Forecasting Risk Impact on ERP Maintenance with Augmented Fuzzy Cognitive Maps

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Abstract—Worldwide, firms have made great efforts to implement Enterprise Resource Planning (ERP) systems. Despite these efforts, ERP adoption success is not guaranteed. Successful adoption of an ERP system also depends on proper system maintenance. For this reason, companies should follow a maintenance strategy that drives the ERP system toward success. However, in general, ERP maintenance managers do not know what conditions they should target to successfully maintain their ERP systems. Furthermore, numerous risks threaten these projects, but they are normally dealt with intuitively. To date, there has been limited literature published regarding ERP maintenance risks or ERP maintenance success. To address this need, we have built a dynamic simulation tool that allows ERP managers to foresee the impact of risks on maintenance goals. This research would help professionals manage their ERP maintenance projects. Moreover, it covers a significant gap in the literature.

Index Terms—ERP, fuzzy cognitive maps, risk management, simulation, software maintenance.

1 Introduction

Enterprise Resource Planning (ERP) is one the most common systems implemented by firms around the world. These systems allow the modeling, automation, and integration of company business processes, grouping all data into a single database, and providing relevant and updated information for decision making and control.

ERP system adoption is a strategic decision that can be motivated by technical and business factors to improve processes, establish a common platform, improve links to clients and suppliers, or reduce data errors [1], [2]. ERP system implementation lasts between one and three years [3] and requires significant effort. Firms spend from hundreds of thousands of dollars to several million dollars [4]. This investment is used to buy the system, acquire software licenses, train ERP users, integrate the ERP with other systems, contract specialized consultants, and carry out Business Process Reengineering. Despite the effort, and even if the implementation process has been completed satisfactorily, the success of ERP adoption is never guaranteed. It depends on both effectiveness and performance during the postimplementation stage [5], [6], [7].

Once the implementation process finishes, the ERP does not remain static. It must be maintained to meet rapidly changing business needs given the strategy followed by the firm. In addition, ERP professionals have to correct bugs, deploy new versions, take into account user requirements, and continue improvements to the system. If the company does not properly maintain the ERP system, failures will arise, performance will decrease, and the expected benefits will not be obtained [8]. This may even lead to early retirement of the ERP application. Hence, ERP maintenance becomes a key process in the postimplementation stage.

This fact is reflected in the associated business activity. A report [9] indicated that ERP maintenance revenues amounted to $10,375 million in 2006. This represents 36 percent of total ERP revenues. Moreover, this study forecasts that revenues will continue to grow, adding up to $15,390 million in 2010. In spite of this, ERP maintenance has scarcely been researched in previous literature, although this is changing. Various surveys show that interest in the postimplementation stage has recently increased [10], [11]. However, unexplored issues remain.

ERP maintenance is ambiguous because there is no clear framework to indicate the goals that ERP professionals should pursue. In addition, these complex environment projects are threatened by a wide range of critical risks due to their size, complexity, and the large number of external and internal actors involved [12]. Consequently, there is a lack of suitable ERP maintenance standards or methodologies that define the best way to manage the process [13].

One study [14] indicates that a firm's satisfaction with its ERP depends on three elements: 1) successful user training and change management, 2) effective handling of the risks and the fundamentals of project management, and 3) continued executive commitment. If ERP professionals do not manage these risks, the risks may convert into serious problems that will threaten maintenance success, and by extension, will affect the organization's satisfaction with the adoption of the ERP.

Given the significant risks inherent in ERP maintenance and the serious consequences that may follow, it is necessary to manage all risks properly. However, research on this particular issue remains inadequate. Previous studies neither indicate which goals must be reached to support successful ERP maintenance nor identify the risks that may threaten maintenance.

Accordingly, this paper assesses the effects of risks on the success of ERP maintenance through a systematic

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approach similar to that proposed elsewhere [15]. With this in mind, we identify risks to ERP maintenance success. Moreover, we specify which goals must be reached so that ERP maintenance will be considered successful. Finally, we create a Fuzzy Cognitive Map (FCM) to forecast risk effects on ERP maintenance goals and simulate distinct scenarios. This tool may help ERP maintenance managers assess existing risks in their projects.

The structure of the paper is as follows: Section 2 presents a literature review of ERP maintenance and risk. Section 3 presents the fundamentals of FCM. Moreover, this section presents key aspects of the tool, such as its dynamic behavior and how it achieves a consensual result. Section 4 describes the process for building an FCM to model risk in ERP maintenance. Section 5 studies the impacts of both highly controllable and poorly controllable risks on ERP maintenance goals. For this purpose, we define two scenarios and simulate them using the FCM. Finally, Section 6 offers conclusions and describes possible future research lines.

2 Background

2.1 ERP Maintenance

An ERP system can be defined as a single software system to support the complete integration of information from all functional areas of a company by means of a single database [16] that is accessible through a unified interface and channel of communication [17].

The ERP life cycle begins when top management decides to install the software. Following this decision, numerous tasks are carried out to implement the system. However, the ERP life cycle is not finished as soon as the application is operative and the ERP implementation stage has been concluded. At that moment, ERP enters into the postimplementation stage which continues until its retirement [18].

During the postimplementation stage, adopter companies use their ERPs and try to obtain a return on investment in a short time. In addition, they continuously carry out activities to improve their systems [19]. The companies thus seek to maximize ERP value [20] to achieve a competitive advantage over their competitors. In this way, they stabilize their systems, synthesize business process improvements, integrate complementary applications, and achieve value from their use of the ERP [21]. For the ERP postimplementation phase to be successful, ERP maintenance is key [22].

ERP maintenance includes all those activities executed from the time the system is operative until it is withdrawn. This includes matching the system to business strategies, goals, structure, and organizational processes so that the ERP responds to requests, corrects mistakes, and prevents future problems.

We can define ERP maintenance success in terms of compliance of time limits, budgets constrains, and demanded requirements [23], provided that:

- The ERP system is not damaged.
- Users are satisfied with the ERP.
- The ERP is perfectly fit to the company and its environment.

A successful maintenance of ERP improves the system and information quality and, consequently, enhances capabilities and effectiveness of system users, organizational results, and capabilities [24]. Hence, if ERP maintenance process is successful, these will improve ERP performance [25], [26], increasing system adoption success.

If the adopter firm fails to perform this maintenance, the system will not perform well. The ERP will not fulfill initial expectations. Moreover, daily business activities may be hindered. The ERP project might even become a failure that severely impacts company stability. Therefore, ERP maintenance is critical to the success of ERP adoption.

In spite of this, the majority of ERP publications focus on the implementation stage. However, in the last decade, ERP postimplementation stage studies have arisen in the literature [10], [11]. A framework based on stakeholders, the source of software, and its organizational size has even been proposed to classify ERP maintenance research [27]. Nonetheless, there are still unexplored research issues resulting from the fact that the technology was new and few companies were in the postimplementation phases.

Today, many firms worldwide have implemented these systems and they must now maintain them properly. Hence, there is demand for methodologies, tools, large-scale maintenance support from ERP vendors, and best practices on maintenance management [28].

In the literature, various papers propose models to support ERP maintenance management [17], [29], [30]. Other research concerns those aspects that influence ERP benefits after the implementation phase [25]. In the same line, another study proposed a taxonomy to classify maintenance requests depending on the business benefits that they help reach [8]. Critical factors for a successful ERP upgrade [31], [32] and maintenance [22] have even been identified.

Nevertheless, managers must also know which are the goals or desired results in the project [33]. In spite of this, no single research study has identified ERP maintenance goals. These goals have to be reached to consider the ERP maintenance outcomes successful. In addition, these reflect manager insights into maintenance performance. Hence, this knowledge would help manage the process better. For this reason, identifying the goals for ERP maintenance was one aim of our research.

