Customized risk assessment in military shipbuilding

José Crispim* [a,b], Jorge Fernandes[a,c], and Nazaré Rego[a,b]

* correspondence author: crispim@eeg.uminho.pt

[a]*Escola de Economia e Gestão, Universidade do Minho, Campus de Gualtar, 4710-057 Braga, Portugal*
[b]*INESC TEC, Campus da FEUP, Rua Dr. Roberto Frias, 4200-465 Porto, Portugal*
[c]*Brazilian Navy, COrM, Esplanada dos Ministérios, Brasília. 70.055-900, Brazil*

Customized risk assessment in military shipbuilding

Abstract

This paper describes a customized risk assessment framework to be applied in military shipbuilding projects. The framework incorporates the Delphi method with visual diagrams, Bayesian Networks (BN) and the expression of expert opinions through linguistic variables. Noisy-OR and Leak Canonical models are used to determine the conditional probabilities of the BN model. The approach can easily be adapted for other shipbuilding construction projects. The visual diagrams that support the Delphi questionnaire favor the comprehensive visualization of the interdependencies between risks, causes, risks and causes, and risks and effects. The applicability of the framework is illustrated through the assessment of risk of two real military shipbuilding projects. This assessment includes a sensitivity analysis that is useful to prioritize mitigation actions. In the two cases studies, the risks with higher probability of occurrence were failures or errors in production, of the contracted, in the requirements, and in planning. The results of the sensitivity analysis showed that a set of mitigation actions directed at relatively easily controllable causes would have achieved important reductions in risk probabilities.

Highlights:

- The proposed framework for risk assessment is customizable.

- The visual diagrams that support Delphi ease the design of the risk network.

- The use of Bayesian Network provides quantitative measures of risk.

- Leaky Noisy-OR is used to decrease the effort of expert opinion elicitation.

- The application to two real projects shows the suitability of the framework.

1. Introduction

Military shipbuilding projects in private shipyards in Brazil have repeatedly been affected by problems related to delivery delays and increased costs. The literature has shown that insufficient risk management has contributed to project delays and cost overruns [1], therefore, the lack of a formal risk management plan for military shipbuilding projects may have contributed to such occurrences.

It is expected that several ships for the Brazilian Navy are constructed in domestic shipyards in the coming years, which increases the need for the design and improvement of processes to manage the risks of related projects. Kwak and Smith [1] identified a lack of studies about risk management practices for defense projects. This research confirms that the situation persists since only two articles addressing risk issues in military shipbuilding projects were found [2, 3]. This study contributes to narrow this gap by proposing a customized risk assessment framework that comprises the main risks, their cause and effect relations, and a network that shows the interactions between these variables in a military shipbuilding context.

Risk assessment measures risks and identifies the effects of hazardous events on a project or organization and integrates three main processes: risk identification, risk analysis, and risk evaluation [4]. Risk identification is the most important element of the whole risk management process [5].

However, it is normally difficult to identify risks because of the limited knowledge about factors that can cause failures and the high interaction between those factors. In military contexts, the difficulty increases because risk information is usually scarce and restricted. Databases can function as bodies of knowledge in organizations where information about risks and subsequent actions from previous projects can be continuously recorded to be reused when new projects are developed. However, in this work, their use is limited for the reasons pointed out in the literature: 1) generally, the knowledge captured about past projects is organized around single facts, without information about the causes, conditions (risk factors), and possible interactions related to the failure events [6]; and 2) military shipbuilding projects are very dependent on technology and, consequently, their environment and associated risks are continuously evolving [7]. Moreover, in the case of the Navy of Brazil, databases that comprehensively integrate risk related knowledge did not exist at the time of the study and other instruments had to be used to collect information about risks. *Expert opinion interviews* are commonly used to collect this type of information [see e.g., 4, 8].

In the military arena, knowing the hierarchy of a participant may inhibit the opinion of others, especially those from lower ranks. Therefore, in this study, it was essential to preserve the anonymity of the experts since the early stages of the research. The Delphi method is a formal communication technique that guarantees the required anonymity and confidentiality.

Risk as a numerical quantity is useful for risk prevention and for prioritizing mitigation measures, therefore risk assessment should be considered as a tool for rational decision making [9]. In line with this idea, our approach to risk assessment is quantitative although limited by the data availability conditions of the organization.

The complexity of defense projects results in a network of interdependent risks: a risk in an "upstream" activity can trigger several risks "downstream", and a risk in a "downstream" activity may emerge from the combined occurrence of several risks located "upstream" [10]. The questionnaire developed is supported by visual diagrams because it was impossible to show the interdependencies between risks only through word questions. This approach eases the understanding of interrelationships by the experts and the customization of the risk network structure for specific projects. Bayesian Networks (BN) are used as a method of representation that is closer to the complex reality and the dynamics of risks in different types of projects [11]. They are suitable for knowledge representation and reasoning [12] and to deal with uncertain information in complex environments [13].

To show the functionality of the framework, a risk evaluation based on BN for two shipbuilding projects of the Navy of Brazil was performed. The HUGIN Expert software was used to build and run the BN. This software facilitates visual BN model formulation, reasoning, and decision making. The determination of the probabilities of occurrence of the identified risk events can help the decision maker develop mitigation actions to decrease those probabilities and hence the correspondent risks (e.g., delivery delays or budget slippage).

2. Literature review

There is limited research about risk assessment in shipbuilding and even less in military shipbuilding projects. Most of the studies assess risks only qualitatively.

Queiroz [14] reviewed the literature and used the risks identified as a starting point for brainstorming sessions in order to obtain list of risks suitable for Brazilian shipbuilding. Pires Jr. et al. [15] and Ferreira et al. [16] used brainstorming and Delphi to develop risk matrixes to assess risk in Brazilian shipyards. Kochetkov and Aliev [17] also created a risk matrix (through the analysis of statistical data) to compare the probability of undesirable results and the extent of possible damages in the shipbuilding and ship repair industry in Latvia. Jacinto and Silva [18] use the bow-tie model for risk identification and a classical risk-matrix approach to assess risk of a Portuguese shipyard qualitatively. Christiansen and Thrane [2] used interviews and risk report analysis to study how managers translate emerging risks into reported risks in the acquisition of military ships. Only Lee et al. [19], Basuki et al. [20], Fragiadakis et al. [21], Iwańkowicz and Rosochacki [22], and Sokri and Ghanmi [3] applied quantitative approaches in risk assessment of military shipbuilding. Lee et al. [19] developed a Bayesian Belief Network based on information collected through a survey to 250 experts of the eleven major Korean shipbuilding companies. Basuki et al. [20] developed a risk assessment method using probabilistic value at risk in each production subprocess (design, material procurement, production) to control the production of fast patrol vessels in Indonesia. Fragiadakis et al. [21] applied an adaptive neuro-fuzzy inference system to predict the effect of working conditions on occupational injury in Greek ship repair yards. Iwańkowicz and Rosochacki [22] used clustering and simulation and the accidents database of a Polish shipyard to predict shipbuilding risks related to the health and life of workers. Sokri and Ghanmi [3] developed a hybrid method that combines a learning curve model with stochastic simulation to estimate the probability distribution of the project labor cost.

A systematic literature review to identify possible risks and their causes, and risk assessment methods in related contexts (shipbuilding, defense, construction, and development and integration of technological systems) was carried out by searching referential databases, namely, EBESCO, Scopus, and Google Scholar, using combinations of appropriate search words: [(*shipbuilding* OR *construction*) AND *risk*], [(*systems development* OR *systems integration*) AND *risk management*], [(*defense* OR *defence* OR *military*) AND *project* AND *risk management*], and (*risk assessment* AND *project management*). The area of integration of technological systems was included because military shipbuilding projects have a strong technological component. Except for shipbuilding, an area where a small number of articles was identified, the search was limited to the last eight years (2010 and afterwards). Additionally, we considered risk related documents collected from the websites of the Departments of Defense of Australia and the United Kingdom.

As a result of skimming through the documents pre-identified, 78 were selected due to their relevance for the study (Table 1), resulting in the identification of 89 risks, causes and effects, and 18 different assessment techniques and methods (normally combined in hybrid approaches). For risk identification, the most used source of information has been the opinion of experts, collected by interviews, questionnaires, brainstorming or Delphi. Historical data was used in six works, in conjunction with expert opinion in two of them. This evidence shows that databases with information about previous projects are scarce. Project managers are usually the keepers of information about past experiences. This is the case in a military context since information may be classified as confidential.

In terms of analysis and evaluation methods, traditional techniques (i.e., matrix of probability and impact or probability index, impact index for time, impact index for cost, and weighted risk factor) are still being used because of their simplicity, although they have often been criticized. Thomas et al. [23] argue that, despite being intuitive and simple, there is no empirical evidence showing that the risk matrix actually improves risk management or the outcomes of decision making. Failure Mode and Effect Analysis has also been criticized. For example, Zhang and Chu [24] claim that different combinations of occurrence, severity and detection may result in the same risk priority value, while the hidden risk implications of these sets may be totally different. Fuzzy logic, combined with other techniques (for example, AHP or TOPSIS) has been the most used evaluation method, since it is tolerant to imprecision when modelling uncertainty. AHP has been the second most used technique, but it can be time consuming and tedious if the decision hierarchy has many levels. BN, alone or combined with other methods, are a very flexible method that can be used to [25]: 1) model uncertainties and provide probabilistic estimates; 2) combine historical data with specialized experience or prior knowledge; 3) show visual cause-effect relationships (which provide explicit knowledge for risk analysis and planning); 4) perform "what-if" analysis in order to explore the effect of changes made in specific nodes of the network on other nodes; and 5) develop sensitivity analysis, diagnosis, prediction, classification and causal reasoning.

