A Fuzzy-Based Approach to Estimate Management Processes Risks

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1 Introduction

The delivery of mega infrastructure projects with success faces many risks that are not essentially parts of conventional typical projects. Among the important project risks, and yet neglected, are the ones associated with the managerial skills of stakeholders associated with such mega projects. Westney [1] defines project management as the application of knowledge, skills, tools, and techniques to project activities in order to meet or exceed stockholders' need and expectations from the project. Project management has evolved from a management philosophy restricted to a few functional areas to now an enterprise project management system affecting every functional unit [2]. The Project Management Maturity Model which comprises of six major stages (namely planning, design, scoping, tendering, scheduling and ending with the implementation which also includes benchmarking and continuous improvement) notes the degree of interaction between strategic management and planning and successful implementation of the project [3].

The key management processes identified in the literature are the communication, coordination, knowledge sharing, and decision-making [4]. Effective communication practices ensure that all major players are kept fully informed of any problems or difficulties and have procedures for decision making and managing these immediately when they occur and not allow them to disrupt the project [2]. Zwikael et al. [5] examined project management practices and concluded

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that various types of management styles, scope and time management impact on improving the technical performance of projects while communication and cost management impact on improving overall success measures of projects. Other researchers suggested the use of communication effectiveness models to predict satisfaction levels by contractors and clients at the earliest possible stage in the project life-cycle [6]. To minimize defective designs, and subsequent overrun of cost and schedules, Zou et al. [7] reported that the design team needs to establish an efficient communication scheme among the designers. The lack of communication among parties was reported among the ten most important causes of project delay [8].

Coordination is recognized as a key issue in transportation infrastructure projects. Timmermans and Beroggi [9] stressed the importance of coordination between organizations with diverse objectives. The concept of international coordination for transportation infrastructure projects is addressed by Short and Kopp [10]. Chen and Partington [11] emphasized the ability of project managers to coordinate activities on the site. Lack of coordination among project participants was identified as a key risk factor in Australian projects [7].

Jackson and Klobas [12] stressed the need to develop a knowledge sharing process model for project managers. Kovacs and Paganelli [13] argued that data and knowledge interchange is urgently needed for improving efficiency and standardize operations of complex distributed organizations. Gabor [3] suggested that for the six stages of infrastructure development; namely, planning, scoping, design, scheduling, tendering and construction, a feedback loop should be incorporated to allow for the knowledge experience in the process of new project management and development. The necessity of a feedback loop to gain insights on decision making in various projects is emphasized by Short and Kopp [10]; suggesting that in order to improve planning processes and decision making, it should be helpful to look back at the taken decisions and extract lessons from them. Decision-making is significantly tied to the communication media and effectiveness. Decentralized communication channels are known to facilitate better information flow and decision making when problems arise. Clients who have decentralized communication channels ease communication and facilitate faster decision-making [6]. In assessing the project performance measures, project managers need to understand what causes or factors result in time overrun or cost overrun. Once these factors become clear, the managers can take proactive steps to avoid such situations. Sambasivan and Soon [8] identified slow decision-making by clients as a primary factor for time and cost overrun.

The application of "fuzzy techniques" has been gaining popularity in the research area of project management over the past decade. Chan et al. [14] provide a thorough review of the various fuzzy techniques in construction management. They indicated that fuzzy research, as adopted in the construction management over the past decade, can be divided into two broad fields: fuzzy set/fuzzy logic and. hybrid fuzzy techniques. They indicated that hybrid fuzzy techniques, such as neuro-fuzzy can be more broadly adopted because they can better solve some construction problems that fuzzy set/fuzzy logic alone may not best suit. Neuro-fuzzy systems can represent qualitative, vague, and imprecise concepts and combine the ability of knowledge representation with the learning power of neural networks.

Another interesting study by Taroun [15] provides a thorough review of the literature of construction risk modeling and assessment. The author concluded that there is a lack of a comprehensive assessment approach capable of capturing risk impact on different project objectives, and that would require an effective mechanism for aggregating individual risk assessments. He also concluded that a simple analytical tool that uses risk cost as a common scale and utilizes professional experience could be a viable option to facilitate closing the gap between theory and practice of risk assessment.

