use of ad hoc approaches may lead to some relevant risks being difficult to identify [29, 30]. As Figure 1 illustrates, for the identification of risks associated with innovation processes in a collaborative context,

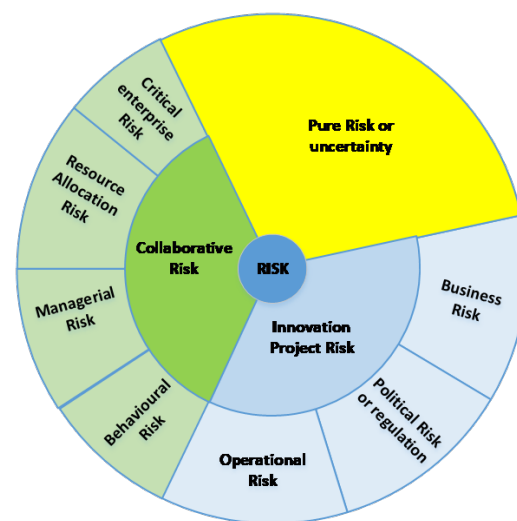


Figure 1: Wheel of innovation risks in a collaborative ecosystem.

the following dimensions were defined: pure risk or uncertainty, risk of an innovation project and the collaborative risk.

Pure risk or uncertainty - This dimension of risk is related to the probability of an event occurring that endangers the success of the innovation project.

Risk of an Innovation Project - This dimension of risk is related to the fact that a project is a unique effort and there is a substantial portion of the risks associated with estimates, such as: resources, duration of the task, costs, among others. In this dimension of risk, it is possible to define three classes of risks or vulnerabilities:

- Business risk - Risk related to the loss of a business opportunity. The identification and characterization of this type of risk includes the following aspects: commercial viability, commercialization capacity, customer responsiveness and response, competitors, among others.
- Political risk or regulation - Risk related to decision making in a favorable political context (Blue Ocean Strategy (BOS)), as opposed to the conventional market characterized by a high level of competition (Red Ocean Strategy (ROS)) [31].
- Operational risk - Risks related to the ability to perform tasks/operations without errors. The identification and characterization of this type of risk comprises the following aspects: who performs a task for the first time or performs a complex task and is able to do so? How many tasks cannot be performed if a resource is removed? Entities have access to the resources needed to perform tasks such as: the supply chain, information, technology, skills, among others.

Collaborative Risk - This dimension of risk is related to the fact that a collaborative ecosystem can be characterized by a set of relationships that are established between several entities, such as companies/organizations, knowledge, resources and tasks. In this dimension, it is possible to define four classes of risks or vulnerabilities resulting from the interaction between the entities that are members of the ecosystem:

- Risk of critical enterprises - Risks associated with network members who have exclusive competencies, resources or are assigned to a task of great complexity. The identification and characterization of this type of risk comprises the following aspects: Does the removal of a partner affect the ability to achieve the defined objectives? Are there companies that have access to unique skills, resources or tasks?

- Risk of assigning tasks to partners - Risks resulting from how tasks are distributed by network partners can compromise the success of the innovation process. The identification and characterization of this type of risk comprises the following aspects: Do companies have access to resources such as the knowledge, technology and capacity they need to perform the assigned tasks? Has the workload been distributed equally by all partners?
- Risk of collaborative network management - Risks related to the authority structure and level of communication within the collaboration network. The identification and characterization of this type of risk comprises the following aspects: Can companies request help whenever it is necessary to carry out the tasks? Is communication decentralized or centralized?
- Behavioural Risks - Risks related to the types of relationships that are established between the various partners during the innovation process. The identification and characterization of this type of risk comprises the following aspects: risk of transfer of key competences to other members such as patents; assessment of the level of collaboration between companies with complementary skills; evaluation of the level of collaboration between companies with similar skills.

## 4 Model of innovation risk assessment in collaborative ecosystems

The proposed model is intended to permit an assessment of the risk level associated with an innovation process and identify key constraints. In this sense, the developed model uses the concept of fuzzy logic to integrate both aspects of risk assessment, quantitative and qualitative, into a single index, as well as being a model compatible with the ambiguity and uncertainty of human assessment.