2.2 Risk with ERP Maintenance

ERP maintenance is a large-scale, unstructured, and highly complex undertaking [34], [35]. In some cases, it even requires the use of unfamiliar technologies and tools. Hence, many controllable and uncontrollable risks can affect its outcome [36].

A risk is an event characterized by uncertainty because it may or may not occur. If this risk turns into a real problem, it may cause dangerous failures. In such a case, the project performance and the maintained ERP will be seriously damaged. For example, the personnel turnover rate is normally high in ERP maintenance projects, representing a risk to the project. When a developer leaves the team, the project may be delayed and/or its cost might be increased [37]. Moreover, high turnover in the ERP maintenance team can also harm the quality of system programming and, hence, system quality. Business activity of the ERP-adopting organizations can thus be affected.

Therefore, risk management becomes a crucial process to ensure ERP adoption success.

Risk management must be fully integrated into the project. This involves identifying, evaluating, treating, monitoring, and controlling the existing risk factors. In this way, the literature provides numerous methods, checklists, analytical frameworks, risk assessment tools, and risk response strategies to help project managers to handle risk factors more effectively [38]. These studies mainly focus on classic software projects.

However, different risks affect ERP project success because classic software projects and ERP projects are not similar [8], [12], [17], [22], [26], [27]. The ERP maintenance projects' complexity is greater than other software maintenance projects. This is due to the size of ERP systems, the high number applications connected to them, the high number of actors involved, and the continuous changes performed in the applications during the implementation and postimplementation stage. Moreover, the maintenance tasks carried out throughout the software maintenance life cycle model are different [39].

This has encouraged the appearance of ERP project risk studies in the literature. However, these studies focus on the implementation stage. Various research efforts have identified risk in the context of ERP projects. Sumner [40] identified, described, and categorized the risk factors associated with ERP implementation. Moreover, Sumner also marked which risks are unique in ERP projects. Aloini et al. [41] also identified the risk factors in addition to their effects. Huang et al. [42] combined a multicriteria methodology and the Delphi method to identify and prioritize risks.

Other studies propose methods, models, and even systems for risk management in ERP projects. Poba-Nzaou et al. [43] described a method to minimize risks associated with ERP adoption in small and medium-sized firms. Scott and Vessey [44] created a risk factor model based on the implementation case studies of Dow Corning Incorporated and Fox Meyer Drug Corporation. Zafeiropoulos et al. [45] proposed an application for risk management in the implementation of an ERP system.

By contrast, postimplementation stage risk research is scarce in the literature. In fact, we could only find two articles. One study [26] identifies and assesses the ERP maintenance risks, but this assesses the relative effects of each risk on maintenance process. This also indicates that it would be relevant to research the relations between risks and its effects on ERP maintenance success. The other [46] evaluates the ERP exploitation risks. Peng and Nunes [47] also present the same risks in another paper.

The remainder of the literature only reports on three risks in the maintenance phase [40]. However, other risks affect ERP maintenance success. Managers should handle them effectively to avoid failures and increase the likelihood of project success [41], [48]. In this way, they should begin identifying and assessing ERP maintenance risks [49]. But, which risks will impact on ERP maintenance goals? How will these impact ERP maintenance goals and the rest of the risks?

To help managers to answer the previous questions and cover a gap in the literature [26], identifying and assessing the risks effects on ERP maintenance success was the main objective of our study. This is a wider area of interest, and we focus on building a tool called FCM for forecasting the joint impact of risks on ERP maintenance goals. In the following section, we present FCMs and explain important issues about this technique.

3 Fuzzy Cognitive Maps

Cognitive Maps (CM) [50] and, later, FCM [51] have been applied in such diverse fields as medicine [52], computer science [53], simulation and prediction [54], and other domains [55], [56]. These have emerged as tools for modeling and studying the behavior of complex systems.

The FCM technique specifically describes a cognitive map model with two significant characteristics. First, causal relationships between nodes have different intensities, represented by fuzzy numbers. A fuzzy number is a quantity whose value is uncertain, rather than exact. It can be thought of as a function whose domain is usually the interval between 0 and 1 (or -1 and 1), inclusive [57]. Each numerical value in the interval represents the degree of membership in a fuzzy set, where 0 is nonmembership and 1 represents full membership.

The second characteristic is that the system is dynamic—it evolves with time. The system involves feedback, and a change in a concept node may affect other concept nodes, which in turn can impact the node initiating the change. Feedback plays a prominent role in FCMs by propagating causal influences along complicated pathways.

FCMs have similar features to other modeling techniques, at the same time as providing other different aspects which solve the constraints of the others. Deterministic, stochastic, and connective approaches have been used to model complex phenomena.

Deterministic models (e.g., [58]) represent factors thorough mathematical formula, ignoring the uncertainty [59]. In contrast, FCMs are capable of dealing with uncertainly using procedure such as human reasoning [52]. An evolved FCM even includes grayness as a measure of uncertainty [60].

Stochastic models (e.g., correlation or regression analysis [46]) treat uncertainty in terms of the variance [59]. These models represent the relationship between a dependent factor and one or more independent factors. Therefore, stochastic models do not allow us to represent all possible causal relationships among the factors. Hence, this approach is not suitable to show dynamic behavior of complex systems, as ERP maintenance risks, which multiple factors are closely related.

In contrast, FCMs show the behavior of a system in terms of concepts; each concept represents an entity, a variable, or a characteristic of the system [61]. The variable state evolves depending on the fuzzy weight values assigned to the feedback links between variables. Therefore, FCMs support the analysis of the evolution of a scenario at successive times [51] and the evaluation of alternatives by applying a complementary analysis. That is, FCMs allow us to simulate scenarios, but this method does not assess the resulting scenarios for itself. Simulated alternatives assessment needs a forward or complementary analysis.

Connective models describe the long term dynamic behavior of complex systems, based on cause and effect relationships between nodes. Methods such as FCMs, System Dynamics, Bayesian Beliefs Networks, and neural network belong to this modeling approach.

System dynamics model (e.g., [62]) allows the execution of scenarios, although the simulations are related to time-based changes in output variables, not uncertainty in outcomes [59]. In contrast, FCMs take into account the uncertainty and make visible it in outcomes.

Bayesian belief networks (e.g., [63]) model the relationships among a set of factors, although represented by a directed acyclic graph [64], which limit their evolution at successive times. In contrast, FCMs are directed graph with cycles that allow the analysis of the evolution of a scenario at successive iterations. Moreover, Bayesian belief networks also deal with uncertainties, although in probabilistic terms. For this reason, this tool requires the conversion of continuous variables to discrete distributions [59], which is not needed in FCMs.

A similar method to FCMs is neural networks (e.g., [65]). They differ from their structures. In this method, the propagation is based on a linear structure composed of layers (input, hidden, and output layers); meanwhile, FCM is based on a nonlinear structure of factors, which freely interacts through feedback dynamics [66]. We consider that FCMs are more suitable mechanism for modeling them due the nonlinear nature of ERP maintenance risks and its relationships. Moreover, it is considered an excellent tool for representing complex system when data lack [67]. To do so, this method aggregates the diverging perceptions of experts.

Other features of FCMs, such as flexibility, adaptability, fuzzy reasoning, and the capacity of abstraction of this tool [68], also have influence on our choice. FCMs provide an intuitive, yet precise, way of expressing concepts and reasoning about them at their natural level of abstraction. By transforming decision modeling into causal graphs, decision makers with no technical background can understand all of the components in a given situation. In addition, with an FCM, it is possible to identify and consider the most relevant factor/variable that seems to affect the expected target variable.

