A Survey on Usage and Diffusion of Project Risk Management Techniques and Software Tools in the Construction Industry

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Muhammad Jamaluddin Thaheem and Alberto De Marco

***Abstract*—**The area of Project Risk Management (PRM) has been extensively researched, and the utilization of various tools and techniques for managing risk in several industries has been sufficiently reported. Formal and systematic PRM practices have been made available for the construction industry. Based on such body of knowledge, this paper tries to find out the global picture of PRM practices and approaches with the help of a survey to look into the usage of PRM techniques and diffusion of software tools, their level of maturity, and their usefulness in the construction sector. Results show that, despite existing techniques and tools, their usage is limited: software tools are used only by a minority of respondents and their cost is one of the largest hurdles in adoption. Finally, the paper provides some important guidelines for future research regarding quantitative risk analysis techniques and suggestions for PRM software tools development and improvement.

***Keywords*—**Construction industry, Project risk management, Software tools, Survey study.

I. Introduction And Motivation

RISK management must be a vital and significant concern to project managers as unmanaged or unmitigated risks are one of the primary causes of project failure [1]. Responding to the threat, the notion of PRM, as a derivative practice within the broad concepts of the risk management theory, is being recognized as a central and integral part of project management [2].

Today risk is considered to be a major factor influencing project success, and PRM is an important activity in any capital project [3]. Project Management Institute defines PRM as a subset of project management with four processes: risk identification, risk quantification, risk response development and risk control [4].

The literature considers a variety of qualitative and quantitative techniques to account for the risks in a project while focusing and explaining the functions of risk management and statistical methods. Along with these fundamental methods, various tools, combined with project management software, help to deal with a variety of typical operational problems of project management [1], [5].

Moreover, the software for PRM has served as a tool for analysts since the 1980s [6]. In many product and service trades, quantification and risk modeling have been used for promoting communication and risk planning among project teams [7].

Due to a high level of risks and uncertainties (that affects its projects); the construction industry is positioned to be an ideal environment for the diffusion and application of PRM techniques and software tools. Construction projects are reported to bear considerable, and at times unforeseen and unmanaged, cost and schedule variations [8]. Furthermore, the tendency to develop large-sized projects results with increased complexity, bundled with greater level of risk and uncertainty [9]. Also, the intricate nature of stakeholder relationships further stresses the need for affective risk management [10]. Therefore, the construction industry is well-positioned to benefit from exposure to PRM formal techniques and associated software. PRM software tools help in achieving quick and correct results, but their usage in the construction industry is limited, even though with high reported success rate [5].

There are a number of mature and established software tools in the market that might apply to construction risk practice; however, it is perceived that construction professionals are still seeking other viable techniques. This is probably affected by the shortage of literature supporting the development of commercial software tools and their testing has largely been limited to research only [11]. Despite the claim that PRM needs to be implemented in construction projects, risk management techniques are not practical and do not enhance the effectiveness of PRM as compared to current PRM software tools. In an attempt to explore the reasons and justifications for lesser diffusion of PRM techniques and related software tools in construction industry, the objective of this paper is to understand how risk is managed; which methods and techniques are used; what is the level of penetration of software tools; and how the monitoring and control activities are performed in the construction sector across the world. In order to obtain sizeable and considerable information regarding such critical queries, a survey was carried out that exclusively targeted management personnel working in construction industry in various areas, such as project management, finance, legal, claims and contracts, etc.

The next section discusses the rationale and importance of PRM in the construction industry. The approach and techniques of PRM are further defined in the successive section. Further, the software tools for PRM are elaborated.

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The adopted research methodology is then explained in detail followed by the results and findings of the survey. Finally, the research implications are discussed and conclusions drawn.

II. PRM in the Construction Industry

Risk-free construction projects are fictitious: regardless of their size and complexity, all construction projects involve risks with varying impacts [12]. New projects mostly excite the participants and they often enthusiastically underestimate the risk, probably based on the prior preparations and project management, which leads to an attitude of idealism. However, the construction rarely lives up to this in reality [13], as it is often a risky undertaking for all the stakeholders. Therefore, there is no way PRM can be overlooked because of its function of dealing with potential exposures [14]. Furthermore, its ultimate purpose is anticipation, mitigation or avoidance of risky situations. To accomplish this, project schedule, budget, cost or quality may be revised so that uncertainties can be reduced and the project objectives can be kept intact [15].