Shi et al. [16] highlighted the extra risks associated with the large construction projects. A mixed approach was used to explore the management of delivery risks. The approach included the use of a mixed approach of fuzzy logic together with Data Development Analysis (DEA) to assess the delivery risks. Other fuzzy logic applications include the detailed assessment of construction delays [17]. Probabilistic fault tree analysis and fuzzy fault tree analysis methods were used to estimate the likelihood of delay.

Many other researchers used fuzzy logic in capturing various risk elements of construction projects [18–21]. Zeng et al. [18] estimated the risk magnitude may be assessed by considering two parameters: risk likelihood and risk severity. They indicated that there are many possible risk factors in construction, which lead to a project failure and these risk factors should be incorporated into the evaluation process. The so-called “Factor index” is therefore introduced to the structure and evaluate these factors and integrate them into the decision-making process of risk assessment. A modified analytical hierarchy process is used to structure and prioritize diverse risk factors. Lam et al. [19] presents a decision model which transforms the linguistic principles and experiential expert knowledge into a more usable and systematic quantitative-based analysis by using the fuzzy logic. Seven risk allocation criteria and a set of knowledge-based fuzzy inference rules are established according to the expert knowledge. Risk events are assessed on each criterion and the relevant rules. The corresponding risk allocation decisions between the owner and contractor are then suggested by the model.

Dikmen et al. [20] proposed a fuzzy risk assessment methodology for international construction projects and develop a tool for estimating a cost overrun risk rating at the bidding stage.

Nieto-Morote and Ruz-Vila [21] considered four categories of risks; project management risk, engineering risks, execution risks, and suppliers risks. In a way, the adopted framework includes the risks of the various stages of construction. The management risk in specific is judged by four indicators including the lack of adequate process, the lack of resources, inexperienced team members and the lack of motivating attitudes.

In conclusion, the existing literature is diverse in capturing various aspects of risks in construction projects. Nonetheless, there is still a room for improvement by capturing additional risk elements that particularly address:

1. The impact of the various managerial processes (e.g. the communication, coordination, decision making and knowledge sharing) on the project overall risk. These processes were identified in the literature as indicated earlier to be key factors to project success or failure [4].
2. The impact of the stakeholder importance and as such the possibility of delays and cost overruns to respond to the stakeholder requests during the various stages of construction. Stakeholders' importance may vary throughout the various stages of the project and as such may have various levels of risk implications. Following the stakeholder topology concept by Mitchell et al. [22], we identified Sponsors/Clients, Government Department, Management Firms, Consulting Firms and Contractors as the key stakeholders influencing infrastructure projects [4].

This research is particularly the first to address the risk of the management processes using fuzzy logic while integrating the specifics of the stakeholder theory. The overall aim of this research is to investigate the key processes for the effective management of mega infrastructure projects and to develop a quantitative model that can be used to assess the risks associated with these processes by the various stakeholder groups during the various phases of the project execution stages. Given the uncertainties of the stakeholders' perceptions on stakeholders' importance levels during the various project phases, the effectiveness of management processes and the risks associated with these processes at the various project stages, an appealing approach would be to use a fuzzy logic modeling approach as it accounts for such uncertainties and variations of stakeholders' perceptions.

2 Risk Modeling Approach

The literature review indicated that several attempts in the area of risk management of infrastructure projects [15–21]. This paper is closing a gap on an element of risk that was overlooked or underemphasized by early researchers. The literature review indicated also that it is essential to include the risk that is associated with management processes such as communication, coordination, decision making and knowledge sharing [4]. Nonetheless, there are no adequately validated models that can be used. Moreover, earlier research on the risk assessment of construction projects overlooked the effect of the stakeholders themselves on the project. It is well known that as the importance of the stakeholder group increases, the impact of such group on the risk is likely to increase. For instance, inadequate decision making or delay in decision making by the client (among the most important stakeholders in the project planning stage) is likely (with a great deal of certainty) to cause project delays and as such cost overruns which are naturally translated into higher project risk.

The risks of successfully implementing mega projects include financial, technical, as well as risks due to management processes. Herein, we develop a modeling approach to estimate the project risk associated with the management processes only. It is believed that this management risk is the most important risk element [4].

To quantify the risks associated with the management processes, we envision the risk model to be a three-dimensional model. The first dimension entails the effectiveness of the various management processes (communication, coordination, decision making and knowledge sharing). The second dimension refers to the criticalness level (or the importance) of the management processes itself. Some of these processes might be of more influence during some of the project stages and alternatively un-influential during other stages. For example, one may regard the decision-making management skills of a particular stakeholder group to be highly important during the earlier stages of the project, while such skills to be less than essential at later stages. The third dimension includes the importance of the stakeholders involved in the project, which may also change from one project stage to another.