BN depend on databases or experts' elicitation for model construction and parameterization. When databases exist, large number of data points are available; if not, the large number of conditional probability entries put a great workload on the experts and pose challenges to the quality or consistency of the elicited result [26]. Therefore, as Pourreza et al. [27] recognize, new methods for experts' knowledge elicitation should be developed and applied to improve the model validity. Canonical models (like OR, AND, Noisy-OR and Leaky Noisy-OR) can be used to overcome this situation. Although a canonical model reduces significantly the work of the experts and contributes to improve consistency during the BN model parameterization process [26], in a military context, only Louvieris et al. [28] used this kind of approach (Noisy-OR). In other areas, the use of BN with Noisy-OR has been more common, e.g., in the energy sector [e.g., 27], railway infrastructures [e.g., 29], new product development [e.g., 30], and Human Reliability Analysis [e.g., 31].

Table 1 – Risk assessment methods

Studies	Year	Area	Risk identification	Risk analysis & evaluation
Abdul-Rahman et al. [32]	2013	Construction	Expert opinion	Fuzzy-AHP
Aliahmadi et al. [33]	2011	Construction	Expert opinion	Fuzzy AHP & game theory
Badri et al. [34]	2012	Healthcare and safety	Expert opinion	AHP
Barlas [35]	2012	Shipbuilding	Historical data	-
Barney [36]	1986	Defense (acquisitions)	Historical data	-
Basuki et al. [20]	2014	Shipbuilding	Historical data	BN
Bennet [37]	2010	Defense	Expert opinion	-
Büyüközkan and Ruan [38]	2010	Software	Expert opinion	Choquet Integral
Camastra et al. [39]	2015	Genetic engineering	Brainstorming with expert	Fuzzy Logic
Carbonara et al. [40]	2015	Construction	Delphi	Matrix of Probability and Impact
Cárdenas et al. [41]	2013	Construction	Questionnaires to workers	BN
Chan et al. [42]	2011	Construction	Expert opinion	Matrix of Probability and Impact
Cheng and Lu [43]	2015	Construction	Delphi	Fuzzy FMEA
Christiansen and Thrane [2]	2014	Shipbuilding	Expert opinion	Risk report analysis
Creemers et al. [44]	2014	General	Fictional data	Ranking Index
Del Águila and Del Sagrado [45]	2011	Software	Historical data	BN
Felderer and Ramler [46]	2014	Software	Risk test reports	-
Fragiadakis et al. [21]	2014	Shipbuilding	Historical data	Adaptive neuro-fuzzy inference system
Ferreira et al. [16]	2018	Shipbuilding	Literature	Qualitative
Hashemi et al. [47]	2013	Port Projects	Expert opinion	Nonparametric Bootstrap Method
Hsueh et al. [48]	2013	Construction	Delphi	Fuzzy Logic and AHP
Hu et al. [25]	2013	Software	Expert opinion	BN
Hung et al. [49]	2014	Software	Survey & Interviews	-
Iden et al. [50]	2011	Information systems	Delphi	-
Iwańkowicz and Rosochacki [22]	2014	Shipbuilding	Historical data	Clustering, FMEA & simulation
Issa et al. [51]	2015	Construction	Delphi	Probability Index, Impact Index & Weighted Risk Factor
Jacinto and Silva [18]	2010	Shipbuilding	Historical data	Matrix of Probability and Impact
Jitao et al. [52]	2010	Innovation	Questionnaires to managers	AHP
Jozi et al. [53]	2015	Construction	Delphi	AHP with TOPSIS
Karim et al. [54]	2012	Construction	Expert opinion	Relative Important index
Kochetkov and Aliev [17]	2016	Shipbuilding	Expert opinion	Qualitative
Kuo and Lu [55]	2013	Construction	Expert opinion	Consistent Fuzzy Preference Relations
Lee et al. [19]	2009	Shipbuilding	Survey	BBN
Li and Zou [56]	2011	Construction	Expert opinion	Fuzzy Logic with AHP
Li et al. [57]	2013	Construction	Expert opinion	Fuzzy-AHP
Liu and Tsai [58]	2012	Construction	Expert opinion	QFD, Fuzzy ANP & Fuzzy-FMEA
Liu et al. [59]	2011	Construction	Fictional data	Fuzzy-AHP
Lu et al. [60]	2010	IT	Expert opinion	Evidential Theory
Manalif et al. [61]	2012	Software	Expert opinion	Fuzzy Logic
Marcelino-Sádaba et al. [5]	2014	SMEs projects	Expert opinion	FMEA
Meier [62]	2010	Defense	Historical Data	-
Mostafavi and Karamouz [63]	2010	General	Expert opinion	Fuzzy Logic with TOPSIS
Mousavi et al. [64]	2011	Construction	Brainstorming, Historical data & Expert opinion	Nonparametric Bootstrap Method
Murphy et al. [65]	2015	Construction	Delphi	FMEA
Neves et al. [66]	2014	Software	Interviews & Document analysis	-
Nieto-Morote and Ruz-Vila [67]	2011	Construction	Expert opinion	Fuzzy Logic & AHP
Peibin et al. [68]	2012	Oil industry	Delphi	Fuzzy Logic & AHP
Perera et al. [69]	2014	Construction	Delphi	AHP
Pinto, Nunes [70]	2010	Construction	Fictional Data	Fuzzy Logic
Pires Jr. et al. [15]	2010	Shipbuilding	Brainstorming	Matrix of Probability and Impact (using Delphi)
Queiroz [14]	2012	Shipbuilding	Literature	AHP
Rodger et al. [71]	2014	Defense	Expert opinion	Fuzzy logic
Shi et al. [72]	2014	Construction	Expert opinion	Fuzzy Logic & DEA
Sokri and Ghanmi [3]	2017	Defense	-	Learning curve
Tang and Wang [73]	2010	Software	Expert opinion	Fuzzy Logic
Taylan et al. [74]	2014	Construction	Expert opinion	Fuzzy Logic, AHP & TOPSIS
Venkatesh et al. [75]	2015	Supply chain	Delphi	ISM with Fuzzy Logic
Wan et al. [76]	2013	Software	Interviews	-

Wang et al. [77]	2011	Fire at sea case study	Historical data & Expert opinion	Fuzzy Fault tree analysis & BN
Wu et al. [4]	2015	Shipbuilding	Expert opinion	Interpretive Structural Modelling - ISM & BN
Xiao et al. [78]	2011	Software	-	Multiple FMA & Weighted Risk Priority
Xu et al. [79]	2010	Construction	Delphi	Fuzzy Synthetic Evaluation
Bi and Wang [80]	2011	Construction	Expert opinion	Fuzzy Entropy
Yang and Zou [81]	2014	Construction	Interviews with stakeholders	Social Network Analysis
Yao et al. [82]	2009	Shipbuilding	Expert opinion	AHP
Yazdani-Chamzini [83]	2014	Construction	Expert opinion	Fuzzy Logic
Yu et al. [84]	2013	IT & Software	Interviews with managers	-
Yu and Lee [85]	2012	Construction	Expert opinion	Fuzzy-FMEA
Zacharias et al. [86]	2014	Large projects	Workshop with experts	Fuzzy Logic
Zeng et al. [87]	2010	Construction	Expert opinion	FMEA
Zhang and Li [88]	2011	Construction	Historical data & Expert opinion	Fuzzy Logic
Zhang at al. [89]	2013	Hydroelectric	Expert opinion	Interval AHP & TOPSIS
Zhang at al. [13]	2016	Construction	Interviews with experts	BN and Fuzzy logic
Zhao et al. [90]	2010	Construction	Delphi	Matrix of Probability and Impact
Zhao et al. [91]	2013	Joint Ventures	Questionnaires to managers	Risk Criticality index
Zhou and Fang [92]	2010	Construction	Historical data	Fuzzy Influence Diagram
Zhou and Zhang [93]	2011	Construction	Historical data & Expert opinion	Fuzzy Logic & BN
Zou and Li [94]	2010	Construction	Expert opinion	Fuzzy Logic & AHP

3. Proposed framework

The risk assessment framework proposed incorporates several methods (explained in detail in the next subsections). Figure 1 displays its main steps: 1) a literature review to identify (and contextually adapt) an initial list of risks, causes and related effects; 2) the selection of the two panels of experts: the first to adapt the framework to the context of problem under analysis, and the second to operationalize and control the application of the framework; 3) the application of the Delphi method (with the participation of the first panel) to create a network of risk events; 4) the assessment of the risks, i.e., assigning and confirming risk events probabilities (by the second panel); and 5) simulation and ranking of mitigation actions (also with the participation of the second panel).