III. PRM Approach

In the literature, there are several approaches/ methodologies to manage risk and uncertainty in a project [16]. The Project Management Institute [4] has established an approach for risk management, which "includes the processes of conducting risk management planning, identification, analysis, response planning, and monitoring and control on a project".

The process begins with a general and global risk management plan, under which the policy and strategy of risk management for any given project are set out. Then comes the risk identification phase, which serves as an important step where threatening and/or profitable situations are determined and documented for further analysis. In order to investigate the significance and implications of identified risks, the PRM process divides the risk analysis phase into two steps: qualitative and quantitative analyses. Qualitative analysis is the process of prioritizing risks for further analysis or action by assessing and combining their probabilities of occurrence and impacts. Quantitative analysis is the process of numerically analyzing the effect of identified risks on overall project objectives. Then the risk response is planned where various options and actions are developed to enhance the opportunities and reduce the threats to project objectives. The PRM process, as a final phase, suggests the continuous monitoring and control of risk by executing risk response plans, tracking identified risks, monitoring residual risks, identifying new ones, and evaluating the effectiveness of the process throughout the project.

IV. PRM Techniques

There are several techniques available for the PRM process. Following is a proposed classification of various typologies as reported by the literature and field practice in many industries. The classification is further decomposed into the distinct categories of identification, qualitative or quantitative assessment, and monitoring/control techniques.

A. Risk Identification Techniques

The identification of risks allows risks and threats to surface before they become problems and have an adverse impact [17]. Structured documentation reviews, information gathering, checklists, assumptions analysis, and diagrams are some of the most used techniques to help identify risks [4]. The information gathering technique, Brainstorming, is focused on acquiring a detailed list of risks under the leadership of a facilitator [18]. The Delphi technique is a consensus developing technique; anonymous participation of project risk experts under a facilitator, who uses a questionnaire to implore ideas about the important project risks, takes place for identification of risky situations, and consensus on the main project risks is reached in a few rounds by circulating and commenting on the submitted responses [19]. Interviews of experienced project managers or subject matter experts are carried out for identifying project risks [20]. Considered risks are then examined in the analysis of strengths, weaknesses, opportunities, and threats (SWOT) [20]. Checklists also serve for risk identification and are quick and easy-to-use [21]. The assumptions analysis technique is employed for checking assumptions' validity [18].

Graphical diagrams are also valid techniques to support the process of risk identification. The cause-and-effect diagram is used to identify causes of risks in a project and the resulting effects. System or process flow charts allow showing the interrelation and interplay of various elements of a system. Influence diagrams help representing causal influences, time ordering of events and other relationships among variables and outcomes [20].

B. Qualitative Risk Analysis Techniques

Qualitative risk assessment techniques generally rely on probability assessment or on categorization, ranking of risks, and associated impacts. The risk probability and impact assessment technique uses ordinal dimensions ("high", "moderate", "low" etc) to qualitatively measure risk probability and consequences. Risk probability is the likelihood that a risk will occur. Risk consequences are the effects on the project's objectives if the risk event occurs. Risk analysis allows identifying the risks that require aggressive management [22]. Similarly, the probability/impact risk rating matrix assigns ratings ("low", "moderate", "high" etc) to risks or conditions [23].

Instead, risk can be categorized using a risk breakdown structures (RBS). Due to the nature and variability of individual construction projects, the development of a global RBS is impractical. Therefore, organizations develop their own customized versions based on different input information; such as project type, complexity, project drivers, etc. Specific RBSs may exist for large projects based on their size, scope, complexity and objectives [24].

Unbiased assumptions are always necessary for qualitative assessment of risks. Therefore, it is important to test the identified project assumptions against two criteria: stability of the assumption and the project consequences in case the assumption is false. Possibly true (or correct) alternative assumptions must be identified, along with their effect on project's objectives in the qualitative risk-analysis process [25]. A data precision ranking technique may be used to evaluate the validity of data and to help establish the usability of data. If a qualitative risk analysis is performed using low precision data where the risk is not very well understood, it may lead to less useful and reliable results [26].