### 4.1 Architecture of the model

The proposed model, as illustrated in Figure 2, consists of two hierarchical levels, in Level 1 the Primary Risk level ( $R$ ) of a risk event is estimated as a function of probability ( $P$ ) and its impact ( $I$ ) in the process of innovation, having as reference four categories - Scope ( $IS$ ), Time ( $IT$ ), Cost ( $IC$ )

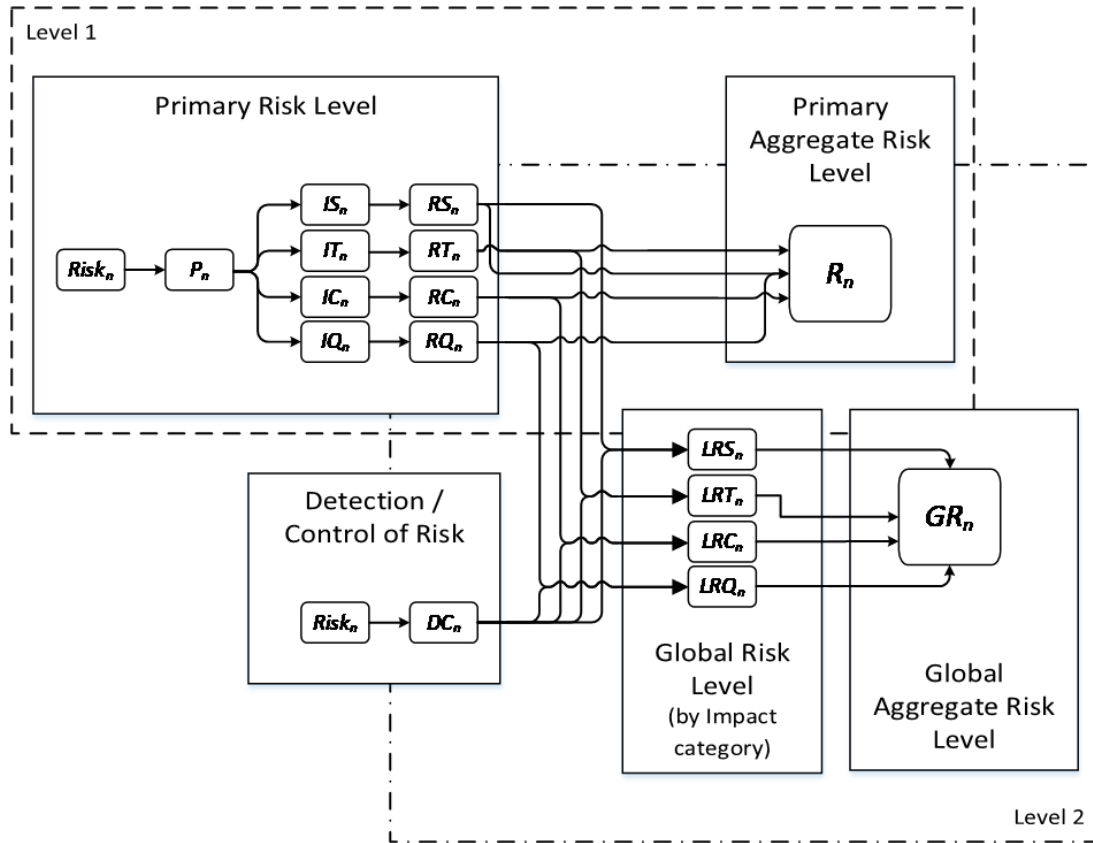


Figure 2: Structure of the model.

and Quality ( $IQ$ ). The level of Primary Risk ( $R_n$ ), for any risk  $n$  with a probability of occurrence ( $P$ ), for one of the four impact categories is calculated by:

$$RS_n = P_n \times IS_n \quad (1)$$

$$RT_n = P_n \times IT_n \quad (2)$$

$$RC_n = P_n \times IC_n \quad (3)$$

$$RQ_n = P_n \times IQ_n \quad (4)$$

The Aggregate Primary Risk ( $R_n$ ) level is calculated by the following equation:

$$R_n = w_1 \times RS_n + w_2 \times RT_n + w_3 \times RC_n + w_4 \times RQ_n \quad (5)$$

where,  $w_n$ , represents the weighting of each variable, being  $w_1 + w_2 + w_3 + w_4 = 1$ .