FCM is an adaptable tool which can be customized in order to consider the specifics of the represented phenomena. This is also very flexible. That is, if the initial representation is incomplete or incorrect, further elements can be added to the map, and the effects of the new parameters can be quickly seen.

In addition, FCM technique suffers some limitations. The resulting FCM is highly dependent on the data source. In fact, a number of experts are required [69] to ensure objective and globally valid results. However, the complexity of data analysis and manipulation increases with the number of experts interviewed [68]. To avoid this, the number of participating experts was selected according to a recommended range [69], [70], [71]. In addition, the model has to be as accurate as possible because an inconsistent model eliminates the results' validity. For this reason, we carefully made up heterogeneous panels of experts.

Other limitation of FCM is its high number of degrees of freedom in the design of the experiment. In fact, there are no rules which guide to the FCM designers in the choice of the transformation functions, assignation of parameters' values, among others.

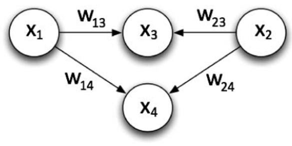

Fig. 1. Fuzzy cognitive map example.

In spite of these limitations, FCMs have been successfully applied for structuring and supporting decisional processes [55]. Also, FCMs provide excellent mechanisms to develop forecasting scenarios, especially "what-if" analysis [72]. This technique thus helps to take critical decisions in areas such as manufacturing, medicine, industrial engineering, marketing, finance, and other domains which require multiple and interrelated time-constrained decisions within strongly uncertain and complex environments. For these reasons, we think that FCM is a valuable tool. In the present study, we build an FCM to model the factors that can lead to critical failure in ERP maintenance projects and the relationships between them.

3.1 FCM Fundamentals

An FCM is a diagraph composed of nodes and edges. The nodes (x_i) are the most relevant dynamic variables or factors describing a target real-world dynamic system. These may represent concepts such as costs, diseases, medication, investment, or marketing strategy, to name a few. For any context, the nodes are a set of entities that are relevant to the domain of study.

Relationships between nodes are represented by directed edges (w_{ij}). An edge linking two nodes can model the influence of the causal variable on the effect variable [61]. In addition, edges also indicate the type of connection, incorporating either a plus (+) or a minus (−) sign [73]. A positive relationship between two factors indicates that an increase or decrease in a causal variable causes the effect variable(s) to change in the same direction. When the relationship is negative, the change in the effect variable is in the opposite direction (i.e., an increase in the cause variable causes a decrease in the effect variable).

Because FCMs are hybrid methods [57] that mix fuzzy logic [74], [75] and neural networks [66], each causal connection is assessed by its intensity, $w_{ij} \in [-1, +1]$, where i is the presynaptic (causal) node and j is the postsynaptic (effect) node. Fig. 1 shows an example of an FCM model.

An adjacency matrix A represents node connectivity for the FCM illustrated in Fig. 1. FCMs measure the intensity of the causal relation between two factors and if no causal relation exists, this is denoted by 0 in the adjacency matrix:

$$A = \begin{pmatrix} 0 & 0 & w_{13} & w_{14} \\ 0 & 0 & w_{23} & w_{24} \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}.$$

The high level FCM building process is summarized in Fig. 2.

FCMs are dynamic systems involving feedback [76] whereby change in a node may affect other nodes, which in

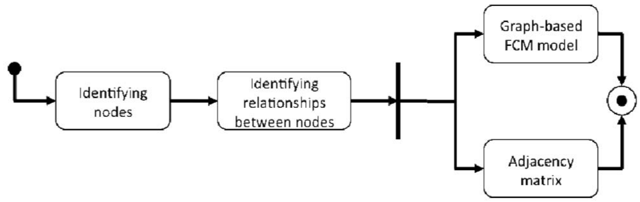

Fig. 2. FCM building process.

turn can affect the node initiating the change. The analysis begins with the design of the initial vector state (C^0), which represents the initial value of each variable or concept (node). The initial vector state with n nodes is denoted as

$$C^0 = \left(C_1^0\, C_2^0\, \cdots\, C_n^0\right), \tag{1}$$

where C_i is initial value. The new values of the nodes are computed in an iterative vector-matrix multiplication process with a transformation function, which is used to monotonically map the node value into a normalized range $[0, 1]$.

3.2 Consensus in FCM

Various methodologies can be used to represent a consensual FCM among experts [69], [77]. Delphi is a well-known methodology used to structure the communication process among experts to reach a consensus regarding a complex problem [78]. One of the main features of the Delphi study is that when the experts receive feedback reports, they have the opportunity to change their own opinion based on this feedback.

The Augmented FCM approach [69], [73], unlike the Delphi method [79], does not require experts to change their former opinions slightly for reaching a consensual result. This is possible because the Augmented FCM approach is an additive method. This approach consists in adding the FCM generated by each expert. Combining the FCMs together, conflicting relationship is canceled out or minimized, whereas agreement reinforces causal connections [67].

In this sense, the augmented adjacency matrix is built adding the adjacency matrix of each expert [73]. The resulting augmented matrix includes the union of the causal nodes for all of the experts. If an expert's FCM does not include a specific concept, then those rows and columns in the adjacency matrix are all zero. The resulting augmented matrix is computed as follows:

$$A^{Aug} = \sum_{i=1}^{n} A_i, \tag{2}$$

where n is the number of experts A_i and is the adjacency FCM matrix for expert i.

Let us define two FCMs with no common nodes: FCM_A with C_i as nodes $FCM_A = \{C_i\}$, and FCM_B with C_j as nodes $FCM_B = \{C_j\}$. The adjacency matrix of FCM_A is $A_A = (w_{ij}^A)$ and the adjacency matrix of FCM_B is $A_B = (w_{ij}^B)$. The augmented adjacency matrix is

$$A^{AUG} = \begin{pmatrix} w_{ij}^A & 0 \\ 0 & w_{ij}^B \end{pmatrix}. \tag{3}$$

If there are common nodes, then the element w_{ij}^{Aug} in the augmented matrix is

$$w_{ij}^{Aug} = \frac{\sum_{k=1}^{n} w_{ij}^k}{n}, \tag{4}$$

where n is the number of FCMs added, one from each expert, k is the identifier for each FCM, and i and j are identifiers of the relationships (Fig. 2).

For example, let us consider two FCMs with some common nodes. Starting from each adjacency matrix:

$$A^{FCM1} = \begin{array}{c} \\ A \\ B \\ C \end{array} \begin{array}{c} \begin{array}{ccc} A & B & C \end{array} \\ \begin{pmatrix} 0 & 0.8 & -0.4 \\ 0 & 0 & 0.1 \\ 0 & 0 & 0 \end{pmatrix} \end{array},$$

$$A^{FCM2} = \begin{array}{c} \\ A \\ C \\ D \end{array} \begin{array}{c} \begin{array}{ccc} A & C & D \end{array} \\ \begin{pmatrix} 0 & 0.2 & 0 \\ 0 & 0 & 0 \\ 0.7 & 0.1 & 0 \end{pmatrix} \end{array}.$$

The augmented adjacency matrix would be built as follows:

$$A^{Aug} = \begin{array}{c} \\ A \\ B \\ C \\ D \end{array} \begin{array}{c} \begin{array}{cccc} A & B & C & D \end{array} \\ \begin{pmatrix} 0 & 0.4 & -0.1 & 0 \\ 0 & 0 & 0.05 & 0 \\ 0 & 0 & 0 & 0 \\ 0.35 & 0 & 0.05 & 0 \end{pmatrix} \end{array}.$$

3.3 FCM Dynamics

The vector state C_j^{t+1} at the instant $t+1$ would be computed as

$$C_j^{t+1} = f\left(\sum_{\substack{i=1 \\ i \neq j}}^{n} C_i^t \cdot w_{ij}\right), \tag{5}$$

where $f(x)$ is the transformation function.