C. Quantitative Risk Analysis Techniques

One of the analysis techniques to quantify the likelihood and effects of project objectives is interviewing. As a first step, an interview with project stakeholders and subject experts may be conducted. The probability distribution and statistics of the interview data may determine the degree of information that could be extracted. For instance, if triangular distributions are used, information would be gathered on the optimistic, pessimistic, and the most likely scenarios, or on mean and standard deviation for the normal and log-normal distributions [27]. Some risk practitioners estimate that the project manager might be able to identify 60-80% of foreseeable risks through use of a structured interview approach [23].

For performing quantitative risk analysis, continuous probabilistic distributions are commonly used. Distributions are graphically displayed and probability and time/cost elements are represented [28]. Continuous probability distributions include normal, log-normal, triangular, beta, and uniform distributions [25]. Expert judgment yields a single representation, leading to an aggregated probability distribution of an unknown quantity [29]. Experts from within or outside the organization may be consulted [18]. Sensitivity analysis is a quantitative risk analysis technique [30] which is used to measure and assess the potential impact of a risk event. It may be represented graphically using a tornado diagram [28]. Expected monetary value is a statistical technique for calculating the mean anticipated impact of the project's financial decision. It is the sum of the products of probability and impact of individual risks. Decision tree analysis portrays the risks as a tree with the leaves being events and the branches being their interconnections or consequences. Typically, a risky situation is characterized by variety of options, with each of them having a separate and often distinctive affect on the project. A tree is formed by plotting available choices starting on the left, with the risk decisions branching out to the right with the possible outcomes [31].

Modeling and simulation techniques are a type of quantitative risk analysis [31]. They are often used for schedule and cost risk analysis due to their regressive nature [32]. Project objectives can be observed and monitored with modeling by replicating the risk behavior and its impact. It involves interplay of various inputs and their driven calculations determining the probability distribution of any selected variable [31].

V. Software Tools for PRM

Research has mainly been concentrated on manual techniques, as evident from earlier sections. This has caused a void in the literature for software systems for PRM. A common feature of the majority of commercially distributed PRM software tools is their capability of enabling the building of complex risk models. The inputs are time and cost or other quantities along with corresponding probability distributions.

There are several quantitative risk analysis software products today that support risk modeling and risk estimating under the forms of spreadsheet adds-in or planning package adds-in. Enterprise risk management also suggests usage of technology and software tools [33].

Caldwell and Eid have attempted to assess vendors of risk management software associated with financial processes [34]. This assessment includes most of the vendors of commercially available tools. Also, there is a comparison of software tools for analyzing information security risks [35].

Further, for a review and analysis of commercially available software, it is recommended to read Diep's work [36] where he provides an extensive and informative market review and comparison between various PRM software tools.

It can also be argued here that recent work on assessing and comparing risk analysis and management software tools seems missing, giving rise to the need of more research and focus in this area.

VI. Research Methodology

Built upon a thorough literature review, this research aims at understanding the degree of acceptance, penetration and usage of the PRM process, techniques and software in the construction sector.

The general methodology of this study relies on a survey carried out targeting the construction management professionals internationally. One of the main research objectives is to know which tools, among the ones available, are currently used in the construction industry by the majority of practitioners. As mentioned earlier, the basic theoretical framework followed is PMI [4], [25], which identifies the tools and techniques for each one of the PRM processes.

A structured questionnaire methodology is adopted for this research as mentioned in the following sections.

A. Submission of Questionnaire

The questionnaire was divided into three sections: Section 1 – Background Information, Section 2 – Risk Management Processes, and Section 3 – Software Tools. The request to participate was done using a letter of invitation, stating the objectives and scope of research. The questionnaire was designed in order to require suitable time to be completed. For practical purposes, participation in Section 1 was voluntary and it was presented at the end of the survey in order to encourage data collection without asking the participants for personal details.

Section 2 concentrated on collection of participant responses regarding the PRM process. In this section, an assessment of the current tools and techniques used by participants was carried out covering all the steps of the risk management process.

Section 3 of the questionnaire focused on professionals who use software tools for PRM. Starting from the type of input to the level of pre-processing required for them, questions in this part centered on the software tools, their usability and the output received from them. In particular, the respondents were required to respond according to the Likert scale of 1-5 for the attributes and functions of the software tools.

For the group of professionals who did not use software tools, reason(s) were asked to help software vendors tracking the needs of risk management professionals as potential software adopters.