Level 2 is used when assessing the capacity of the actors involved in the innovation process of predicting and responding to the risk, called Detection/Control ( $DC$ ). Thus, the integrated risk level ( $LR$ ), for any one risk  $n$ , for one of the four impact categories is calculated by:

$$LRS_n = RS_n \times DC_n \quad (6)$$

$$LRT_n = RT_n \times DC_n \quad (7)$$

$$LRC_n = RC_n \times DC_n \quad (8)$$

$$LRQ_n = RQ_n \times DC_n \quad (9)$$

The Global Aggregate Risk ( $LR_n$ ) level is calculated using the following equation:

$$GR_n = w_1 \times LRS_n + w_2 \times LRT_n + w_3 \times LRC_n + w_4 \times LRQ_n \quad (10)$$

In each of these levels a Fuzzy Inference System (FIS) based on a set of *IF-THEN* heuristic rules that is used to obtain the risk levels (by impact category). Thus, for level 1, we have:

$$R_{xy} = P_x \times I_y \quad (11)$$

Thus, inference rules are formulated as: “*IF* probability is  $P_x$  *AND* impact is  $I_y$  *THEN* the primary risk level is  $R_{xy}$ ”.

Similarly, for level 2, it will be:

$$LR_{wz} = R_w \times DC_z \quad (12)$$



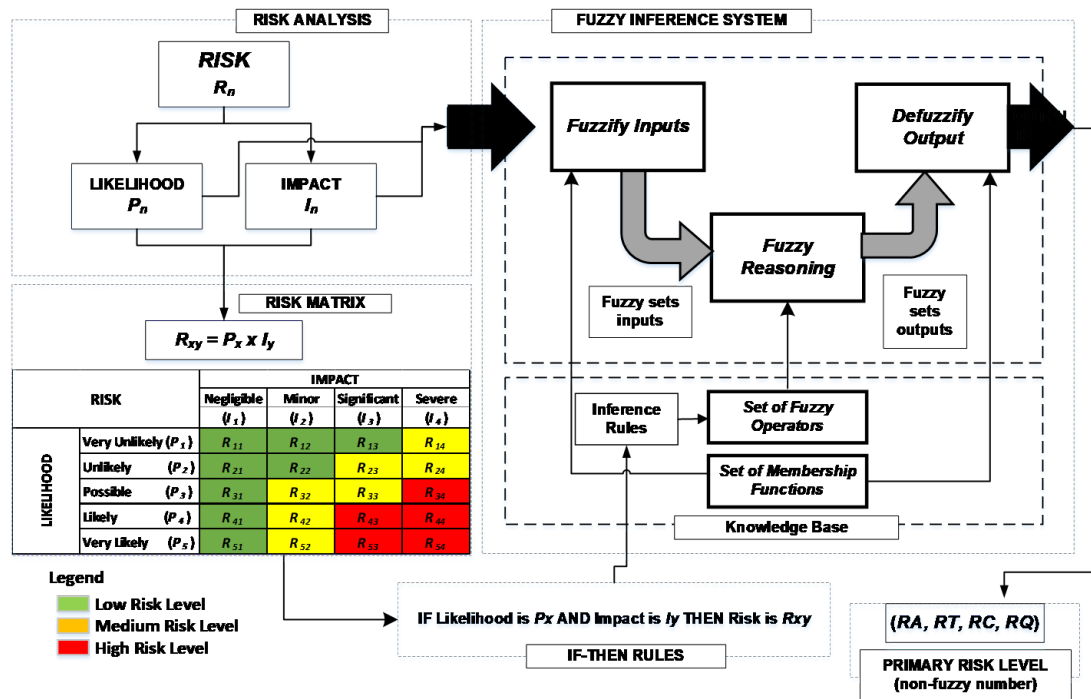


Figure 3: Structure of the Fuzzy Inference System for level 1.

Table 1: Linguistic variables for the probability ( $p$ ) and membership functions.

Linguistic Variables	Description	Membership Functions
Very Unlikely ( $P_1$ )	Unlikely event occurrence	(0, 0, 0.25)
Unlikely ( $P_2$ )	Low probability of event occurrence	(0, 0.25, 0.5)
Possible ( $P_3$ )	Probable occurrence event	(0.25, 0.5, 0.75)
Likely ( $P_4$ )	Event may occur more than once	(0.5, 0.75, 1)
Very Likely ( $P_5$ )	Event may occur frequently	(0.75, 1, 1)

Therefore, the inference rules are formulated as: “IF primary risk level is  $R_w$  AND detection/control is  $DC_z$  THEN integrated risk level is  $LR_{wz}$ ”. Figure 3 illustrates the Fuzzy Inference System for level 1 of the proposed model.