3.1. Delphi method

The Delphi method is a formal communication technique designed to obtain the maximum number of unbiased opinions from a panel of experts [51]. The iterative nature of the procedure generates new information in each round, allowing the appraisers to modify their assessments and to project them beyond their own subjective opinions [95]. Typically, the interaction between the Delphi administrator and the members of the panel occurs through questionnaires. Our questionnaire is based on interrelationship diagrams representing causes, risks and effects identified in the literature. These diagrams facilitate: a) the construction of the network (the experts can easily add/delete nodes and edges), and b) the expression of the level of importance of each risk event and/or of the relationships between risks.

The application of the Delphi method involves three critical steps: i) selection of the number and profile of the participants; ii) method to obtain consensus; iii) number of rounds.
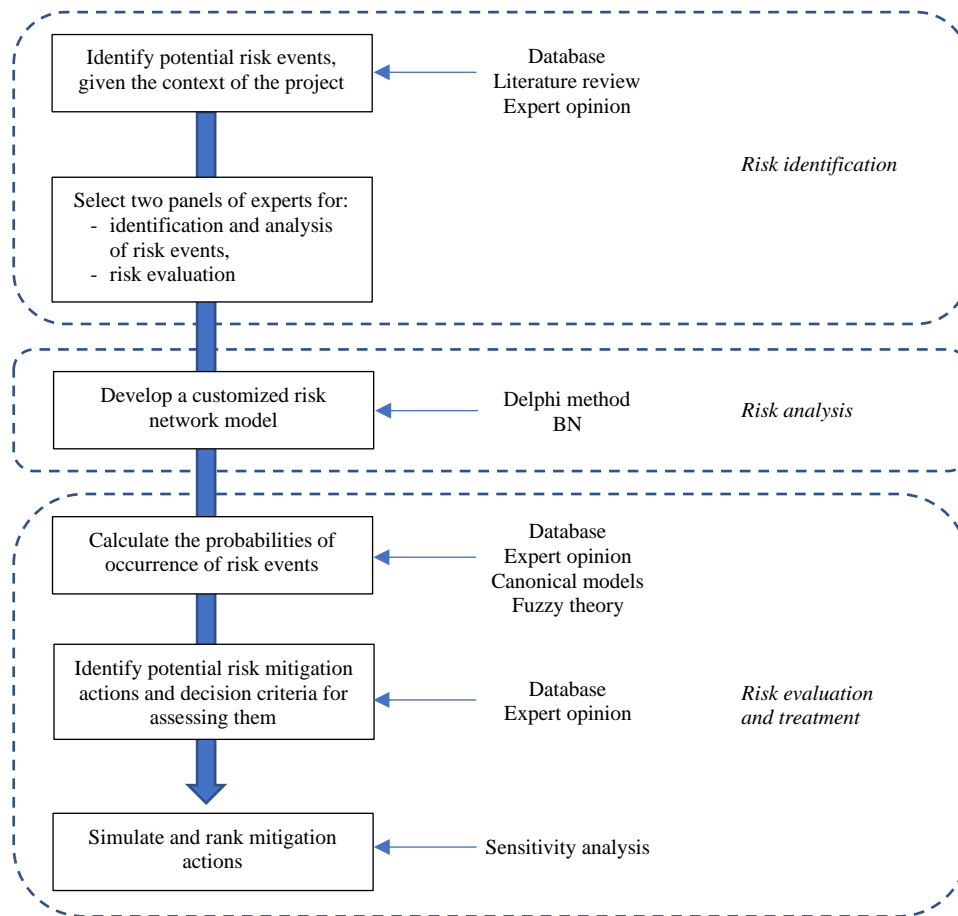
Fig. 1 – Risk assessment framework

Number and profile of the participants

The ideal size of a Delphi panel does not depend on statistical power but rather on the group dynamics for achieving consensus; thus, 10 to 20 experts have been recommended [96]. This study had the participation of 17 experts from the Navy of Brazil.

The profile of the experts is directly related to the validity of the study [79]. In project risk contexts, a minimum experience time or the participation in a minimum number of projects have frequently been considered as selection criteria [see e.g., 43, 48, 53, 65, 68, 75, 79, 90, 97]. At the time of their participation in this study, the experts had a minimum of five years of experience in, at least, one of the following functions in a military shipbuilding context: shipbuilding supervision, member of management team, naval systems expert, project manager or advisor. Furthermore, they had participated in, at least, three military shipbuilding projects. The profile of the participants selected (first panel) is detailed in Table 2.

Table 2 – Profile of the respondents (first panel)

Type of expertize			Number	%
Area of study		Naval Sciences	4	24%
		Management / Economics	2	12%
		Accounting	1	6%
	Engineering	Electrical	2	12%
		Chemistry	1	6%
		Systems	3	18%
		Mechanical	1	6%
		Naval	3	18%
Academic qualifications		Graduation	1	6%
		Specialization	3	18%
		Master	9	53%
		PhD	4	24%
Experience in shipbuilding projects	Years	5 to 10	12	71%
		More than 10	5	29%
	Number of projects	3 to 5	14	82%
		More than 5	3	18%
Main area of operation		Project Managers	4	24%
		Consultancy / Supervision	4	24%
		Big Project teams	4	24%
		Naval Systems	5	29%

Measurement of consensus and number of rounds

There is still no unanimous way to measure consensus in Delphi studies [98]. The following have been used for this purpose: the percentage of agreement [e.g., 40, 51], the stability of the responses in two successive rounds [e.g., 65, 99], and associations of central tendency and dispersion measures [e.g., 69, 100]. Consensus criteria, such as the median and interquartile range (IQR), have been widely used in other fields (e.g., corporate governance and information technology) [101, 102]. Another widely recognized metric is Kendall's coefficient of concordance (W) [96], an inferential statistical measure that can be used to estimate agreement between raters [98]. This metric determines if any consensus has been achieved, if it is increasing and its relative force [103]. A W between 0.5 and 0.7 indicates moderate agreement, and a W higher or equal 0.7 is a signal of strong agreement. Since this metric is only suitable for ordinal variables, the extension of the kappa method, Fleiss' kappa (k) [104], should be used for nominal variables. Values of k less than 0.4 mean weak agreement, between 0.41 and 0.6 are considered moderate, between 0.6 and 0.8 mean substantial agreement, and higher than 0.8 mean almost perfect agreement [105]. In this work, we used a combination of metrics with the objective of obtaining more robust results. For the set of ordinal variables: 1) at least a moderate W should be found; 2) a low dispersion, represented by an IQR<1, should be obtained for each item assessed. Regarding the set of nominal variables, at least a moderate k index should be found. Without the fulfillment of these conditions, the process would end if there was no change of stances between two successive rounds. Frequently, three iterations are enough to collect the necessary information and reach a satisfactory level of consensus [40].

In this work, the first round had a total duration of 25 days and a response rate of 100%. The results obtained by the end of this round suggested a weak consensus (W=0.178 and k=0.167, p<0.005). In order to check the consensus between respondents with similar experience, the participants were divided according to their professional function (project managers, members of project management teams, naval systems experts, and consultancy/ supervision). The W obtained showed weak consensus for all groups (W<0.5). In terms of measures of location and dispersion of each assessed item, we obtained an IQR<1, and an answer convergence of over 50% for all nominal variables.

Possible reasons for the low level of consensus are: 1) lack of access to available information (8 of the 17 respondents did not visit the site created to explain the meaning of each risk, cause and effect); 2) the process of grouping and summarizing the risks and their causes (obtained from the literature) may have reduced the detail of the information, making it too broad and difficult to assess, and thus allowing for different interpretations; 3) the experts may have different perceptions about what is the success of a project. After the first round, some adjustments were made: clarification of the questions, graphical representation of the responses, inclusion of comments.

The response rate of the second round was 94%. The global agreement of the experts' assessment was above 0.7 (Table 3). The results indicate that the adjustments made may have contributed to a significant change in the opinions from the first to the second round.

Table 3 – Levels of agreement on the assessed sets

Set	W	Group	W
Possible causes	0.796	Naval Systems	0.846
Interactions between causes	0.798	Project Managers	0.942
Risk events	0.723	Consultancy / Supervision	0.686
Interactions between risk events	0.732	Big project teams	0.845
Interactions between causes and risk events	0.788		
Assessment of the global agreement between ordinal variables	0.767		

W= Kendall's Coefficient of Concordance.

Two additional tests were performed: the *Kruskal-Wallis* nonparametric test, to test possible differences between the opinions of each group, and the *Spearman* nonparametric test, to assess the stability between rounds. Differences were observed in the distribution of responses for only two variables, "Planning failures may occur due to acts in bad faith (sabotage) by one of the stakeholders" and "Requirement errors may occur due to lack of financial capacity". Divergent opinions presented by some participants, possibly related to differences in professional experience, were not enough to compromise the global consensus. The *Spearman* test showed no statistically significant correlations between the variables assessed.

Due to the strong consensus at the end of the second round, it was decided not to hold a third one, given the low benefit (over cost) that it could provide.

One of the main limitations of the Delphi method, discussed by Rowe and Wright [106], is the possibility that "consensus" is only apparent, since respondents may change their estimates in order to be in accordance with the group, without actually changing their opinions about the topic under analysis.