The survey was in English, to be answered on-line through a 24-hour accessible website without time limits for responding.

It was assumed that professionals may use multiple techniques and in order to capture the real image, respondents were allowed to select multiple responses, raising the total percentages over 100%. As the survey focused on both the users and non-users of software tools, heuristics provided by the online data collection tool took the participants to appropriate questions/pages based on their preceding choice of yes or no.

B. Selection of the Sample Size

A critical aspect for the research to be reliable is the selection of an appropriate and adequate sample size of survey respondents [37].The sample size in this research is based on the procedures for categorical variables using Cochran's equation [38], which yields a minimum sample size of 267 respondents. As a total of 271 respondents participated in this survey, it can be deducted that the sample is significantly representative.

C. Selection of Survey Group

The selection of a survey group is a big step as the goal is to reach the practitioners and professionals of construction project risk management at a wider global level. Since there may exist an unlimited and unknown population of professionals working with PRM in the construction industry, selection of respondents was difficult. But due to online professional communities at LinkedIn®, the selection of respondents became easy. LinkedIn® operates the world's largest professional network on the Internet with more than 100 million members in over 200 countries and territories. This provides the opportunity to contact construction risk management professionals in any country across the world. Furthermore, there are specialized interest groups in this online community of professionals and keeping in view the requirements of this research, the groups selected for participating in the survey were "Contract Risk Management Group-Construction Industry" and "Construction Risk Management Group". The participants in these groups belonged to all parts of the construction industry: contractors, vendors, consultants, architects, engineers and owners.

VII. Survey Results

This section highlights the findings of research; it demonstrates the analysis performed on collected data and the obtained results. The survey has been responded by a total of 271 respondents, from 56 countries which were grouped in regions: America, Europe, and Australia-Asia-Africa. The higher portion of the sample corresponds to the segments of Australia-Asia-Africa with 39% respondents. 33% participants from America and 24% from Europe also participated. In terms of countries, the highest number (66) of respondents was from USA.

A. Risk Management Process

Survey results show that PMI [4], [25] standard tools and techniques are employed by respondents to a large extent, along with some custom/proprietary tools. As mentioned earlier, the total percentage exceeds 100% to find out if practitioners are in the habit of using multiple tools and techniques.

1. Risk Identification Techniques

The results show that 72% of respondents identify risks through "Documentation review", 64% through "Brainstorming" and 48% through "Checklist Analysis", as shown in Fig. 1. The established trend of risk taxonomies in construction industry can be attributed to high usage of documentation review and checklist analysis techniques. Also, the human interaction (brainstorming) is affective in identifying risks. On the other hand, Influence Diagrams, Delphi Technique and Ishikawa Diagram, probably based on their complexity, scored as the least (6%) used risk identification techniques. It can be argued here that construction industry professionals look for easier and affective techniques.

Apart from standard techniques, various new techniques were mentioned by respondents, such as "HAZOPS", "FMECA", "HLRA's", "Client risk", "Experience", "Physical inspections", "Risk surveys", "Dynamic risk assessments", "On-site inspection", "Analogous data analysis" and "Cost control tracking system".

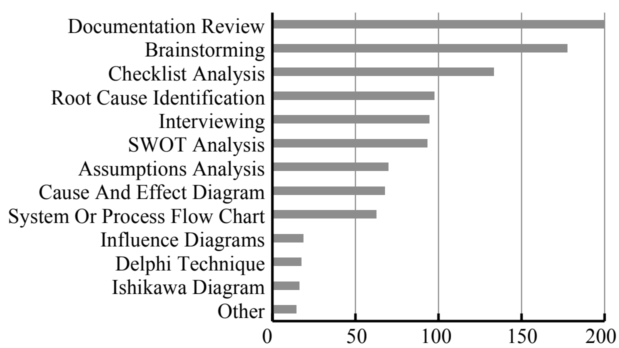

Fig. 1 Risk identification tools and techniques

2. Qualitative Risk Analysis Techniques

It is found that 66% of respondents use "Risk Probability and Impact Assessment" for qualitative risk analysis, 49% use

"Risk categorization" and 35% use "Probability and Impact Matrix", as shown in Fig. 2. The rationale of this phenomenon is probably based on the fact that since very beginning, the risks are associated with their probabilities of occurrence and resulting impacts, therefore, it is more natural and fluid that practitioners assess risk probabilities and impacts in the early stages.