## 4.2 Linguistic variables and membership functions

The ad-hoc use of linguistic terms and corresponding membership functions is always criticized when using fuzzy logic [32]. In this phase of the model development it was decided to adopt linguistic terms and corresponding membership functions from the literature, applied in similar approaches [33, 34]. It is generally suggested that linguistic levels do not exceed nine levels, which represent the limits of human perception for discrimination [32].

Thus, the linguistic variables and corresponding triangular membership functions were adopted for the input variables as shown in Tables 1, 2 and 3. The outputs of the proposed model are all variables whose prefixes are R- or NR- (primary or integrated, respectively) and Table 4 illustrates the linguistic variables and corresponding membership functions adopted.

The risk assessment variables have three levels - Low, Medium and High, to contemplate the negative response strategies defined in the PMBoK - Project Management Body of Knowledge PMBoK [35]:

- Accept: in this case the project members acknowledge the existence of the risk, but decide not to implement any preventive measure. This strategy is adopted when team members are unable to identify any other appropriate response strategy, or when it is not possible, or it is not feasible to eliminate risk.

**Table 2:** Linguistic Variables by Impact (*I*) Category and Membership Functions.

Linguistic Variables	Description	Membership Functions
<b><i>Scope (IS) - deviation from the proposed objectives</i></b>		
Negligible ( $IS_1$ )	Responds to all objectives in full or with insignificant deviation in some objectives	(0, 0, 3.33)
Minor ( $IS_2$ )	One or more non-critical objectives are partially met	(0, 3.33, 6.66)
Significant ( $IS_3$ )	It does not respond to some non-critical objectives in its entirety, or does not entirely satisfy critical objectives	(3.33, 6.66, 10)
Severe ( $IS_4$ )	Risk of failure on one or more critical objectives	(6.66, 10, 10)
<b><i>Time (IT) - delay in deadlines</i></b>		
Negligible ( $IT_1$ )	No delays or delays without relevance	(0, 0, 3.33)
Minor ( $IT_2$ )	Acceptable/manageable delay	(0, 3.33, 6.66)
Significant ( $IT_3$ )	It will cause unrecoverable delays, requiring a change in planning	(3.33, 6.66, 10)
Severe ( $IT_4$ )	Significant delays that may jeopardize the success of the innovation project	(6.66, 10, 10)
<b><i>Cost (IC) - relative increase in estimated cost</i></b>		
Negligible ( $IC_1$ )	No deviation or slight deviation within the cost estimates	(0, 0, 3.33)
Minor ( $IC_2$ )	Acceptable increase, but may require a revision of cost estimates	(0, 3.33, 6.66)
Significant ( $IC_3$ )	Considerable deviation that may have to be borne by the responsible stakeholders	(3.33, 6.66, 10)
Severe ( $IC_4$ )	Large deviation that could result in high costs for stakeholders, or jeopardize the viability of the innovation project	(6.66, 10, 10)
<b><i>Quality (IQ) - meet stakeholders' requirements</i></b>		
Negligible ( $IQ_1$ )	Does not significantly compromise requirements	(0, 0, 3.33)
Minor ( $IQ_2$ )	May compromise some non-critical requirements	(0, 3.33, 6.66)
Significant ( $IQ_3$ )	Compromises non-critical requirements and may compromise critical requirements	(3.33, 6.66, 10)
Severe ( $IQ_4$ )	Compromises critical requirements	(6.66, 10, 10)

**Table 3:** Linguistic Variables for the Detection/Control (*DC*) and Membership Functions.

Linguistic Variables	Description	Membership Functions
Reduced ( $DC_1$ )	Ability to prevent and/or respond to risk is questionable and not guaranteed	(0, 0, 50)
Reasonable ( $DC_2$ )	Stakeholders/organization with relevant experience, however, their capacity for prevention and/or response is not fully guaranteed	(0, 50, 100)
High ( $DC_3$ )	It is guaranteed an ability to predict and respond appropriately to the risk event	(50, 100, 100)