The state changes along the process. Usually, two kinds of transformation functions are used in FCM dynamics [80]. The first one is the unipolar sigmoid (6). The sigmoid is the most common function [80] when the concept (node) value maps onto the range $[0, 1]$:

$$f(x) = \frac{1}{1 + e^{-\lambda \cdot x}}. \tag{6}$$

The second is the hyperbolic tangent (7). This is the most common function [81] when the concept value maps onto the range $[-1, 1]$:

$$f(x) = \tanh(x) = \frac{e^{\lambda \cdot x} - e^{-\lambda \cdot x}}{e^{\lambda \cdot x} + e^{-\lambda \cdot x}}. \tag{7}$$

Both functions use λ as a constant for function slope (degree of fuzzification). The FCM designer has to specify the lambda value. For large values of lambda (e.g., $\lambda \geq 10$), the sigmoid approximates a discrete function that maps its results to interval $(0, 1)$; for smaller values of lambda (e.g., $\lambda \leq 1$), the sigmoid approximates a linear function; while values of lambda closer to 5 provide a good degree of fuzzification in the $[0, 1]$ interval [72], [80].

The FCM inference process finishes when stability is reached. The final vector state shows the effect of the change in the value of each node on the FCM. After the inference process, the FCM reaches one of three states

TABLE 1
Experts Profile

Position		Average of experience in ERP maintenance	
Project leaders	43.3%	1 – 5 years	10.0%
Consultants	16.7%	6 –10 years	46.7%
Analysts	6.7%	10 years and over	23.3%
Programmer	3.3%	Not reported	20.0%
Others	13.3%	**ERP vendor**	
Not reported	16.7%	SAP	26.7%
Academic background		Oracle	20.0%
Ph.D.	13.3%	Microsoft Dynamics Navision	6.7%
MSc.	23.3%	Openbravo	6.7%
MBA	16.7%	MIC 2000	6.7%
BSc.	20.0%	Made-to-measure ERP	3.3%
BBA	6.7%	Others	13.3%
Graduate	3.3%	Not reported	16.7%
Not reported	16.7%		

following a number of iterations. It settles down to a fixed pattern of node values, the so-called hidden pattern or fixed-point attractor.

Alternatively, the state can continue cycling between several fixed states, known as a limit cycle. With a continuous function, a third possibility is a chaotic attractor. This occurs when, instead of stabilizing, the FCM continues to produce different results (state vector values) for each cycle. In this case, the technique fails to offer a useful outcome for risk analysis.

4 FCM Construction to Model Risk Impact on ERP Maintenance Success

The aim of this study was to create an FCM for predicting the effect of risks on the goals for ERP maintenance. Toward this end, we carried out to the following steps.

4.1 STEP 1: Selecting the Experts

To build the FCM, advice was sought from two panels of experts. The quality of the panels was of paramount importance for us. In this study, multiple choices were explored to select the respondents. Table 1 shows the profile of consulted experts.

The main selection criterion was profound knowledge and experience in ERP maintenance and/or software risk management and absence of conflicts of interest. Over 70 percent of them had more than five years of experience in ERP maintenance. In order to build an accurate FCM which faithfully represents ERP maintenance reality, we formed heterogeneous panels. A heterogeneous group is understood to be a group of people with the same knowledge, but on a different social or professional scale, which describes our experts' panels. Moreover, the experts were not chosen just because they were easily accessible. All conditions were respected. All experts' opinions were considered to be of the same importance.

The optimal number of experts is quite difficult to establish, and no study has been conclusive with respect to this number [79]. The optimal panel size depends on the characteristics of the research itself. We can say, however, that the greater the heterogeneity of the group, the fewer the number of recommended experts. Between 10 and 20 seems to be a good group size [70], [71].

A total of 20 ERP system projects and/or worldwide risk management experts comprised the first panel. They were consulted via the web. The participating experts checked the preliminary lists of risk factors and goals in ERP maintenance, and added further elements. We created the preliminary list based on a broad literature review of software risk management and ERP projects. In Section 4.2, we explain this process.

Subsequently, 10 leading experts in ERP maintenance comprised the second panel. These experts were part of the ERP maintenance teams supplied by different vendors, including SAP, Oracle, Microsoft Dynamics Navision, and Openbravo, among others. One expert had even participated in the maintenance team for a "made-to-measure" ERP. Thus, by consulting a team of experts, we avoided omitting relevant factors in the augmented FCM.

Note that these experts were different from those who participated in the first panel. Therefore, the above process did not influence the outcome. Each expert individually created an FCM. For this purpose, we sent the lists determined by the first panel to each member of the second panel to help them in the design of his/her FCM. These lists did not influence the experts' activity because they could add further elements that were not included in the preliminary list or, even, they could not use it.

4.2 STEP 2: Identifying Preliminary Nodes

The FCM features two types of node. First, there are nodes that represent the risk factors that affect ERP maintenance processes. Other nodes represent the goals for ERP maintenance. We began with a thorough review of the literature to identify the risk nodes (R). The criteria used to select papers were:

1. "Risk Management" in the title, abstract, or keywords.
2. One of the following expressions in the title, abstract, or as a keyword: "IT/IS Project," "Software Project," "Software Maintenance," or "ERP."
3. The study must identify the risks clearly.
4. The time horizon was not limited. Thus, all target studies were collected and reviewed.

Different risk factors (313) were identified from 20 papers [40], [41], [42], [44], [45], [46], [82], [83], [84], [85], [86], [87], [88], [89], [90], [91], [92], [93], [94], [95]. However, not all of these risks affect ERP maintenance success. We found that many studies identified the same or similar risk factors. Accordingly, we carefully analyzed and removed duplicates and eliminated any risks that do not impact ERP maintenance. In addition, risks were renamed and adapted to match the scope of our study. We ultimately generated 25 risks nodes from the critical literature review.

We used the same process to identify relevant success conditions for ERP maintenance. The above criteria for related research changed as follows:

1. With the terms "Success Conditions," "Performance Measure," or "Metrics" in the title, abstract, or keywords.
2. One of the following expressions in the title, abstract, or as a keyword: "Software Project," "Software Maintenance," or "ERP."

3. The studies must identify the success conditions clearly.

We found seven maintenance goals in our literature review [90], [93], [96], [97], [98], [99], [100]. These represent conditions that must concur in ERP maintenance contexts at the level of process performance, system performance, and user satisfaction to consider the ERP adoption successful.

Given the absence of research on risk factors and goals for ERP maintenance, it is possible that relevant preliminary nodes were not identified during the critical literature review. Accordingly, we consulted the participating experts in the first panel. They checked the preliminary nodes and made helpful comments. Moreover, some experts added further risk factors and goals. We thus created a longer list of preliminary nodes. This was made up of 32 risks and nine maintenance goals. We subsequently sent this list via the web to experts in the second panel.

4.3 STEP 3: Building the FCMs

FCMs are normally built by experts who have experience and sound knowledge in this regard. They offer specific knowledge in designing the FCM model (nodes, intensity, and signs of the edges). Different methods can be used to build FCMs [55], [60], [101], [102]. However, if it is foreseeable that the map may feature a large number of variables and causal relationship between them, it can become necessary to use methodologies, such as Augmented FCM, to reach a consensual result.

The Augmented approach allows to reach a consensual FCM. In this way, this method requires that experts do not change their judgment for consensus purposes, as is required by the Delphi methodology [69]. Moreover, participants' answers are not constrained by strict nodes. This allows us to construct a complete FCM that represents all experts' opinions. For these reasons, we decided to use this approach to construct the FCM.