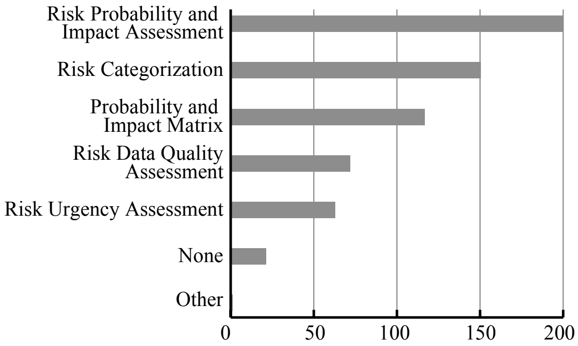

Fig. 2 Qualitative risk analysis techniques

3. Quantitative Risk Analysis Techniques

Survey results suggest that 64% of respondents use "Expert Judgment" and 44% use "Interviewing" for quantitative risk analysis. Techniques more quantitative in nature, such as Expected Monetary Value, Modeling and Simulations, Sensitivity Analysis, Probability Distributions etc, are found to be diffused less (on average, these are used by 30% respondents).

It can be argued here that more complex quantitative techniques are not highly utilized and therefore convenient techniques (such as expert judgment and interviewing) find their way in highly utilized techniques.

Also, respondents suggest "Brainstorming" as a technique for Quantitative Analysis. Also, 2% respondents don't use any quantitative risk analysis techniques, as shown in Fig. 3.

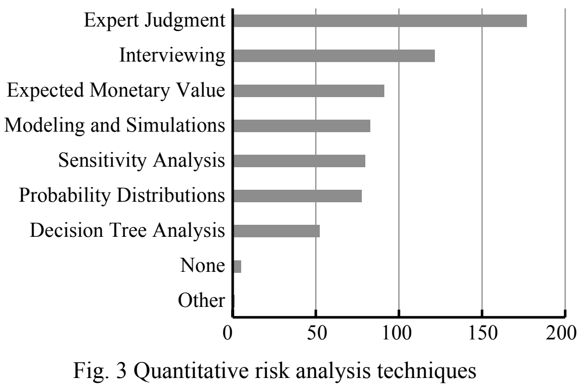

Fig. 3 Quantitative risk analysis techniques

4. Risk Monitoring and Control Techniques

Results suggest that 76% of respondents use "Status meeting" and 51% use "Project Risk Response Audits" techniques to monitor and control the risk, as shown in Fig. 4. The affectivity of direct human interaction is established once again here as the most used monitoring and control technique is to conduct status meeting.

Some new techniques are also reported by respondents, such as "Tracking by risk department", "Other case studies", "Decision analysis based on quantitative risk analysis outputs", "Incident investigation", "Safety & loss control review" and "Periodic risk register review".

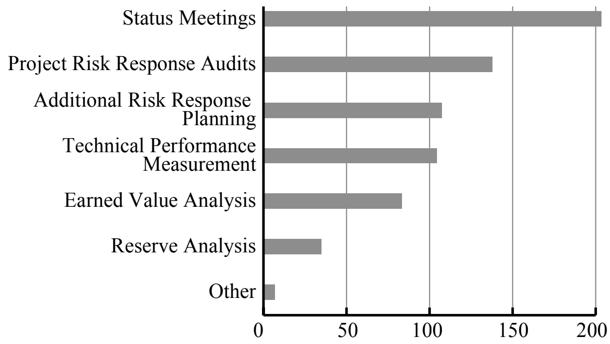

Fig. 4 Risk monitoring and control techniques

B. PRM Software Tools

Contrary to our perception, the survey results show that only 21% of the participants use software tools for PRM, the remaining majority of 79% participants don't use these tools due to reported reasons. The region-wide distribution of those 21% (57 out of 271) respondents shows that the UK leads the list with 26.3% of users, followed by US with 15.7% users.

The tool @Risk can be considered as industry-leader amongst the respondents, based on its 42% (24 users) share, followed by Risk+ with 32% (18 users) share, as shown in Fig. 5. A number of software tools were reported by respondents in "Other" category, such as "ViewPoint", "Primavera Risk Analysis" (formerly Pertmaster), "Predict QRA Analysis", "PHA Pro", "ERA Methodware", "RiskAid", "RIS3" and proprietary tools developed in-house.