**Table 4:** Linguistic Variables for Risk Variables *R*- (Primary) or *LR*- (Integrated) and Membership Functions.

Linguistic Variables	Description	Membership Functions
Low ( <i>L</i> )	Accept - does not compromise the viability of the project, however its "existence" should not be neglected	(0, 0, 5)
Medium ( <i>M</i> )	Mitigate - Can compromise project viability; management should monitor the cause of the event	(0, 5, 10)
High ( <i>H</i> )	Prevent - The viability of the project is compromised; management should give high priority to its resolution	(5, 10, 10)

This strategy can be passive or active. Passive acceptance does not require any extraordinary measure in relation to the active acceptance strategy. The most widely used measure involves the implementation of contingency reserves including time, financial resources and other resources to deal with risks.

- Mitigate: in this case project members must implement the necessary measures to reduce the probability of occurrence or the impact of a risk. This implies a reduction of the likelihood, and/or impact of an adverse risk, to limits considered acceptable. Taking early actions to reduce the likelihood and / or impact of a risk is often more effective than attempting to repair the damage after the risk has occurred. Adopting simpler processes, conducting more trials or choosing more reliable suppliers and partners are examples of mitigation actions. When it is not possible to reduce the probability of occurrence, a mitigation strategy can be to seek to reduce the impact of the risk, for example through the implementation of redundant processes, thus achieving a reduction of its severity.
- Prevent: in this case project members must implement the necessary measures that lead to the elimination of the threat or protect the project from the impacts of the risk. Examples of some measures are: lengthening the duration of the project, reducing scope, changing objectives that are endangered, improving communication or acquiring specialized skills, among others. However, the most radical prevention strategy is to close the project.

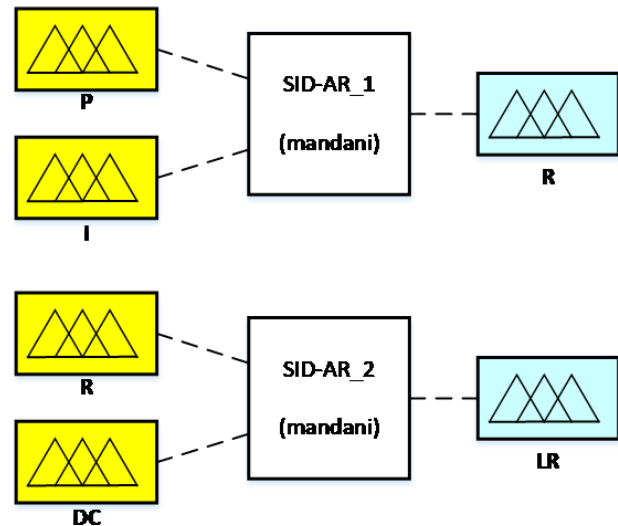


Figure 4: Fuzzy Inference System for level 1 and 2.

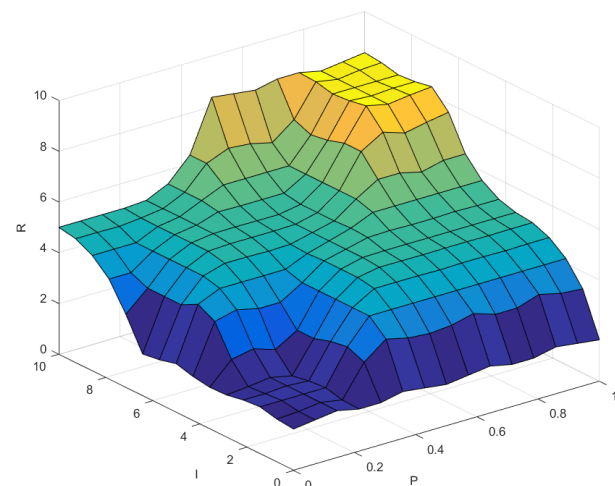


Figure 5: Surface of the Fuzzy Inference System for level 1.