In order to understand how the group worked to reach consensus, at the end of the questionnaire, the experts were asked to indicate the two factors that influenced their assessment the most. The options presented to them were:

a) *The description and examples of the risks and causes enabled a better understanding about the questions;*

b) *The comments from experts helped to think about some questions;*

c) *The general trend (percentage) of the responses to the first questionnaire favored a better reasoning about each problem;*

d) *I gave an opinion on a particular item only because most of the experts did, and it does not represent my personal judgment on the questions;* and

e) *Other.*

The responses to this question suggest that the convergence of opinions found in the second round did not result from compliance with other panel members, but rather from a genuine change of opinions. Respectively, 81.3% and 93.8% of the respondents chose options a) and c). None of the respondents chose option d).

Data collection

Data was collected through an online questionnaire based on interrelationships diagrams (Figure 2 shows the example of question 4) and structured around the following questions[1]:

1. Can the success (viewed through schedule delays and cost overruns) of a military ship construction project be affected by the risks represented in the figure? Would you like to suggest other risk(s)?

2. For each risk, how often do the causes of risk represented in the figure occur in the construction of a military ship? Would you like to suggest other cause(s)?

3. Do you agree that the interactions between risks represented in the figure could occur in the construction of a military ship? Would you like to add/delete any interaction?

4. Do you agree that the interactions between causes, and between causes and risks represented in the figure could occur in the construction of a military ship? Would you like to add/delete any interaction?

The assessment of the questions was carried out using a 5-point Likert scale. For questions 1 and 2, 1 corresponded to "Never", 2 to "Seldom", 3 to "Sometimes", 4 to "Often", and 5 to "Always". For

---

[1] The whole questionnaire (in Portuguese) is available at http://goo.gl/forms/0Ykuq1lmZZe54WnK2

questions 3 and 4, 1 corresponded to "I strongly disagree", 2 to "I disagree", 3 to "Undecided", 4 to "I agree", and 5 to "I strongly agree".

At the end of each section/question, fields for comments or additional contributions by the respondents were included. The sequential construction interactively helps the decision maker creating a network of interconnected causes and risks.
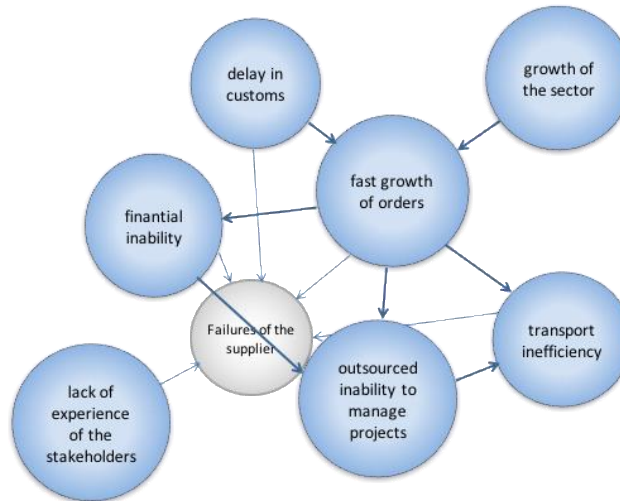

Fig. 2 – Interrelationship diagram showing the causes of a given risk

3.2. Bayesian networks (BN)

BN are directed acyclic graphs with nodes that represent random variables and edges that represent their conditional dependencies. Each node has a finite set of mutually exclusive states and is associated with a conditional probability distribution that gives the probability of each state for each combination of values of its parents. The parent node directly affects the child node. The joint probability distribution of a BN over its set of variables $X_i \in X = \{X_1, \dots X_n\}$ is given by the product of all the conditional probability distributions [107]:

$$P(X) = \prod_{i=1}^{n} P(X_i | pa(X_i)), \qquad (1)$$

where $pa(X_i)$ are the parent nodes of X_i in the network. In this work, we considered that each node of the network has two states: "true" and "false". The "true" state indicates a state of positive affirmation of cause due to that particular variable. A Conditional Probability Table is associated with each node to denote the causal influence between variables represented by the edges. BN can be used to support visible and repeatable decision-making, which is an important advantage. They have, however, been criticized for subjectivity in the construction of the influence diagrams and in the determination of the conditional probabilities. In general, a BN models the belief of its constructor [10]. Another limitation emerges when a child node has more than two parents, since, for every event, the number of possible

combinations grows exponentially [7]. For example, the risk "failures of production" is a child node with 16 parents (causes) which leads to a total of 2^{16}= 65.536 possible combinations. This makes elicitation from experts an impossible task. One way to reduce the complexity of the elicitation of numerical probabilities is to rely on canonical models that build probability distributions from a small number of parameters. Among the existing canonical models, the best known are *Noisy-AND* and *Noisy-OR* [108], the model used in this study:

$$Noisy\ OR: P(Y/X_i, X_j) = 1 - (1 - P(Y/X_i)) * (1 - P((Y/X_j))) \qquad (2)$$

We also used the *"leak probability"* [109] to incorporate an additional edge corresponding to the probability that an effect occurs even when all the causes listed in the model are not active. Lemmer and Gossink [110] incorporated the idea of *"leak probability"* assuming the *"leak"* to be independent of the other causes of the model. This allows the modeler to focus on significant causes and to group insignificant, incidental or unimportant causes in a single factor, thus simplifying large networks. In practice, we considered an additional casual interaction for each child node. The probability of occurrence of a *Y* effect, given a cause *X*, is calculated according to the following expression:

$$Noisy\ OR/leak: P(Y/X) = 1 - (1 - P(leak)) * (1 - P^R(X)), \qquad (3)$$

where *P(leak)* represents the probability of occurrence of *Y* in the absence of other causes listed in the model and $P^R(X)$ is the probability estimated by the *Noisy OR*.

We used the HUGIN Expert software[2] to build a BN for conducting risk assessments of shipbuilding projects because it eases BN model formulation, reasoning, and decision making under uncertain conditions. The software has been used for risk analysis in different areas [e.g., 13, 111, 112].

A BN model will be valid if it is representative of reality. The following steps were taken to assure the internal validity of the model: 1) posterior probability distributions were confirmed through redundant computation for several nodes; 2) the final model structure, the number of variables, their states, and casual relationships were confirmed by the first panel of experts in the successive Delphi rounds; 3) the second panel of experts confirmed that the results from the application of the model to two real projects were consistent with the reality of those projects; and 4) a sensitivity (what-if) analysis was then performed and validated by the same panel of experts. In terms of external validation, the experts (second panel) confirmed that the proposed model meets the users' requirements.

3.3. Linguistic variables

When historical data is unavailable, it is more realistic and intuitive to use linguistic terms than numerical values to assess risk events. Fuzzy set theory, initially proposed by Zadeh [113], has been

---

extensively applied to reflect ambiguities in human judgment. The *fuzzy set* concept is a convenient way of keeping track of imprecise, vague, and uncertain informative statements [114].

A fuzzy number (FN) is a way of representing *uncertain* or *fuzzy* information. The most widely used format of fuzzy numbers is the Triangular Fuzzy Number. The linguistic term set and their membership functions are defined in Table 4.

Table 4 – Linguist terms and experts weight importance

Linguistic term	TFN	
Extremely unlikely (EU)	(0,0,1)	
Very unlikely (VU)	(0,1,2)	
Unlikely (U)	(1,2,3)	
More or less (ML)	(2,3,4)	
Likely (L)	(3,4,5)	
Very likely (VL)	(4,5,6)	
Extremely likely (EL)	(5,6,6)	

Level	Criteria	Score
I - More than 20 years of experience and participation in more than 5 projects		1.0
II - From 11 to 20 years of experience and participation in 4 or 5 projects.		0.9
III - From 6 to 10 years of experience and participation in 2 or 3 projects		0.8
IV - From 1 to 5 years of experience, with participation in 1 project		0.7
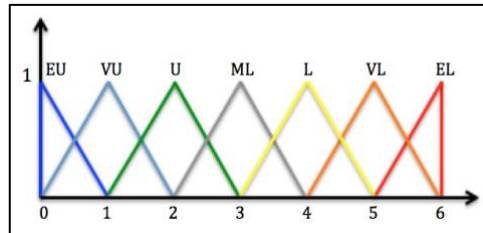
To aggregate the information, we weighted each opinion expert differently depending on two factors: 1) his/hers experience (in years) in functions related to shipbuilding projects, and 2) the number of projects in which he/she participated. This indicator was inspired by the work of Zhang et al. [13].

For determining the fuzzy probability of occurrence of risk events the following formula was used:

$$Weighted\ FN = E_1 \text{opinion} * \frac{E_1\ \text{score}}{E_1\ \text{score} + \cdots + E_n\ \text{score}} + \cdots + E_n \text{opinion} * \frac{E_n\ \text{score}}{E_1\ \text{score} + \cdots + E_n\ \text{score}} \qquad (5)$$

In the *defuzzification* procedure, we used the *α-weighted* method developed by Detyniecki and Yager [115]. To obtain the final probabilities of occurrence of project risks, we run the model with the *Noisy-OR* and *Leak* input probabilities in HUGIN.

4. Application of the proposed framework

4.1. Risk event identification

The risks identified through the literature review performed were grouped, synthetized and sketched, resulting in the scheme presented in Figure 3.