A survey form was developed to assess the validity of the suggested risk modeling approach. The form was designed to assess the importance of the various stakeholder groups as well as their perceptions of how critical are the management processes (Communication, Coordination, Decision Making and Knowledge Sharing) during the design construction stages of the project. Only the design stage was considered here in demonstrating the modeling approach as it was identified by the survey participants to be among the most critical stages that contribute to higher project risk [4].

The envisaged system may be used to assess the managerial processes risks for all types of infrastructure projects. Nonetheless, it worth mentioning that the data with which the system is calibrated were collected by surveying stakeholders involved in mega projects; ones significantly affected by the management processes [4]. Nonetheless, the authors are currently undertaking more research and data collection that will enable the development of such system for general infrastructure projects, and not necessarily mega projects.

3 Fuzzy Logic Model

Let s refers to the stage of the construction, $s = [1, 6]$ (where $s = 1$ refers to planning stage, 2 refers to scoping, 3 refers to design stage, 4 refers to tendering stage, 5 refers to scheduling stage and 6 refers to construction stage).

Let g refers to the index of the important stakeholder groups involved in mega projects, $g = [1, 5]$ (where $g = 1$ refers to the client, 2 refers to the governmental agency, 3 refers to management firms, 4 refers to consulting firms, and 5 refers to contracting firms).

Three attributes are considered in measuring the importance of a stakeholder [18]:

– Legitimacy: the moral or legal claim a stakeholder has to influence a project;
– Power: their capacity to influence the outcome of a given project; and
– Urgency: the degree to which their claims are urgent or compelling.

Let I_{gs} refers to the importance of the stakeholder group, g, during a specific construction stage, s, where $I_{gs} = L_{gs} + U_{gs} + P_{gs}$, and L_{gs} is the legitimacy level, U_{gs} is the urgency level and P_{gs} is the power level of group, g, during construction stage, s. L_{gs} , U_{gs} , and P_{gs} are regarded as fuzzy variables of three terms each {low = (1), medium = (2) and high=(3)} representing the legitimacy, urgency and power levels. As such, the importance level I_{gs} can take any numeric value within the range of $[3, 9]$.

Given the explicit uncertainty and the subjective judgment involved in estimating the importance levels, it can be also considered a Gaussian2 fuzzy variable (herein, we considered five terms indicating very high, high, medium, low and very low importance levels), with the numeric value of 3 corresponds to very low importance and the value of 9 corresponds to a very high importance level. Figure 1 shows the fuzzy membership function of the I_{gs} variable.

Let p refers to the management process to be assessed, $p = [1, 4]$ (where $p = 1$ refers to the communication, 2 refers to the coordination, 3 refers to the decision making and 4 refers to the knowledge sharing)

Let C_{ps} refers to the criticalness level of the management process, p, during the construction stage, s. The C_{ps} varies among the various p and s values and it ranges from $[1, 4]$, where 1 is the least critical and 4 is most critical.

The criticalness level C_{ps} is commonly estimated from stakeholder surveys subjectively, and it is likely to change from a group of stakeholders to another. Given the explicit uncertainty and the subjective judgment involved in estimating