### 4.3 Model implementation process

The proposed model was developed in MATLAB® software, using Fuzzy Logic Toolbox™ (called Fuzzy Logic Designer in version R2016a). Thus, in the Fuzzy Logic Designer the two levels of the proposed model were implemented, using in this exploratory phase the approach proposed by Mamdani for the fuzzy inference mechanism. The choice of the approach proposed by Mamdani is due to the fact that it is intuitive and better adapted to inputs from human reasoning and to have a wide acceptance [35]. As shown in Figure 4, level 1 of the model has as inputs the Probability ( $P$ ) and the Impact ( $I$ ); and outputs the Primary Risk Level by category ( $R$ ). Level 2 of the model has as inputs the Primary Risk Level by category ( $R$ ) and the Risk Detection/Control ( $DC$ ) and outputs the Integrated Risk Level by category ( $LR$ ).

The centroid method was used as the defuzzification approach, as it is the most commonly used, for applications of the genus. After constructing the entire model, Figures 5 and 6 illustrate the risk surfaces that can be obtained for the two levels of the model developed.

## 5 Case study

The research was based on a case study of innovation at the design stage in an SMEs network with activities in the metal industry. The selection of the collaborative network constitutes a convenience sample due to the particularity of the studied phenomenon and the access to the data, having been relevant its location. Data were col-



Table 5: Identified Risks in Piping Design.

Risk	Description
Risk 1	Over-engineering - The risk of over-engineering events occurs when a solution developed for the project is more complex or robust than is necessary to meet expected requirements and is considered wasteful from a value-added point of view. It occurs for example with the application of exaggerated security coefficients, oversizing, inefficient application of materials, etc.
Risk 2	Application of materials not readily available on site - The risk of unforeseen difficulties in making the various materials and components available at the site of implementation of the infrastructures. It occurs if during the design phase, and in the selection of the materials, all the variables of the procurement and delivery of materials are not considered and weighted.
Risk 3	Errors in information upstream (project inputs) - The risk of project inputs are inconsistent or wrong potentially originates design errors events.
Risk 4	Low Flow Efficiency - A pipeline under design has the ultimate goal of allowing the displacement of a fluid inside it, and the thermodynamic properties to be verified in the flow during the installation are an input of the project. There is a risk that after the design of the lines, flow conditions that do not coincide with the expected ones will be foreseen, with low flow efficiency.

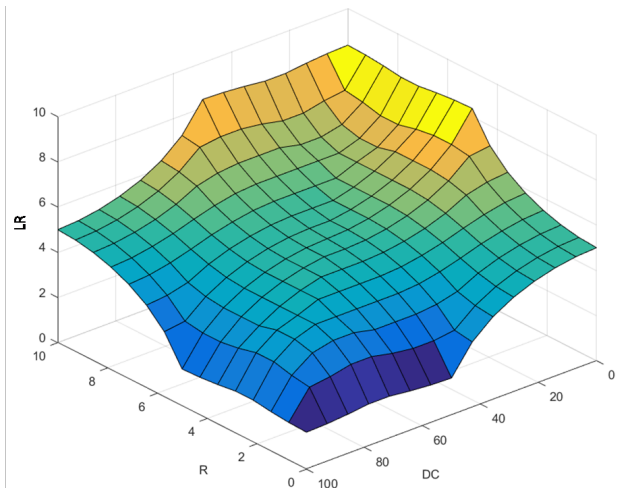


Figure 6: Surface of the Fuzzy Inference System for level 2.

lected through visits to companies, particularly among project team leaders, product engineers and quality engineers. The data collection followed a protocol that defined the procedures followed in each of the companies visited.

The selected network allowed to ensure that the learning process was “observable transparent” [36]. Mill’s “method of difference” [37] was adopted to compare cases with different learning patterns of the phenomenon studied.

Intensive study of the selected network is a useful method for obtaining information and suggesting additional research. According to Yin [38], the method of the case study is often used for this type of studies. The main focus is to get information rather than to test existing hy-

potheses. In practice, a view is sought through the features and characteristics of the object studied.

The developed model was applied in an innovation project in the design phase of a piping system for the transportation of fluids. It intends to evaluate the risks inherent to the projects of these infrastructures for the process industry, focusing on the risks associated with the variables and decisions taken in the design phase. Risks in piping design may have multiple sources such as economic, technological, organizational, among others.

These may be associated with for example: limitations in the characteristics of materials or their wrong selection; limitations of economic resources; lack of experience of those involved; limitations in the management of organizations; tight deadlines; design errors; limitations of applied tools; etc. Table 5 shows the four identified risks associated with piping design.