Fig. 3 - Causes, risks and effects
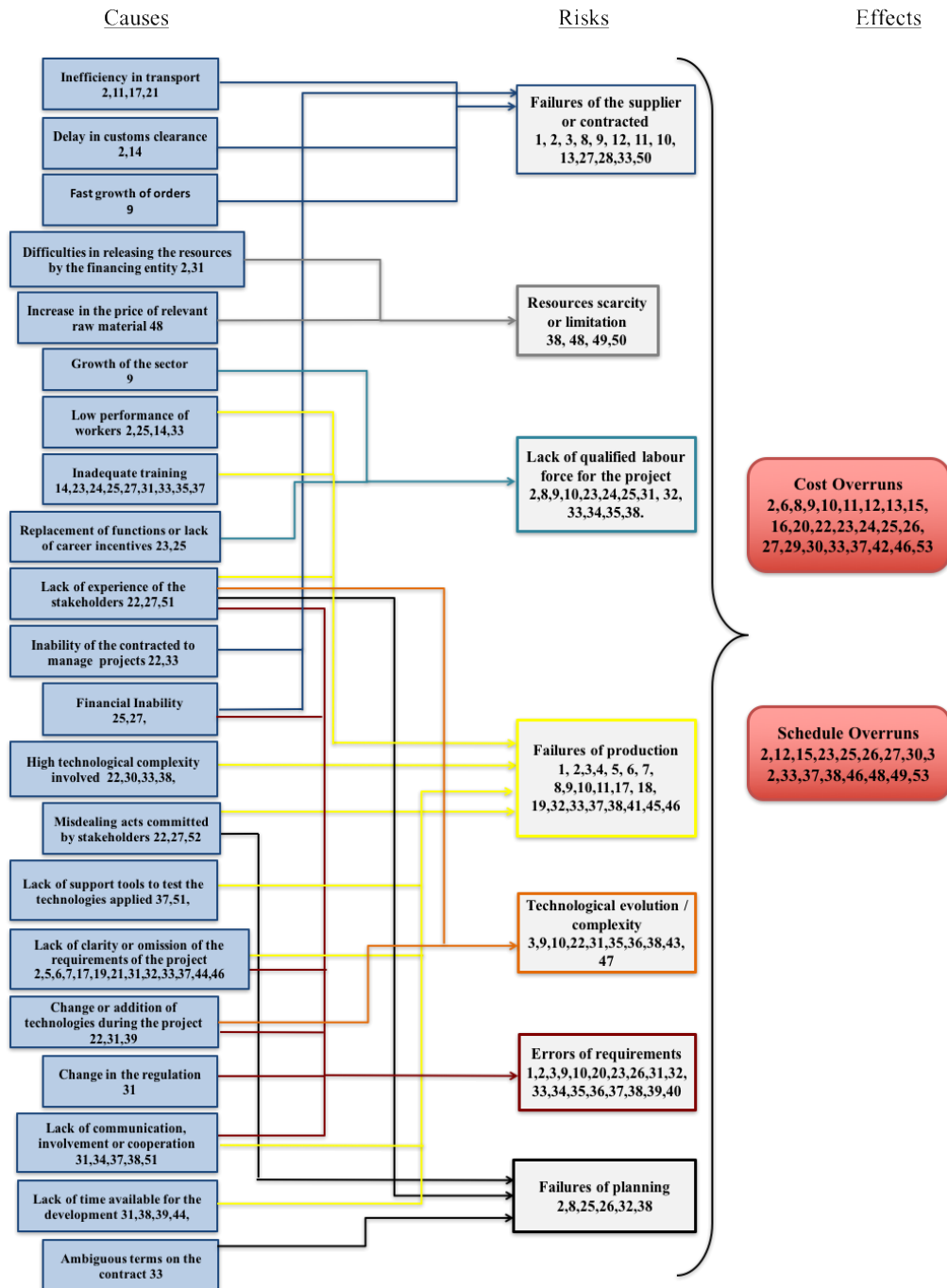
Legend: (1) Basuki et al. [20]; (2) Queiroz [14]; (3) Basuki et al. [116]; (4) Iwańkowicz and Rosochacki [22]; (5) McManus and Haddad [117]; (6) Fragiadakis et al. [21] (7) Pérez-Garrido et al. [118]; (8) Pires Jr. et al. [15]; (9) Lee et al. [19]; (10) Lee et al. [119]; (11) Venkatesh et al. [75]; (12) Yao et al. [82]; (13) Carbonara et al. [40]; (14) Sokri and Ghanmi [3]; (15) Yue and Zhang [120]; (16) Lu and Tang [121]; (17) Barlas [35]; (18) Cheng and Lu [43]; (19) Jacinto and Silva [18]; (20) Barney [36]; (21) Yun and Park [122]; (22) Bennet [37]; (23) Meier [62]; (24) Nowinski and Kohler [123]; (25) Kwak and Smith [1]; (26) National Audit Office [124]; (27) Department of Defence [125]; (28) Rodger et al. [71]; (29) Nicoll and Delaney [126]; (30) Nicoll and Delaney [127]; (31) Tuunanen et al. [128]; (32) Neves et al. [66]; (33) Wan et al. [76]; (34) Keith et al. [129]; (35) Yu et al. [84]; (36) Karvetski and Lambert [130]; (37) Iden et al. [50]; (38) McLeod and MacDonell [131]; (39) Stanley and Wilhite [132]; (40) Siemieniuch and Sinclair [133]; (41) Moreland et al. [134]; (42) Radjenovic and Paige [135]; (43) Boehm and Bhuta [136]; (44) Schaefer [137]; (45) Wang et al. [138]; (46) Hung et al. [49]; (47) Philip et al. [139]; (48) Christiansen and Thrane [2]; (49) Mane and DeLaurentis [140]; (50) Marmier et al. [141]; (51) Felderer and Ramler [46]; (52) Kochetkov and Aliev [17]; (53) Marmier et al. [141].

4.2. Risk analysis

The final model (obtained using the Delphi method with the collaboration of the first panel) comprises eight risk groups and twenty causes (Figure 4). Based on their experience, the experts on the first panel also stated the frequency of occurrence of a given risk qualitatively (using the linguistic term set ={almost never, infrequently, sometimes, often, always}). These frequency perceptions were used to control the probabilities of occurrence referred by the second panel. Given the complexity of the network, the three less frequent causes (Transport inefficiency, Fast growth of orders, and Growth of the sector) were not included in subsequent analysis (also because the strength of related interconnections was relatively low).
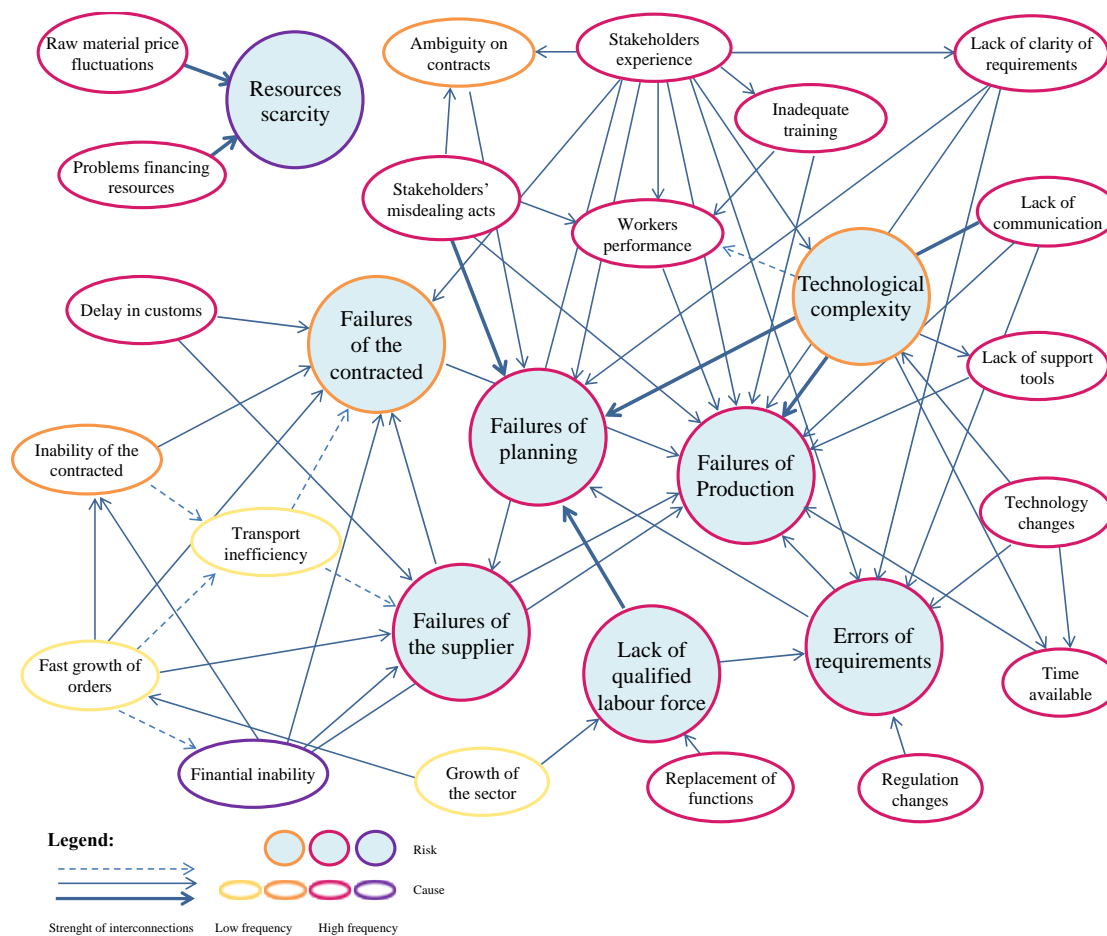
Fig. 4 - Risk Network Model for military shipbuilding projects