We sent the preliminary list of nodes to the experts in the second panel. This list was only a guide for them. Experts could include the nodes they considered appropriate regardless of whether these were in the list or not. Experts individually used this list and added further nodes to build their FCMs. The experts specifically identified the nodes and the relationships between them. Thus, we obtained an adjacency matrix describing each expert's opinion. We eventually created the augmented matrix by aggregating the adjacency matrix of each expert [66]. This aggregation process depends on whether there are common nodes between the FCMs. Because our experts' adjacency matrices had common nodes, we computed the elements for the augmented matrix using (4).

The final FCM consists of 34 risk nodes and nine maintenance goals nodes (G). Table 2 summarizes the nodes and indicates where each was identified. As expected, the previous literature did not include all of the risks that affect ERP maintenance success. Our experts identified nine additional risks. Moreover, they indicated two new maintenance goals. These are derived from ERP characteristics and require that the ERP perfectly fits the company and its environment. This also proves that ERP maintenance projects are different from classic software projects [8], [12], [17], [22], [26], [27], [39].

TABLE 2
FCM Nodes

ID	NODES	
R1	Changing structure/processes/ tasks ERP-adopting organization	LR
R2	Unstable organizational environment	LR
R3	Managers and/or employees (not maintenance team members) do not cooperate/ support the maintenance project	LR
R4	Miscommunications or misunderstanding of the requirements	LR
R5	Conflicting ERP requests	LR
R6	Continuing stream of requirement changes	LR
R7	Evaluation of performance requirements	LR
R8	Inadequate requirements prioritization	LR
R9	Inadequate ERP maintenance manager	LR
R10	Conflict and non-cooperation between ERP maintenance team members	LR
R11	Team members lack skills/knowledge/ experience required by ERP maintenance	LR
R12	High turnover within ERP maintenance team	LR
R13	ERP maintenance team members are unmotivated/ not committed	LR
R14	Inadequately-trained ERP maintenance team members	LR
R15	Specific competence of ERP consultants	LR
R16	Short/null/poor/documentation	LR
R17	The quality of code	LR
R18	Wrong ERP project resources/size estimates	LR
R19	Poor establishment of standard process/ procedures /methodology	LR
R20	Excessively-complex procedures	LR
R21	ERP project milestones not clearly defined	LR
R22	Inadequate measurements/tools/technology for test/simulation/evaluation	LR
R23	Poor establishment of ERP quality standards	LR
R24	ERP system users are reticent to the changes	LR
R25	Lack of training/support for ERP users	LR
R26	Cyber security risk	P1
R27	Changes in the strategy of the firm	P1
R28	Inappropriate IT infrastructure	P1
R29	Lack of proper tests	P1
R30	Wrongly-fit ERP system with pre-existing applications	P1
R31	Incorrect choice of the ERP modules	P1
R32	Excessively-complex techniques	P1
R33	Procedures to manage requests is not clearly defined	P2
R34	Lack of support of ERP vendor	P2
G1	ERP system functionality is maintained or enhanced	LR
G2	ERP system quality is maintained or enhanced	LR
G3	ERP system complexity is controlled	LR
G4	ERP system volatility does not increase	LR
G5	ERP system maintenance costs does not surpass the amount budgeted	LR
G6	ERP system maintenance runtime does not surpass the time planned	LR
G7	Users are more or equally satisfied with the ERP system	LR
G8	ERP is implemented well in all business functions	P1
G9	ERP is properly fitted to the environment of the firm	P1

LR: Literature review; P1: First-panel experts; P2: Second-panel experts.

In addition, the FCM contains 221 edges, represented by the 43×43 augmented matrix and shown in Table 3. The first column and row show the causal and effect nodes, respectively. The cells indicate the influence of one variable on another. All of the relationships between risks were positive. This means that values would change in the same direction. Moreover, the majority of connections between risks and maintenance goals were negative. When these risks increase, they negatively impact the relevant maintenance goals. However, the adjacency matrix also revealed five positive impacts, (e.g., $w_{R6,SC1} = 0.23$). In this example, the positive impact means that a continuing stream of requirement changes enhances ERP system functionality, although this risk negatively impacts other maintenance goals.

Last, the graphical representation of the final FCM is not clear due to the large number of elements that compose it. For this reason, we did not include it in this paper.

4.4 STEP 4: Validation

The process of validation is essential in the modeling of complex systems. This provides insights on degree in which it represents the relevant aspects of the problem studied.

TABLE 3
Adjacency Matrix

ID	R1	R2	R3	R4	R5	R6	R7	R8	R9	R10	R11	R12	R13	R14	R15	R16	R17	R18	R19	R20	R21	R22
R1	0.00	0.00	0.055	0.06	0.14	0.33	0.025	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.04
R2	0.245	0.00	0.00	0.00	0.00	0.065	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R3	0.00	0.00	0.00	0.235	0.13	0.05	0.17	0.07	0.09	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.025	0.00	0.00	0.00
R4	0.00	0.00	0.00	0.00	0.235	0.055	0.585	0.245	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.06	0.03	0.105	0.00	0.06	0.00	0.00
R5	0.00	0.00	0.025	0.00	0.00	0.07	0.05	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00
R6	0.00	0.00	0.00	0.00	0.05	0.00	0.13	0.135	0.00	0.04	0.04	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00
R7	0.00	0.00	0.025	0.00	0.00	0.00	0.00	0.37	0.00	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.00	0.14	0.00	0.00	0.09	0.00
R8	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R9	0.00	0.00	0.075	0.00	0.00	0.00	0.11	0.185	0.00	0.33	0.18	0.16	0.195	0.075	0.195	0.025	0.04	0.21	0.31	0.08	0.1	0.305
R10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.075	0.305	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00
R11	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.035	0.00	0.00	0.00	0.00	0.00	0.275	0.48	0.00	0.00	0.14	0.00	0.12
R12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.15	0.00	0.255	0.175	0.00	0.02	0.085	0.00	0.00	0.00	0.00	0.00
R13	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.07	0.15	0.00	0.035	0.00	0.05	0.05	0.00	0.00	0.00	0.00	0.00
R14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.26	0.00	0.04	0.00	0.00	0.165	0.235	0.00	0.00	0.07	0.00	0.03
R15	0.00	0.00	0.00	0.05	0.04	0.00	0.07	0.00	0.00	0.00	0.155	0.00	0.00	0.00	0.00	0.01	0.15	0.15	0.215	0.035	0.02	0.00
R16	0.00	0.00	0.025	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.355	0.095	0.05	0.00	0.00	0.00
R17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00
R18	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.155	0.00
R19	0.00	0.00	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.12	0.00	0.00	0.08	0.00	0.025
R20	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.00	0.095	0.11	0.00	0.00	0.00	0.00	0.00
R21	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00
R22	0.00	0.00	0.00	0.00	0.00	0.00	0.12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R23	0.00	0.00	0.00	0.02	0.00	0.00	0.03	0.00	0.00	0.00	0.095	0.00	0.00	0.075	0.00	0.15	0.485	0.02	0.34	0.08	0.00	0.08
R24	0.00	0.00	0.07	0.07	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R25	0.00	0.00	0.025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R27	0.18	0.03	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R28	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
R29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
R30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R31	0.00	0.00	0.025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.025	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R34	0.00	0.00	0.00	0.09	0.02	0.05	0.025	0.065	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.145	0.13	0.095	0.00	0.00	0.00	0.02
G1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