For the application of the model to the four risks considered, a group of experts evaluated the six parameters that constitute the inputs of the model:  $P_n$ ,  $IS_n$ ,  $IT_n$ ,  $IC_n$ ,  $IQ_n$ ,  $DC_n$  for each of the risks. Table 6 illustrates the classification assigned to the “Over-engineering” risk. After applying the model developed, Table 7 illustrates the results obtained for the four risks under analysis.

Based on the results obtained, in overall terms of the four risks considered, Risk 1 - Over-engineering - is the one with the highest Integrated Risk Level (LR). In a more detailed risk analysis, we can verify that the occurrence of this risk produces a greater negative impact at the level of the time (RT), that is, the execution time of the innovation project will tend to be higher than initially defined if no

**Table 6:** Risk “Over-engineering” - Risks Identified in Piping Design.

<i>P</i>		<i>IS</i>		<i>IT</i>		<i>IC</i>		<i>IQ</i>		<i>DC</i>	
<i>P</i> <sub>1</sub>	□	<i>IS</i> <sub>1</sub>	□	<i>IT</i> <sub>1</sub>	□	<i>IC</i> <sub>1</sub>	□	<i>IQ</i> <sub>1</sub>	■	<i>DC</i> <sub>1</sub>	■
<i>P</i> <sub>2</sub>	□	<i>IS</i> <sub>2</sub>	■	<i>IT</i> <sub>2</sub>	□	<i>IC</i> <sub>2</sub>	■	<i>IQ</i> <sub>2</sub>	□	<i>DC</i> <sub>2</sub>	□
<i>P</i> <sub>3</sub>	□	<i>IS</i> <sub>3</sub>	□	<i>IT</i> <sub>3</sub>	■	<i>IC</i> <sub>3</sub>	□	<i>IQ</i> <sub>3</sub>	□	<i>DC</i> <sub>3</sub>	□
<i>P</i> <sub>4</sub>	□	<i>IS</i> <sub>4</sub>	□	<i>IT</i> <sub>4</sub>	□	<i>IC</i> <sub>4</sub>	□	<i>IQ</i> <sub>4</sub>	□		
<i>P</i> <sub>5</sub>	■										

**Table 7:** Results of Piping Design Risk Ssessment.

OUTPUT	RISK 1	RISK 2	RISK 3	RISK 4
<i>RS</i>	5	5	5	5
<i>RT</i>	8,22	6,14	5	1,63
<i>RC</i>	5	5	3,86	1,63
<i>RQ</i>	3,86	5	5	5
<i>LRS</i>	6,14	3,86	5	3,86
<i>LRT</i>	6,11	4,06	5	3,84
<i>LRC</i>	6,14	3,86	4,87	3,84
<i>LRQ</i>	5,94	3,86	5	3,86
<b><i>NR</i></b>	<b>6,08</b>	<b>3,91</b>	<b>4,97</b>	<b>3,85</b>

mitigation strategies or of prevention of this risk, are defined.

However, as the value of (*LRT*) is lower than that of (*RT*) we can see that the members that participate in this innovation project already have applied detection / control mechanisms that allow a reduction of probability of risk and / or impact, achieving thereby reducing its severity.

## 6 Conclusions

All organizations are aiming for success. Today's success is measured by the growth in profits, the leadership of the market share supported by customer satisfaction and the ability to innovate.

In this context, the role of innovation risk assessment was discussed, and a model was proposed to measure the level of risk associated with the development of an innovation project in a collaborative context.

The proposed model based on fuzzy logic, presents a number of advantages of which are: since risk assessment is inevitably dependent on human perception, therefore, in a context characterized by uncertainty and ambiguity, the assessment of the level of risk based on fuzzy inference systems becomes more rigorous, since by this way it is possible to mitigate the subjectivity of the analysis. On the other hand, while the classic models of risk assessment

are based only on the perception of risk based on the probability of occurrence and its impacts, the recommended model also covers the ability of the stakeholders in the innovation project to anticipate and respond appropriately to risk. This property allows to assess the level of risk that two distinct organizations will have on the risk level of the same risk event in an innovation project. However, more tests are needed to assess and validate the robustness of proposed model and its capability to cope with a variety of innovation project in different knowledge domains.

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