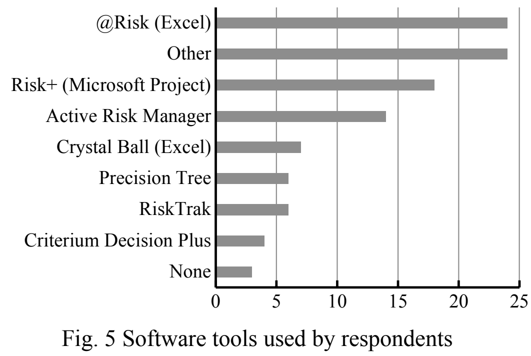

Fig. 5 Software tools used by respondents

For input, 81% users of these tools feed in "Risk register" as input, followed by "Project cost management plan" (60%), "Risk database" (58%) and "Project schedule management plan" (53%). It is also remarkable to observe that these tools take variety of input details (mostly due to their focused usage) and the respondents must really have to know and prepare in advance for being able to successfully use them.

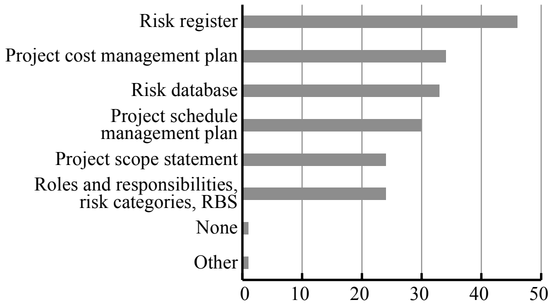

Fig. 6 Input to software tools

Survey results also report that the data input needs to be pre-processed to a *'medium'* level before being fed into the software tool, representing 53% of the total users, followed by *'high'* level of pre-processing, representing 26.31% respondents. This, in turn, shifts some significant amount of work for manual performance, diminishing the productivity of these tools.

A considerable majority of survey respondents (65%) report "Prioritized list of quantified risks" and "Probability of achieving cost and time objectives", followed by "Probabilistic analysis of the project" (44%) as the sort of output received from the software tools, as shown in Fig. 7. Here as well, it is important to underline that these tools have no uniformity of output details, and based on the type of input and the processing algorithm, the type of results vary.

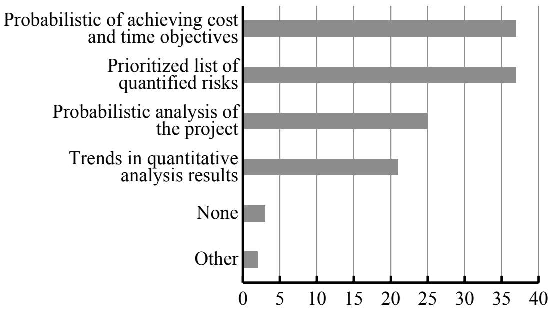

Fig. 7 Output from software tools

Also, the output received from software tools is not readily understandable and presentable, but needs to be further worked upon. A majority of respondents (68%) report such a post-processing of output is needed, whereas 32% report no post-processing. Yet again, the productivity of these tools is challenged by the fact that the semi-processed results are further post-processed by manual performance and this may surely affect the overall results.

Apart from the minority of software users amongst the respondents, those who don't use these tools report three main reasons; "cost of purchasing, maintaining and usage of software tools" (39%), "in-sufficient tailoring for business" (35%), and "lack of product knowledge" (29%), among others for not using software, as shown in Fig. 8. Apparently the market logic for investing in these tools is not sufficient; i.e. the cost savings realized from better risk management does not warrant the investment. Therefore, it motivates the software vendors to take into account the needs and limitations of construction industry and supply them with tools which are easy to use and operate, and are cost-effective as well.