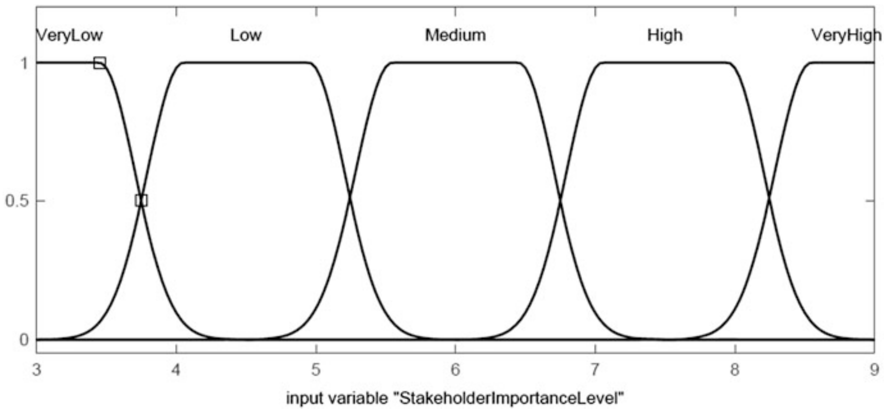

Fig. 1 Gaussian2 membership function of stakeholder importance I_{gs}

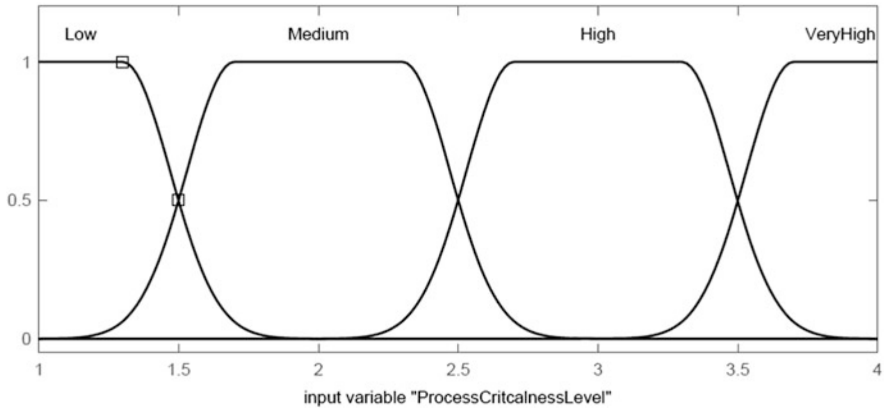

Fig. 2 Gaussian2 membership function of the process criticalness level, C_{ps}

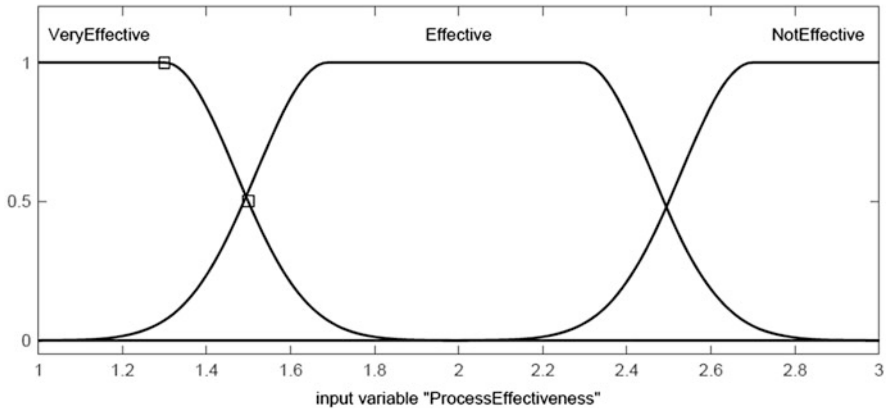

Fig. 3 Gaussian2 membership function of the effectiveness of the management process, E_{pgs} (3 terms; 1: very effective, 2: effective, and 3: not effective)

the criticalness levels, it can be also considered a Gaussian2 fuzzy variable (herein we considered four terms indicating very high, high, medium and low criticalness levels). The fuzzy variable C_{ps} has a range of $[1, 4]$, where 1 indicates a low critical level and 4 indicating a very high critical level. Figure 2 illustrates the C_{ps} fuzzy variable.

Let E_{pgs} refers to the effectiveness level of the specific management process, p, during for a specific group, g, during a specific stage, s. E_{pgs} is a Gaussian fuzzy variable and it ranges $[1, 3]$, where 1, 2 and 3 indicates “very effective”, “effective” and “not effective”, respectively. Figure 3 illustrates the E_{pgs} fuzzy variable.

Let r_{pgs} refers to the management risk associated with a specific management process, p, of a specific stakeholder group, g, during a specific project stage, s. r_{pgs} is a nonlinear multiplication (prod) function of I_{gs} (the importance of the stakeholder group), C_{ps} (the criticalness level of the management process) and E_{pgs} (the effectiveness level of the specific management process). That is, we assume that the risk index of any process p, group, g, and stage, s, is the product of the importance level of the stakeholder group, I_{gs}, the criticalness of the process, C_{ps}, and the effectiveness of the management process, E_{pgs}.

$$r_{pgs} = I_{gs}C_{ps}E_{pgs}, \forall p, g, s \text{ such that } p = 1, 4, g = 1, 5, s = 1, 6 \tag{1}$$

The risk model shown in Eq. (1) was verified by the various survey participants. The various group participants indicated the acceptance of the approach and the formulation of the variables. The risk index r_{pgs} is an integer value ranging from 3 ($I_{gs} = 3$, $C_{ps} = 1$, and $E_{pgs} = 1$), to 108 ($I_{gs} = 9$, $C_{ps} = 4$, and $E_{pgs} = 3$).