ID	R23	R24	R25	R26	R27	R28	R29	R30	R31	R32	R33	R34	G1	G2	G3	G4	G5	G6	G7	G8	G9
R1	0.00	0.165	0.095	0.00	0.025	0.00	0.025	0.00	0.00	0.00	0.00	0.00	0.00	0.05	-0.05	0.00	-0.08	0.00	0.00	-0.1	-0.2
R2	0.00	0.00	0.00	0.00	0.1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.00	-0.05	0.00	0.00	0.00	-0.075	-0.225
R3	0.00	0.05	0.17	0.00	0.00	0.05	0.025	0.00	0.1	0.00	0.00	0.00	-0.05	-0.075	0.00	0.00	-0.05	0.00	-0.07	-0.13	-0.1
R4	0.00	0.00	0.00	0.00	0.00	0.00	0.065	0.1	0.00	0.00	0.00	0.00	-0.22	-0.075	0.00	0.00	-0.06	0.00	-0.17	-0.21	-0.14
R5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.075	0.05	0.00	0.00	0.00	-0.1	-0.025	0.00	0.00	0.00	0.00	0.00	-0.11	-0.125
R6	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.05	0.00	0.00	0.00	0.23	0.05	-0.1	0.00	-0.07	0.00	0.00	0.00	-0.025
R7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.025	0.00	0.00	0.00	-0.23	-0.19	-0.025	0.00	-0.025	-0.06	-0.3	0.00	0.00
R8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	0.00	0.00	-0.09	-0.155	0.00	0.00
R9	0.1	0.00	0.05	0.00	0.00	0.00	0.12	0.01	0.00	0.08	0.00	0.00	-0.03	0.00	0.00	0.00	-0.18	-0.165	0.00	-0.07	0.00
R10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.07	-0.05	0.00	0.00	0.00
R11	0.00	0.00	0.105	0.00	0.00	0.00	0.08	0.00	0.05	0.00	0.00	0.00	0.00	-0.08	-0.025	0.00	-0.025	-0.115	-0.17	0.00	0.00
R12	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R13	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
R14	0.00	0.00	0.05	0.03	0.00	0.04	0.02	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	-0.04	0.00	0.00	0.00
R15	0.035	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.05	0.05	0.00	0.00	0.00	-0.08	0.00	0.00	-0.08	-0.05	-0.11	-0.075	0.00
R16	0.00	0.00	0.01	0.03	0.00	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.17	0.00	0.00	0.00	-0.035	0.00	-0.065
R17	0.00	0.00	0.00	0.035	0.00	0.035	0.00	0.00	0.00	0.03	0.00	0.00	-0.025	-0.3	-0.26	-0.01	-0.05	0.00	-0.075	-0.06	0.00
R18	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.38	-0.53	-0.05	0.00	0.00
R19	0.06	0.00	0.00	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	-0.2	0.00	0.00	0.00	0.00	0.00	0.00
R20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.00	0.00	-0.025	-0.025	-0.125	0.00	-0.05	-0.10	-0.03	0.00	0.00
R21	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.14	-0.41	-0.05	0.00	0.00
R22	0.00	0.00	0.00	0.00	0.00	0.00	0.2	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	-0.05	0.00	0.00	0.00	-0.05	-0.05	0.00
R23	0.00	0.00	0.00	0.00	0.00	0.00	0.095	0.02	0.00	0.00	0.00	0.00	-0.14	-0.475	-0.18	-0.14	0.00	0.00	0.00	-0.05	0.00
R24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.195	0.00	0.00	0.00	0.00	-0.06	-0.07	-0.165	-0.04
R25	0.00	0.43	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	0.00	0.00	0.00	0.00	-0.295	0.00	0.00
R26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.065	-0.01	0.00	0.00	0.00	-0.065	0.00	0.00
R27	0.00	0.00	0.00	0.065	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	-0.125
R28	0.00	0.00	0.00	0.19	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.165	0.00	0.00	-0.04	0.00	-0.085	0.00	0.00
R29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.06	-0.29	0.00	0.00	0.00	0.00	-0.14	-0.05	0.00
R30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.05	-0.04	0.00	0.00	0.00	-0.04	-0.05	-0.05
R31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.09	-0.05	0.00	0.00	0.00	0.00	0.00	-0.15	-0.11
R32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	-0.09	0.00	0.00	0.00
R33	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-0.03	0.00	0.00
R34	0.175	0.00	0.02	0.00	0.00	0.03	0.00	0.02	0.005	0.00	0.05	0.00	-0.19	-0.19	0.00	-0.05	0.00	-0.04	-0.05	-0.035	-0.13
G1	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G3	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G5	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G6	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G7	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
G9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Each cell shows one fuzzy weight (ω_{ij}). This represents the intensity of the relationships between two nodes (i and j). For example, the (R2, R1)' cell indicate the value of ω_{R2R1} (0.24).

Designers should validate the model in two distinct moments [103]. On one hand, the validation process should be embedded in the process of model building. This requires the active collaboration of the experts participating in the model process. On the other hand, the validation process should also be performed once the model building finished. To do so, designers can compare the model output with the real system data.

There is no widely accepted strategy or method by scientific community for validating the models building. The suitability of the strategy selected depends on the availability of data on the phenomena [104], the real system, and model purpose [105]. However, in the present study, we had neither available data nor reliable measures to evaluate with precision all concepts included in FCM. In fact, the validation of FCMs is complex and, many times, even impossible. This is due to the fact that FCMs are qualitative models that do not yield outputs directly measurable in the real world [67].

In such a case, the designers should consult experts in the phenomena studied [106]. If the experts are consulted during formulation of the model, the feedback obtained can be used to improve the performance of the model [107]. Hence, we began the validation during the building of the FCM. In this way, we have applied the modeling-validating process proposed in [107], [108], which has been applied in similar studies as [109].

First, we sought to guarantee the FCM conceptual validity, that is, whether the theories and assumptions underlying in the conceptualization of the phenomena are correct and enough to represent it adequately. In doing so, experts in ERP maintenance replied to the following question: Is this research looking at the study of ERP maintenance risks from the appropriate perspective? The whole set of experts answered affirmatively. In addition, they approved the criteria adopted for conceptualizing the influence of risks on ERP maintenance goals.

Subsequently, we elaborated a formal model. To guarantee the logical validation, that is, any important variable or relationship is excluded from the formal model, we applied the Augmented FCM approach. Subsequently, we verified the FCM obtained comparing it with respect to the conceptual model. During the FCM dynamics, we used standards and methods widely accepted by professional community. We thus guaranteed that the FCM was programmed correctly.

In addition, an expert in ERP maintenance project verified the results reached. This verification corroborated that the results achieved in ERP maintenance real projects and simulation results are similar when the risks simulated turn into problems. We thus verified the experimental validity of FCM. That is, the quality and efficiency of our FCM for predicting the risks impact on the ERP maintenance goal.

Finally, we verified the operational validity of building the FCM. For this purpose, we only consulted leaders or managers of ERP maintenance projects because they are the potential users of our tool. In general, these experts described the FCM created as a useful and applicable tool in ERP maintenance projects.

5 Simulating Scenarios and Interpreting Results

The FCM models risk factors, ERP maintenance goals, and existing connections between them. Furthermore, this tool allows us to predict the impact of risk on maintenance goals by means of dynamic simulations of the FCM behavior over time. To perform this analysis, it is necessary to create "what-if" scenarios and to simulate them separately.