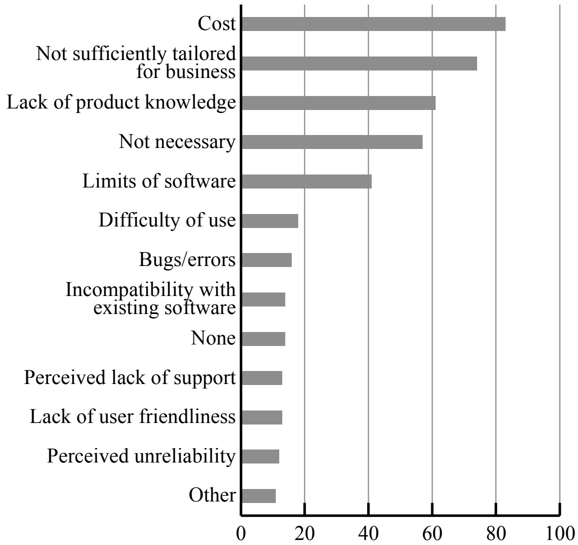

Fig. 8 Causes for not using software tools

C. Assessment of PRM Software Tools

1. Attributes of Software Tools/ Add-Ins

Respondents were also asked to provide the quantitative scoring for various attributes of software tools/add-ins. Table I lists these attributes along with the average scores and the standard deviations. "Usability/user friendliness", as evident from previous results, is marked as the most important attribute by the respondents, followed by the "Ability to customize" with a mean of 3.9. But also, the "Technical support" and "Cost" have been given their fair share of importance. So, it is safe to state that PRM software in construction industry is not only hurdled by their cost but also due to lack of their knowledge and technical support amongst the practitioners.

TABLE I
IMPORTANCE OF ATTRIBUTES OF SOFTWARE TOOLS/ADD-INS

Function	Mean	St. D.
Risk treatment management	4.2	0.7
Probability simulation	4.1	1.0
Reporting	4.0	0.7
Risk/treatment database	4.0	0.8
Importability / exportability to PM software	4.0	1.1
Risk treatment management	4.2	0.7

2. Functions of Software Tools/Add-Ins

The most important software features are found as "Risk treatment management", with a mean value of 4.2 (out of 5) followed by "Probability simulation", with a mean of 4.1, as shown in Table II. It is also identified that even though the main objective of software tools is to calculate the probability of an event to occur, the users do give importance to practical knowledge for dealing with risks.

TABLE II
IMPORTANCE OF ATTRIBUTES OF SOFTWARE TOOLS/ADD-INS

Attribute	Mean	St. D.
Usability/user friendliness	4.4	0.8
Ability to customize	3.9	1.1
Extended functionality /variety of functions	3.8	0.9
Technical support	3.8	1.1
Cost	3.8	1.1
compatibility with other programs	3.7	1.2

VIII. DISCUSSION, IMPLICATIONS AND CONCLUSION

Based on the participation of various PRM practitioners, the survey reveals the status of the PRM practice in the construction industry of 56 surveyed countries, along with the usage of various techniques and software tools. Results show that only 21% of respondents indicate the use of software tools for managing project risks. It was further observed that the cost of the software solutions is the largest barrier of implementation. Additionally, PRM software tools do not necessarily help the professional to the fullest: ranging from medium-to-high pre-processing and high post-processing, the survey observes that software tools may not be fully mature and thus their functionally may not be as robust as expected. It is also deduced from the survey results that there is still a high level of informality in the way professionals deal with the PRM process, depending upon the cost-quality-time tradeoff.

Project success may greatly be enhanced by a successful and effective PRM approach [1]. Interpreting the results, it is perceived that either the complexity or lack of techniques and product knowledge motivate the global construction industry to use more qualitative and easily performable techniques. In turn, this reduces the efficiency of PRM process and, in spite of frequent risk management, the industry still faces uncertainties and the upsets occur.

The implications guide future research in the area of quantitative techniques, which may prove to be efficient as well as convenient for PRM professionals as almost all the PRM approaches suggest various processes and methods for analysis and management of project risk [39]. This paper may also prove to be a guide for PRM software vendors as the survey brings out some surprising findings with special regard to the lack of penetration and usage of software tools. Therefore, there is a need for exploring and improving upon the reasons and justifications for such a phenomenon. The survey results suggest that cost, sufficient tailoring of software tools and ease of gaining product knowledge are the main hindrances faced by a majority of professionals for not utilizing them. It may also be suggested to the designers and producers of such tools to improve the efficiency of tools because, as was reported by the survey respondents, the tools still perform a minimal amount of work and pre and post processing are usually required

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