4.3. Risk evaluation

Two projects for the construction of Brazilian warships in national shipyards, carried out in the last decade, were selected for this study. For reasons of confidentiality, such projects are denominated as "project X" and "project Y". In the context of these projects, seven project managers were

interviewed (in two sequential moments: first, to obtain the input data; afterwards, to validate the obtained results). Table 5 shows some characteristics of the projects and of the interviewed experts (second panel). The guide for the interviews and the research objective of the questions is available in Appendix 1. All the interviewees agreed that implementing the framework steps is easy: 1) the use of diagrams helps understanding the cause-effect relationships; 2) the use of linguistic variables simplifies the expression of the probabilities of occurrence, moreover in situations where lack of experience exists (which is the case of the Brazilian Navy), although, according to the interviewees, expressing opinions about conditional probabilities remains a difficult task. The interviewees also agreed that the results obtained through the use of the framework are in accordance with what really happened in the two projects analyzed and that, given the simplicity of the process and the flexibility of the structure network, it will be easy to adapt the network to other projects/contexts. Moreover, two of the interviewees highlighted the importance of the framework to the organization as a mean to start structuring the assessment of risks and to induce gathering of risk related information for future use.

Table 5 – Project and expert (second panel) characteristics

Project	Expert	Age	Academic qualifications	Years of experience	# of projects	Score	Weight
X	E1	54	Master	11 to 20	3	0.9	0.265
	E2	60	Master	> 20	5	1.0	0.294
	E3	60	PhD	6 to 10	2	0.8	0.235
	E4	60	Master	1 to 5	1	0.7	0.206
Y	E5	50	Master	6 to 10	5	0.8	0.333
	E6	55	PhD	11 to 20	5	0.9	0.375
	E7	43	Master	1 to 5	2	0.7	0.292

Project	Cost	Duration	Shipyard	Team size
X	> US$ 200 millions	> 5 years	Military	10 to 20 persons
Y	between US$150 to US$200 million	3 to5 years	Civil	5 to 10 persons

Note: For example, 0.265=E1 score / sum of scores of all project X experts

The weight (importance) given to the experts was (subjectively) attributed depending on their experience (see Table 4). For a more rigorous approach, other elicitation or scoring methods should be used, for example, Cooke's classical performance-based weight model [142].

In order to illustrate the process of obtaining the probabilities of occurrence, we use the opinions of 3 experts (E5, E6, E7) for risk "failures of the supplier" that has four causes: A - inexperience of the stakeholders, B – financial inability, C - delay in customs clearance, and D - another cause not present in the diagram (like, for example, fast growth of orders) (Table 6). The aggregation of the expert opinions is obtained through a simple weighted arithmetic average.

Table 6 - Probabilities of occurrence (calculation process)

Causes	E5			E6			E7			Fuzzy weighted by the sum of the expert opinions	Crisp value
	linguistic variable	Fuzzy number	Fuzzy weighted by expert weight	linguistic variable	Fuzzy number	Fuzzy weighted by expert weight	linguistic variable	Fuzzy number	Fuzzy weighted by expert weight		
A	VU	(0,1,2)	(0,0.05,0.11)	L	(2,3,4)	(0.13,0.19,0.25)	VU	(0,1,2)	(0,0.05,0.1)	(0.13,0.29,0.46)	0.292
B	VL	(4,5,6)	(0.22,0.28,0.33)	VL	(4,5,6)	(0.25,0.31,0.38)	VL	(4,5,6)	(0.19,0.24,0.29)	(0.67,0.83,1)	0.833
C	VL	(4,5,6)	(0.22,0.28,0.33)	ML	(3,4,5)	(0.19,0.25,0.31)	VL	(4,5,6)	(0.19,0.24,0.29)	(0.60,0.77,0.94)	0.771
D	EU	(0,0,1)	(0,0,0.06)	VU	(0,1,2)	(0,0.06,0.13)	EU	(0,0,1)	(0,0,0.05)	(0,0.06,0.23)	0.089

The structure of the Bayesian Network and the inference results based on the Bayesian Network are shown in Figure 5 for project X and Figure 6 for project Y. To control the results, the obtained probabilities are compared with the results of question 2 of the Delphi method (*For each risk, how often do the causes of risk represented in the figure occur in the construction of a military ship? Would you like to suggest other cause(s)?* – see figure 4). For projects X and Y, none significant difference was detected (it should be noticed that the framework uses two independent samples of experts). In case there are differences, we recommend that the results of question 2 are shown to the second panel in order to verify if they want to reconsider their inputs.
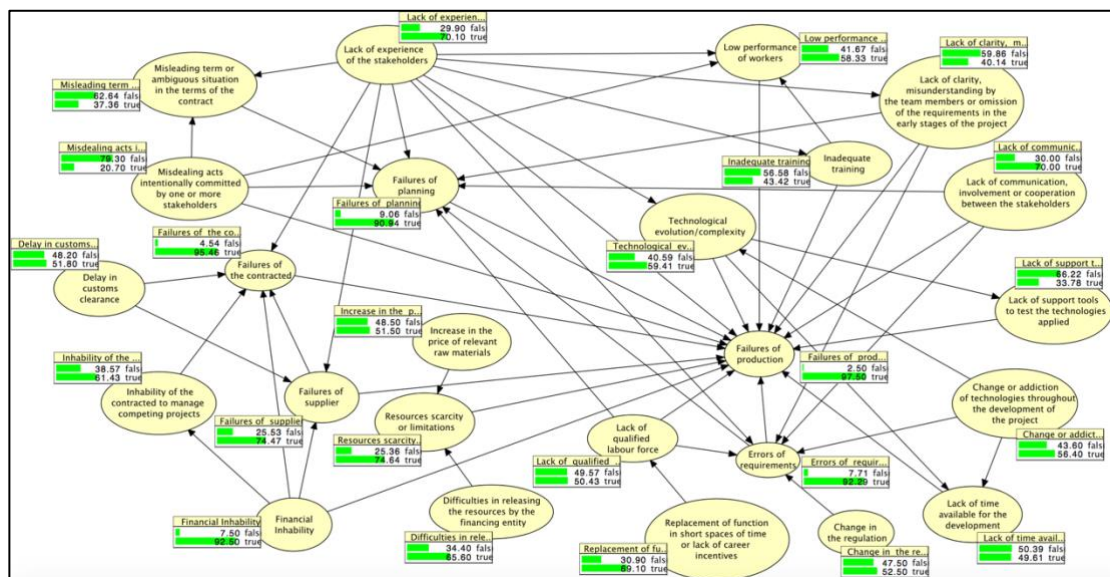

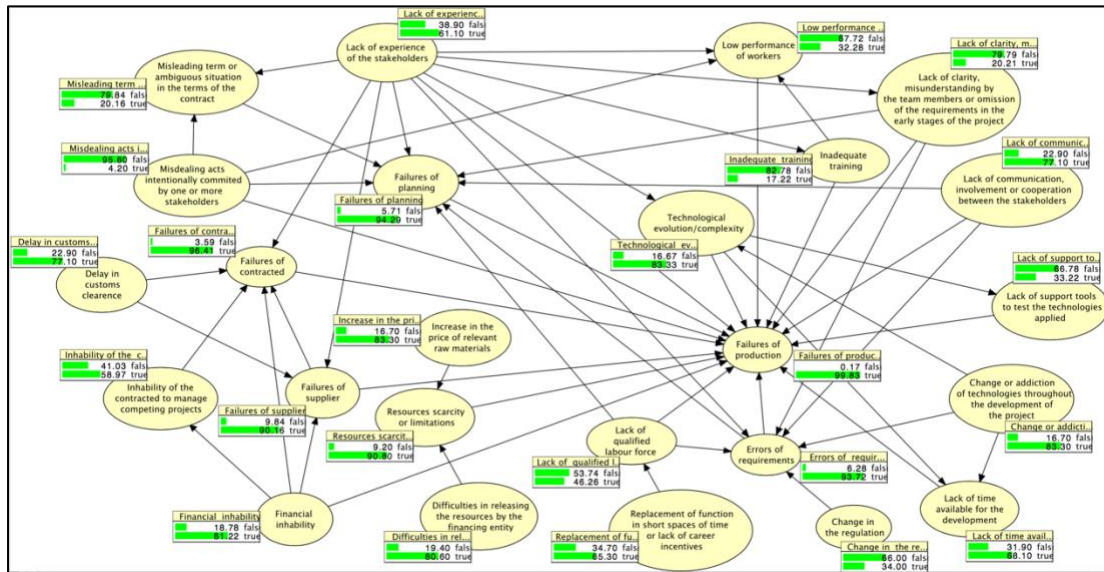**Figure 5** – Risk Network Model for Project X

Figure 6 – Risk Network Model for Project Y

Table 7 shows the probabilities of occurrence obtained for the eight risk groups considered for projects X and Y. It should be noted that the probabilities presented may be higher than those that would have been obtained if the application of the framework to projects X and Y was made in anticipation of project development, because the experts may have overvalued the probabilities of primary causes they knew had occurred. The risks with higher probability of occurrence were, for both projects, failures or errors of production, of the contracted, of requirements, and of planning.