We design two scenarios to study how strongly and weakly controllable risks influence ERP maintenance goals. Note that not all risks are controllable to the same degree by ERP maintenance managers. In fact, one of the most cited

TABLE 4
Simulations' Results

ID	Scenario 1	Results simulation 1	Scenario 2	Results simulation 2
R1	1	0.7101	0	0.0000
R2	1	0.3489	0	0.0000
R3	1	0.8548	0	0.8284
R4	0	0.8293	1	0.8034
R5	0	0.8877	1	0.8502
R6	0	0.8838	1	0.7677
R7	0	0.9747	1	0.9715
R8	0	0.9580	1	0.9549
R9	0	0.6851	0	0.6821
R10	0	0.8644	1	0.8614
R11	0	0.9393	1	0.9376
R12	0	0.8161	1	0.8157
R13	0	0.9174	1	0.9169
R14	0	0.8249	1	0.7990
R15	1	0.7093	0	0.7073
R16	0	0.9337	1	0.9319
R17	0	0.9939	1	0.9937
R18	0	0.9068	1	0.9055
R19	0	0.9275	1	0.9268
R20	0	0.8832	1	0.8820
R21	0	0.8625	1	0.8275
R22	0	0.8771	1	0.8675
R23	0	0.6810	1	0.6794
R24	1	0.9063	0	0.8720
R25	0	0.8619	1	0.8331
R26	0	0.7680	1	0.7420
R27	1	0.5098	0	0.0000
R28	0	0.6675	1	0.6642
R29	0	0.9287	1	0.9234
R30	0	0.7431	1	0.7336
R31	0	0.8020	1	0.7958
R32	0	0.6523	1	0.6518
R33	0	0.0935	1	0.0055
R34	1	0.0055	0	0.0000
G1	0	-0.9410	0	-0.9440
G2	0	-0.9871	0	-0.9882
G3	0	-0.9678	0	-0.9643
G4	0	-0.6341	0	-0.6050
G5	0	-0.9941	0	-0.9920
G6	0	-0.9866	0	-0.9861
G7	0	-0.9946	0	-0.9943
G8	0	-0.9774	0	-0.9694
G9	0	-0.9780	0	-0.9518

articles [86] about software project risks presents a framework. This classifies software project risks according to its level of importance and control.

The controllability of risks depends on the degree to which the ERP maintenance managers perceived that their actions could prevent the risk from occurring [86]. For example, the motivation of the maintenance team is a controllable risk factor from the perspective of ERP maintenance managers. In this sense, they can take measures to increase the team's motivation. However, they cannot take measures to mitigate other risk factors such as an unstable organizational environment.

The above-mentioned study [86] detects that risks considered the most important are often not under the project manager's direct control. Moreover, another study [110] shows that more or less controllable risks impact differently on project outcomes. So, we decided to research it in the context of ERP maintenance.

With this in mind, we define the value of each node in each initial state vector, (1), for each simulated scenario. In Scenario 1, we activate the risks that the professionals could less readily control. These risks arise through the actions of agents external to the project (i.e., ERP users, top management, consultants, and ERP vendors) or following changes in the organizational environment or strategy of the adopter firm. In Scenario 2, we simulate the opposite case. We ascribe a value of 1 to the risks that ERP maintenance managers can most easily control. Risk factors derived from requirements, tools, procedures, standards, the ERP maintenance team, and the process management itself can be prevented by management.

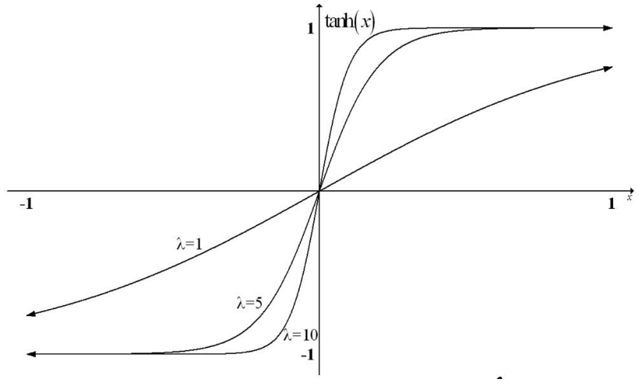

Fig. 3. Inference results depending on λ value.

Only one risk (R9) was not activated in either Scenario 1 or 2. R9 means that the ERP maintenance manager lacks necessary knowledge/experience/skills. An ERP maintenance manager could take measures to prevent his/her lack of knowledge, experience, or skills. But, is he/she aware of his/her lack of necessary knowledge, experience, or skills? If the answer is affirmative, does he/she prepare to take measures to remedy his/her lacks of necessary knowledge, experience, or skills? In the case of such situations, the most coherent action could be that he/she abandons the project. Hence, R9 cannot be clearly assigned either scenario 1 or scenario 2. Therefore, if we had activated R9, we would have damaged the simulation.

The values of the nodes in the initial state vectors are illustrated in Table 4. Both scenarios were transformed according to (5). To do so, we previously have to decide which transformation function should be used in our study. We select the hyperbolic tangent function (7) because the values of the nodes can fall within the range $[-1, 1]$ [81]. That is, the vector nodes could acquire negative values, unlike other transformation functions. In addition, hyperbolic tangent function needs a lower number of interactions to reach a stable scenario compared to other transformation functions [80].

The application of hyperbolic tangent function requires that FCM designers establish the value of λ. This is a parameter that determines the grade of fuzzification of (7). Fig. 3 shows the effect of the choice of value of λ in the transformation or inference results.

For larger values of λ (e.g., $\lambda = 10$), the hyperbolic tangent function approximates a discrete function that maps its results to $[-1, 1]$.

For smaller values of λ (e.g., $\lambda = 1$), the hyperbolic tangent function approximates a linear function.

For values of λ closer to 5, it provides a good degree of fuzzification in the $[-1, 1]$ interval. For this reason, we chose $\lambda = 5$ for our study [111].

In our study, both Simulations 1 and 2 reach a stability threshold. Table 4 also summarizes the findings from both Simulations 1 and 2.

5.1 Analyzing the Impact of Less Controllable Risk on ERP Maintenance Success

In this first simulation, we want to know how uncontrollable or poorly controllable risks affect ERP maintenance. For this reason, we compute R1, R2, R3, R15, R24, R27, and R34 with a value of 1 in (1). The results express how the changes in risks with a low level of control may affect other risks and goals in ERP maintenance.

In Table 4, we see that the risks reach extreme values, within the interval 0.0055 to 0.9939. The average impact is high ($\mathrm{mean} = 0.7708$[1]). Moreover, 24 risks obtain a value greater than the mean. Therefore, fewer controllable risks have high and positive influence on other risks. The five risks that are most strongly impacted are closely related to the ERP system (R16 [0.9337] and R17 [0.9939]), its requirements (R7 [0.9747] and R8 [0.958]), and the maintenance team (R11 [0.9393]).

These results reveal that if there is no suitable cooperation between external parties and the maintenance team, system elements such as the quality of code and system documentation may be damaged. This occurs when ERP code complexity increases, making its comprehensibility and modification difficult. Activated risks also strongly influence risk factors derived from system requirements. For example, changes in the organizational environment usually prompt changes in business objectives, which lead to modifications of greater impact to the ERP. The evaluation and prioritizations of these requests are very complicated because they demand deep structural changes. Moreover, these requests require that the team members have excellent experience with the technology and solid knowledge of ERP systems and their maintenance.

The results also show that the risks activated in Scenario 1 may threaten maintenance goals. Furthermore, the influence on the majority of the goals is very high. In fact, the average impact is extremely high ($\mathrm{mean} = -0.9401$[2]) and eight maintenance goals obtained a value of less than -0.94. This means that when one of above risks changes, it causes a change in maintenance goals in the opposite direction. Therefore, the ERP maintenance project, ERP system performance, and user satisfaction are all threatened by these risk factors. Only G4 is slightly affected (ERP system volatility does not increase). It is affected about 1.5 times less than the rest.

G5 and G7 are the most strongly impacted goals. The first is G7 with a value of -0.9946. This highlights how the action of poorly controllable risk factors decreases ERP user satisfaction. This is very critical because, if ERP users become dissatisfied, they will not use the system properly and/or may not participate in maintenance. They can even sabotage the system. In such cases, the adopting organization will not benefit from the expected results of the ERP adoption. The managers should thus encourage user involvement in the ERP maintenance process to avoid this.