The overall risk index of the project, R, due to the ineffective management processes can be then estimated as the sum of r_{pgs} $\forall p, g, s$

$$R = \sum_{p=1,4}\sum_{g=1,5}\sum_{s=1,6} r_{pgs} = \sum_{p=1,4}\sum_{g=1,5}\sum_{s=1,6} I_{gs}C_{ps}E_{pgs} \tag{2}$$

A Sugeno fuzzy logic model was assumed as shown in Fig. 4. The model has three input fuzzy variables (I_{gs}, C_{ps}, E_{pgs}), and a rule block with "and" connection. The "prod" operator is used. The model's rule block and the output $f(u)$ were calibrated using Neuro-Fuzzy functions of Matlab. A total of 60 rules were calibrated and the $f(u)$ was calibrated to 60 different discrete values. The rules and the $f(u)$ values were calibrated (trained) using a dataset comprising all possible values of I_{gs}, C_{ps}, E_{pgs}, and the estimated r_{pgs} using Eq. (1).

Table 1 illustrates a sample of four different input sets and the corresponding output values. In the first set, the input values [1, 1, 1] were used. The fuzzification and the fuzzy inference processes resulted in the "firing" of one rule only (rule number 1). The output fuzzy term associated with this rule is term 1, which corresponds to a value of 3.01 (following the defuzzification process). For the input values [1, 4, 3], only the 16th rule is fired, resulting in a risk value of 12. For the

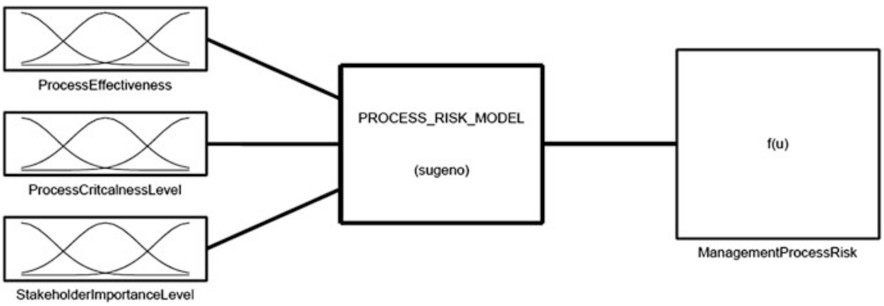

Fig. 4 The fuzzy logic structure of the management processes risk model

Table 1 Sample of the inputs, fuzzy inference rules, output fuzzy terms, and estimated risk

Input values	Applicable rules in the inference process	Output term (s)	Output value (risk)
[1, 1, 1]	1	1	3.01
[1, 4, 3]	16	16	12
[3, 4, 3]	56	56	36
[2.5, 3.5, 5]	32, 37, 52, 57	32, 37, 52, 57	43