Table 7 – Probability of risk occurrence for projects X and Y.

	Project X	Project Y
Failures of production	0.9750	0.9983
Failures of the contracted	0.9546	0.9641
Errors of requirements	0.9229	0.9372
Failures of planning	0.9094	0.9429
Resources scarcity or limitations	0.7464	0.9080
Failures of supplier	0.7447	0.9016
Technological evolution/ complexity	0.5941	0.8333
Lack of qualified labor	0.5043	0.4626

4.4. Sensitivity analysis (risk mitigation actions)

Project managers need to identify preventive actions to reduce risk probability before the risk occurs or protective actions to lower the risk impact after its occurrence. Mitigation actions should be directed at the primary causes associated with the risks with the greatest sensitivity (e.g., in project X, acting on the cause "Replacement of duties or lack of career incentives" would impact the probability of risk "Lack of qualified labor force" significantly, see Table 9).

The causes can be seen individually or can be grouped in categories according to their level of control (high, average or low control). High control corresponds to less complex mitigation measures, usually for internal causes with less costly mitigation actions; average control is usually related to

external causes linked to suppliers or other partners with close relationships, to technology changes, to financing, etc., with a medium mitigation cost; and low control is related to external causes that the organization does not control or has very little control over, for example, the issuing of new laws. Table 8 shows a possible classification.

For illustrative purposes, we performed two simulations: experience A, a reduction of 30% on the primary causes (one at a time, keeping the others constant); and experience B, a 30% reduction on the three groups of causes - high control, partial control, little or no control (one at a time, keeping the others constant). The results of these experiences (presented in Table 9) show that, while the use of mitigation actions directed at individual primary causes may have had significative impact on the probability of occurrence of some individual risks, more generalized reductions may have been obtained through a set of actions. Thus, important effects could have been attained through less complex and less costly internal mitigation actions (directed at the first set of causes) or through actions involving an improvement in the management of the relations with suppliers and other partners (directed at the second set of causes).

Table 8 – Classification of mitigation actions

Set		Primary Causes
1- High control	Less complex mitigation measures. *Examples: Training courses, Internal distribution of personnel, project coordination meetings*	Lack of experience of the stakeholders Lack of communication, involvement or cooperation Replacement of functions in reduced time intervals or lack of career incentives
2- Partial Control	More difficult mitigation measures *Examples: Adoption of stricter internal control and inspection measures, Implementation of detailed rules for verifying the financial health of the partners, Improvements on planning, Implementation of negotiation policies and strategies*	Misdealing acts Financial inability Change or addition of technologies Difficulties in releasing resources
3- Little or no control	Measures to deal with risks *Examples: Implementation of contingency plans, include the definition of risk responsibilities in the contract*	Change in regulation Increase in the price of relevant raw materials Delay in customs clearance

Table 9 – Risk probability variations as a result of the reductions of the probability of occurrence of primary causes (experiences A and B)

Risks / Primary causes	Failures of production	Failures of the contracted	Errors of requirements	Failures of planning	Resources scarcity or limitations	Failures of supplier	Technological evolution/ complexity	Lack of qualified labor force
PROJECT X								
Delay in customs clearance	-0.0012	-0.0110				-0.0492		
Misdealing acts	-0.0015			-0.0063				
Increase in the price of relevant raw materials	-0.0006				-0.0595			
Change in regulation	-0.0044		-0.0186	-0.0042				
Lack of communication, involvement or cooperation	-0.0073		-0.0280	-0.0342				
Financial inability	-0.0115	-0.0953				-0.0657		
Change or addition of technologies	-0.0017		-0.0154	-0.0035			-0.0731	
Lack of experience of the stakeholders	-0.0121	-0.0144	-0.0436	-0.0468		-0.0558	-0.0115	
Difficulties in releasing resources	-0.0018				-0.1961			
Replacement of duties or lack of career incentives	-0.0026		-0.0124	-0.0164				-0.2007
1st set of causes	-0.0301	-0.0144	-0.1143	-0.1370		-0.0558	-0.1150	-0.2007

2nd set of causes	-0.0192	-0.0953	-0.0154	-0.0100	-0.1961	-0.0657	-0.0731	
3rd set of causes	-0.0022	-0.0110	-0.0186	-0.0042	-0.0595	-0.0492		
PROJECT Y								
Delay in customs clearance	-0.0004		-0.0002		-0.0013	-0.0011	-0.0010	-0.0009
Misdealing acts	-0.0342					-0.0512		-0.0057
Increase in the price of relevant raw materials				-0.0072	-0.0307		-0.0348	-0.0239
Change in regulation		-0.0004		-0.0019	-0.0375		-0.0094	-0.0337
Lack of communication, involvement or cooperation			-0.0912					
Financial inability	-0.0560					-0.0759		-0.0114
Change or addition of technologies							-0.1651	-0.0409
Lack of experience of the stakeholders								
Difficulties in releasing resources	-0.0004		-0.0002		-0.0013	-0.0011	-0.0010	-0.0009
Replacement of duties or lack of career incentives	-0.0342					-0.0512		-0.0057
1st set of causes	-0.0173	-0.0052	-0.0745	-0.1074		-0.0104	-0.0374	-0.1767
2nd set of causes	-0.0029	-0.0512	-0.0348	-0.0061	-0.0562	-0.0759	-0.1651	
3rd set of causes	-0.0007	-0.0342	-0.0072	-0.0019	-0.0912	-0.0560		

Notes: Blank cells mean that the variation was 0.000; shadowed lines correspond to experience B.

5. Conclusions

This research has provided some insights about what risks and causes may affect the success of complex projects related to the shipbuilding of the Navy of Brazil according to the (consensual) perception of the experts. Its main contribution has been providing a simple and understandable framework for risk management applicable to complex and unique projects with scarce/limited data, based on visual diagrams and using the Noisy OR canonical model. The effort required by the process used to obtain the experts' opinion was reasonable. Fuzzy theory was helpful to deal with the linguistic inputs of experts. The examples of application show that the proposed framework has acceptance between military experts mostly because it is suitable to customize the structure of the risk network according to the uniqueness and complexity of the ship under construction, it allows a global visualization of the interdependencies of the risk events, it obtains likelihoods of the risks and it allows simulations of risk mitigation strategies along the project duration (in the beginning, with a preventive perspective and, during the execution of the project, with a protective perspective). The proposed approach can be useful even when the project is still in an embryonic stage and it is not possible to design the global network and assess the likelihood of the risk events and measure their impact. The simple perception of the relationships and of the likelihood that each identified risk event may have on the success of the projects will enable decision makers to direct some decisions to the mitigation of the causes of risks.

Additionally, this work contributes to the research in defense contexts by proposing a framework that combines the Delphi method (to collect expert opinion), fuzzy theory, and BN with Noisy OR. The framework starts by identifying risk events (from military shipbuilding and other areas) that are then confirmed (refuted) as suitable for the case under analysis. The customize risk network structure thus obtained is contained in terms of dimension so that it can be used by the decision makers. Two real examples were used to confirm the practical applicability of the framework in real situations. A simple

sensitivity analysis was performed to illustrate how to obtain the necessary information for the discussion of the best mitigation actions to apply in a specific case.

The developed study has several limitations. The need to collect inherently subjective data from groups of experts may have introduced some bias in the analysis. Some effort should be placed to develop and maintain databases to collect and store formal, quantitative and accurate information about shipbuilding projects. It was not possible to validate the BN model by applying it to a project in anticipation of its development and comparing the results of the model with the occurrences of the project. Also, the used approach did not consider the possibility of dependency between causes. This possibility should be addressed in future research. Finally, the results of this research may have been shaped by the context of the study. For different shipbuilding contexts, adaptations will probably be needed.

Interesting developments of this study may arise from the consideration of the whole shipbuilding supply chain since several of the identified causes and risks arise from the interaction with suppliers or contracted partners.

REFERENCES

[1] Kwak YH, Smith BM. Managing risks in mega defense acquisition projects: Performance, policy, and opportunities. International Journal of Project Management. 2009;27:812-20.

[2] Christiansen U, Thrane S. The prose of action: The micro dynamics of reporting on emerging risks in operational risk management. Scandinavian Journal of Management. 2014;30:427-43.

[3] Sokri A, Ghanmi A. Cost risk analysis and learning curve in the military shipbuilding sector. Int J Data Analysis Techniques and Strategies. 2017;9:300-13.

[4] Wu W-S, Yang C-F, Chang J-C, Château P-A, Chang Y-C. Risk assessment by integrating interpretive structural modeling and Bayesian network, case of offshore pipeline project. Reliability Engineering & System Safety. 2015;142:515-24.

[5] Marcelino-Sádaba S, Pérez-Ezcurdia A, Lazcano AME, Villanueva P. Project risk management methodology for small firms. International Journal of Project Management. 2014;32:327-40.

[6] Dikmen I, Birgonul MT, Anac C, Tah JHM, Aouad G. Learning from risks: A tool for post-project risk assessment. Automation in Construction. 2008;18:42-50.