The second most strongly affected goal is G5 (-0.9941). This shows that risks derived from external factors may lead to unexpected cost. Hence, ERP system maintenance costs often surpass the amount budgeted. Therefore, managers should delete extraordinary items from their budgets. Reviewing historical data and consulting with ERP vendors and consultants may help to better estimate such costs as well.

5.2 Analyzing the Impact of Controllable Risk on ERP Maintenance Success

Scenario 2 represents the opposite case. In this simulation, we seek to assess the influence on ERP maintenance goals of those risks that can be most readily controlled by managers. We assigned the values indicated in the fourth column in Table 4 to the nodes in (1).

In Simulation 2, the risks also reach extreme values. Specifically, these values are within the interval 0.00 to 0.9937. However, the average impact is smaller than for Simulation 1 ($\mathrm{mean} = 0.7088$[3]). Moreover, 24 risks yield a value greater than the mean. More controllable risks thus have a slightly lower and positive influence on the majority of risks.

We find that four risks are not affected ($C_i^m = 0$) in the simulation. These belong to Scenario 1. The other two risks (R15 and R24) activated in Scenario 1 are severely impacted. However, ERP maintenance managers have greater control over R15 and R24. For example, to decrease this risk, managers can better train ERP users to operate the system. But both R15 and R24 yield slightly lower values than the rest. These results suggest that there is a correlation between the possible level of control over a risk and the impact from other risks. Therefore, risks with a lower level of control are less easily influenced by other risks.

The five most strongly impacted risks are the same as those in Scenario 1. However, these risks reach smaller values in this simulation: risks related to the ERP system (R16 [0.9319] and R17 [0.9937]), its requirements (R7 [0.9715] and R8 [0.9549]), and the maintenance team (R11 [0.9376]). Fig. 4 shows a graphical comparative of the uncontrollable and uncontrollable risks impact on ERP maintenance risks. Note that the differences are very small. The same results are seen with the rest of the risks. This reveals that uncontrollable risks have a slightly greater impact on other risks.

Table 4 also shows the impact of highly controllable risks on maintenance goals. These results indicate that, like Scenario 1, the activated risks negatively impact maintenance goals. The global influence is also similar ($\mathrm{mean} = -0.9328$[4]). In addition, the results for Scenarios 1 and 2 are very similar. In fact, the four goals most affected are the same. Fig. 5 shows a graphical comparative of the uncontrollable and uncontrollable risks impact on ERP maintenance goals. Nonetheless, we note remarkable results.

1. The mean was calculated by summing the values of all risks and dividing by the number of risks in the list.
2. The mean was calculated by summing the values of all maintenance goals and dividing by the number of maintenance goals in the list.
3. The mean was calculated by summing the values of all risks and dividing by the number of risks in the list.
4. The mean was calculated by summing the values of all maintenance goals and dividing by the number of maintenance goals in the list.

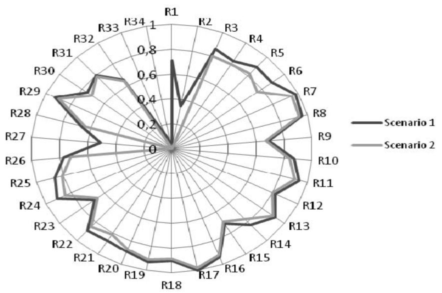

Fig. 4. Comparison of high-low controllable risks impact on ERP maintenance risks.

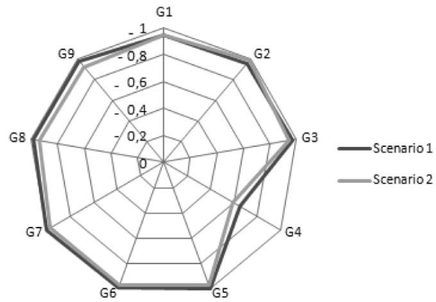

Fig. 5. Comparison of high-low controllable risks impact on ERP maintenance goals.

The same eight maintenance goals reach values of less than -0.94 while decreasing the impact on G4 (-0.605). This goal is affected about 1.7 times less severely than the rest. Moreover, comparing the results across Simulations 1 and 2, the value of G4 is the most different. System volatility is most strongly affected by risks arising from external factors. For example, R27 causes deep structural changes. If managers do not carefully handle these changes, they will increase the ERP volatility. In this case, the state of the ERP may change profoundly.

Last, only the impacts of two goals (G1 and G2) are increased. Both mark a goal given the performance level of the ERP. This highlights how risks with a high level of control most strongly impact the quality and functionality of the system. In contrast, the value of the other maintenance goals decreases in absolute value. Such activated risks have less of an influence on project performance (G5 and G6), user satisfaction (G7), and other goals given the level of system performance (G3 and G4) and fit goals (G8 and G9).

6 Conclusions, Limitations, and Future Works

Numerous risks threaten ERP systems maintenance. These can severely impact ERP user satisfaction, the project outcome, performance, and fitting the system to the firm's needs. To avoid failures, managers should handle these risks effectively by identifying and assessing the risks in their projects. In spite of this, the literature lacks studies on ERP maintenance which help managers in the risks management.

In order to study ERP maintenance risks, we propose an innovative tool called FCM. To do so, we used augmented FCM approach. This additive methodology allows to model faithfully the studied problem based on perceptions of experts on the phenomena. In this study, experts who have experience in ERP maintenance actively participated in the building and validation of the FCM.

From a static perspective, the FCM created indicates the goals which have to be reached for considering successful ERP maintenance. This also represents the risks which threaten the achievement of these goals so that the causal connections exist between these elements. The final map shows that the risks identified are closely related and they negatively impact maintenance goals. From dynamic perspective, the FCM created predicts the joint effects of risks on the ERP maintenance goals. The results will help understand the influence of risks on ERP maintenance better. Consequently, the professionals may take more effective measures to treat or prevent existing risks.

To prove the dynamic behavior of the new FCM, we created two what-if scenarios and simulated them. We specifically modeled the impact of strongly and weakly controllable risks on ERP maintenance goals. Our results confirm that risks strongly affect ERP maintenance performance. Specifically, ERP user satisfaction was the goal that was most strongly affected by the risks. In contrast, ERP volatility was the least impacted goal.

In addition, the findings, as a preliminary study [86], reveal that risks considered the most important are often not under the project manager's direct control. In fact, less controllable risks impact more strongly on maintenance goals than more controllable risks, although the differences are very small (see Fig. 5). Only ERP systems quality and functionality are more damaged by controllable risks. The comparison of the simulation's results also shows a direct relationship between the degree of control over a risk and the amount that risk is influenced by other risks. Therefore, risks that are less readily controllable by managers will be less impacted by other risks (see Fig. 4).

From the academic point of view, the results of the research presented here are also relevant. This paper lays the groundwork for further studies because it is the first time that ERP maintenance risks and goals have been identified. However, this study, while significant, is not exempt from limitations.

This is not empirical research. We simply built a tool (FCM) so that a practitioner can formally assess risks existing in ERP maintenance. The simulation of scenarios demonstrates applicability and usability of the proposed tool, this being the aim of the present paper. However, other scenarios could have been simulated. We invite researchers and practitioners to propose further possible scenarios.

This research is focused in assessing the joint impact of risks on ERP maintenance goals. Nonetheless, ERP maintenance risks are still an under-researched topic with unsolved issues. So, it is necessary to undertake further research on the existing risks in ERP maintenance. To manage such risks most effectively, managers should know which risks are most important to ERP maintenance success. Therefore, research that answers this question is required. The development of techniques to predict the appearance of risks in ERP maintenance projects is also very worthwhile. Moreover, it would be interesting to know real problematic situations which have occurred during ERP maintenance. This will help to achieve better results in these complex projects.

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