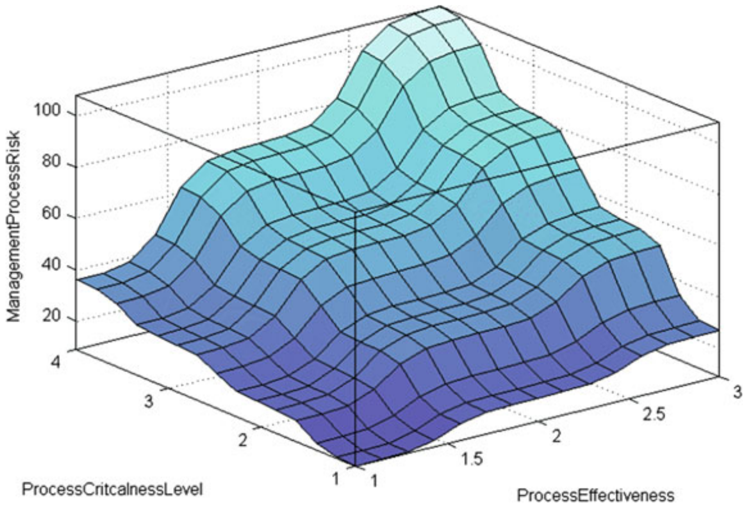

Fig. 5 Risk index r_{pgs} imposed by consultants during the design stage

input values [3, 4, 3], only the 56th rule is fired, resulting in a risk value of 36. For the input values [2.5, 3.5, 5], the fuzzification process results in overlapped input fuzzy terms, and as such the firing of multiple rules; namely, (32, 37, 52, and 57). The corresponding output fuzzy terms are defuzzified and following the aggregation of individual rule results, the estimated final risk value is 43.

Figure 5 illustrates the calibrated r_{pgs} using the fuzzy logic. It shows the induced risk during the project design stage by the consultant group. Consultants impose highest levels of risk during the design stage.

The Sugeno model is known in the literature to be computationally efficient, works well with optimization techniques, and it results in guaranteed continuity of the output surface. The risk model addressed in this paper is developed through the optimization of the model parameters to minimize the SSE between the observed and estimated values. The survey data (of the 23 survey participants) resulted in a data set 1257 rows (training data points). Only 800 data points were used in the training while the remaining ones were used for validation (estimating the model errors), and subsequently selecting best model. Prior to the training, the 800 data points were “narrowed” down (clustered) to only 60 data points by clustering the points of similar input variables and averaging the output risk values.

There are two methods that ANFIS learning employs for updating membership function parameters:

- Backpropagation for all parameters (which employs the well-known steepest descent method of optimization)
- A hybrid method consisting of backpropagation for the parameters associated with the input membership functions, and least squares estimation for the parameters associated with the output membership functions.

In this paper, the hybrid method of was used for updating the membership parameters and optimizing the system. It is worth mentioning that the fuzzy logic system was calibrated with many different forms of membership functions. These include Triangular (trimf), Trapezoidal (trapmf), Gaussian (gaussmf) and Gaussian 2 (gauss2mf) functions. The decision on which membership form to use was taken by estimating the sum of squares of errors (SSE) between observed data and estimated ones from the fuzzy logic. It was found that the Gaussian 2 membership function results in the least SSE value among the tested four different functions. The various forms were calibrated and optimized using the hybrid method of training. A Sugeno model was used as it is computationally efficient, works well with optimization techniques, and it results in guaranteed continuity of the output surface.

As indicated earlier, 60 rules were calibrated. The output variable (risk) was specified as a linear function of the inputs. The Sugeno model results in a number of rules equal to the multiplication of the number of terms in each input variable [$3*4*5 = 60$]. A total of 60 terms were calibrated for the output variable (risk). The output term of each rule corresponds to one discrete value. The result aggregation then accounts for all the discrete values of all the fired rules.

4 Conclusions

This research paper presents a fuzzy logic model that can be used to estimate the risks associated with deficiencies of management processes. The effectiveness of the management processes is treated herein subjectively with linguistic terms and linked to indicators that could be fairly assessed within the various involved stakeholders' organizations. For instance, communication effectiveness is assessed via indicators such as communication personnel, tools, the delegation of authority, etc. Coordination is assessed by indicators such as coordination mechanisms, coordination committees, etc. Decision making is assessed by speed and quality of decision-making, technical competency of involved staff, etc. Finally, knowledge sharing is evaluated by effectiveness of working in teams, and knowledge management systems.

Stakeholders such as clients could utilize this model to study the impact of enhancing the indicators of the communication, coordination, decision making and knowledge sharing. The study of such impact can be quite useful in selecting which areas could lead to a significant marginal reduction in risks. The presented system can also be used in selecting stakeholders by the clients or the sponsoring agencies. In selecting management firms, consultants or contractors, the clients may involve entities that would likely cause lesser risk impacts. Clients may use the system to select best stakeholders to involve in a project (e.g. select the most suitable consultant or contractor from a pool of potential ones). The selection will be based on the criterion of minimizing potential risks that can result from deficiencies of the management processes of the various stakeholders. Moreover, it can be applied through systems or specialized developed tools to enable the stakeholders screening. The clients can also use it to "rectify" deficiency areas or in the registration classification of the various projects, etc. We envision the presented system to be only one module of a large integrated system that combines other aspects of risks such as technical, financial, etc.

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