[7] Cárdenas IC, Al-Jibouri SSH, Halman JIM, van de Linde W, Kaalberg F. Using Prior Risk-Related Knowledge to Support Risk Management Decisions: Lessons Learnt from a Tunneling Project. Risk Analysis. 2014;34:1923-43.

[8] Zhang L, Wu X, Skibniewski MJ, Zhong J, Lu Y. Bayesian-network-based safety risk analysis in construction projects. Reliability Engineering & System Safety. 2014;131:29-39.

[9] Zio E. The future of risk assessment. Reliability Engineering & System Safety. 2018;177:176-90.

[10] Fang C, Marle F. A simulation-based risk network model for decision support in project risk management. Decision Support Systems. 2012;52:635-44.

[11] Alaeddini A, Dogan I. Using Bayesian networks for root cause analysis in statistical process control. Expert Systems with Applications. 2011;38:11230-43.

[12] Holický M, Marková J, Sýkora M. Forensic assessment of a bridge downfall using Bayesian networks. Engineering Failure Analysis. 2013;30:1-9.

[13] Zhang L, Wu X, Qin Y, Skibniewski MJ, Liu W. Towards a Fuzzy Bayesian Network Based Approach for Safety Risk Analysis of Tunnel-Induced Pipeline Damage. Risk Analysis. 2016;36:278-301.

[14] Queiroz J. Análise comparativa de riscos de estaleiros e projetos de construção naval no Brasil [Comparative analysis of the risks of shipyards and shipbuilding projects in Brazil]. Rio de Janeiro, Brazil: Universidade Federal do Rio de Janeiro; 2012. *(available in Portuguese only)*

[15] Pires Jr. F, Guimarães LF, Assis LF, Almeida MF, Nascimento MBC, Filho MR, et al. Um sistema integrado para acompanhamento e controle de projetos de construção naval [An integrated system for shipbuilding projects monitoring and control]. SOBENA2010: 23° Congresso Nacional de Transporte Aquaviário, Construção Naval e Offshore. Rio de Janeiro, Brazil: Sociedade Brasileira de Engenharia Naval; 2010. p. 25-9. *(available in Portuguese only)*

[16] Ferreira FdAL, Scavarda LF, Ceryno PS, Leiras A. Supply chain risk analysis: a shipbuilding industry case. International Journal of Logistics Research and Applications. 2018:1-15.

[17] Kochetkov Y, Aliev B. Risks in the Shipbuilding and Ship Repair Industry in Latvia. Journal of Management. 2016;28:9-13.

[18] Jacinto C, Silva C. A semi-quantitative assessment of occupational risks using bow-tie representation. Safety Science. 2010;48:973-9.

[19] Lee E, Park Y, Shin JG. Large engineering project risk management using a Bayesian belief network. Expert Systems with Applications. 2009;36:5880-7.

[20] Basuki M, Manfaat D, Nugroho S, Dinariyana AAB. Probabilistic Risk Assessment of the Shipyard Industry Using the Bayesian Method. International Journal of technology. 2014;5:88-97.

[21] Fragiadakis NG, Tsoukalas VD, Papazoglou VJ. An adaptive neuro-fuzzy inference system (anfis) model for assessing occupational risk in the shipbuilding industry. Safety Science. 2014;63:226-35.

[22] Iwańkowicz RR, Rosochacki W. Clustering risk assessment method for shipbuilding industry. Industrial Management & Data Systems. 2014;114:1499-518.

[23] Thomas P, Bratvold RB, Bickel JE. The Risk of Using Risk Matrices. 2014.

[24] Zhang Z, Chu X. Risk prioritization in failure mode and effects analysis under uncertainty. Expert Systems with Applications. 2011;38:206-14.

[25] Hu Y, Zhang X, Ngai EWT, Cai R, Liu M. Software project risk analysis using Bayesian networks with causality constraints. Decision Support Systems. 2013;56:439-49.

[26] Zhang G, Thai VV. Expert elicitation and Bayesian Network modeling for shipping accidents: A literature review. Safety Science. 2016;87:53-62.

[27] Pourreza P, Saberi M, Azadeh A, Chang E, Hussain O. Health, Safety, Environment and Ergonomic Improvement in Energy Sector Using an Integrated Fuzzy Cognitive Map– Bayesian Network Model. International Journal of Fuzzy Systems. 2018;20:1346-56.

[28] Louvieris P, Gregoriades A, Garn W. Assessing critical success factors for military decision support. Expert Systems with Applications. 2010;37:8229-41.

[29] Wang G, Xu T, Tang T, Yuan T, Wang H. A Bayesian network model for prediction of weather-related failures in railway turnout systems. Expert Systems with Applications. 2017;69:247-56.

[30] Chin K-S, Tang D-W, Yang J-B, Wong SY, Wang H. Assessing new product development project risk by Bayesian network with a systematic probability generation methodology. Expert Systems with Applications. 2009;36:9879-90.

[31] Ashrafi M, Davoudpour H, Khodakarami V. A Bayesian Network to Ease Knowledge Acquisition of Causal Dependence in CREAM: Application of Recursive Noisy-OR Gates. Quality and Reliability Engineering International. 2017;33:479-91.

[32] Abdul-Rahman H, Wang C, Lee YL. Design and pilot run of Fuzzy Synthetic Model (FSM) for Risk Evaluation in Civil Engineering. Journal of Civil Engineering and Management. 2013;19:217-38.

[33] Aliahmadi A, Sadjadi SJ, Jafari-Eskandari M. Design a new intelligence expert decision making using game theory and fuzzy AHP to risk management in design, construction, and operation of tunnel projects (case studies: Resalat tunnel). The International Journal of Advanced Manufacturing Technology. 2011;53:789-98.

[34] Badri A, Nadeau S, Gbodossou A. Proposal of a risk-factor-based analytical approach for integrating occupational health and safety into project risk evaluation. Accident Analysis & Prevention. 2012;48:223-34.

[35] Barlas B. Shipyard fatalities in Turkey. Safety science. 2012;50:1247-52.

[36] Barney LD. Inflation and risk in naval shipbuilding contracts. Atlantic Economic Journal. 1986;14:30-6.

[37] Bennet F. The Seven Deadly Risks of Defence Projects. Security Challenges. 2010;6:97-111.

[38] Büyüközkan Gn, Ruan D. Choquet integral based aggregation approach to software development risk assessment. Information Sciences. 2010;180:441-51.

[39] Camastra F, Ciaramella A, Giovannelli V, Lener M, Rastelli V, Staiano A, et al. A fuzzy decision system for genetically modified plant environmental risk assessment using Mamdani inference. Expert Systems with Applications. 2015;42:1710-6.

[40] Carbonara N, Costantino N, Gunnigan L, Pellegrino R. Risk management in motorway PPP projects: Empirical-based guidelines. Transport Reviews. 2015;35:162-82.

[41] Cárdenas IC, Al-jibouri SSH, Halman JIM, van Tol FA. Capturing and Integrating Knowledge for Managing Risks in Tunnel Works. Risk Analysis. 2013;33:92-108.

[42] Chan APC, Yeung JFY, Yu CCP, Wang SQ, Ke Y. Empirical Study of Risk Assessment and Allocation of Public-Private Partnership Projects in China. Journal of Management in Engineering. 2011;27:136-48.

[43] Cheng M, Lu Y. Developing a risk assessment method for complex pipe jacking construction projects. Automation in Construction. 2015;58:48-59.

[44] Creemers S, Demeulemeester E, Van de Vonder S. A new approach for quantitative risk analysis. Annals of Operations Research. 2014;213:27-65.

[45] Del Águila IM, Del Sagrado J. Requirement Risk Level Forecast Using Bayesian Networks Classifiers. International Journal of Software Engineering and Knowledge Engineering. 2011;21:167-90.

[46] Felderer M, Ramler R. Integrating risk-based testing in industrial test processes. Software Quality Journal. 2014;22:543-75.

[47] Hashemi H, Mousavi SM, Tavakkoli-Moghaddam R, Gholipour Y. Compromise Ranking Approach with Bootstrap Confidence Intervals for Risk Assessment in Port Management Projects. Journal of Management in Engineering. 2013;29:334-44.

[48] Hsueh S-L, Lee J-R, Chen Y-L. DFAHP multicriteria risk assessment model for redeveloping derelict public buildings. International Journal of Strategic Property Management. 2013;17:333-46.

[49] Hung YW, Hsu S-C, Su Z-Y, Huang H-H. Countering user risk in information system development projects. International Journal of Information Management. 2014;34:533-45.

[50] Iden J, Tessem B, Päivärinta T. Problems in the interplay of development and IT operations in system development projects: A Delphi study of Norwegian IT experts. Information and Software Technology. 2011;53:394-406.

[51] Issa UH, Farag MA, Abdelhafez LM, Ahmed SA. A Risk Allocation Model for Construction Projects in Yemen. 2015;7:78-89.

[52] Jitao G, Renjun Z, Shanyong Q. Research on Innovation Project Man-factor Risk Identification and Assessment. In: Yang Y, Hu H, editors. 3rd International Conference on Information Management, Innovation Management and Industrial Engineering. Kunming, China: IEEE and CPS; 2010. p. 254-8.

[53] Jozi SA, Shoshtary MT, Zadeh ARK. Environmental risk assessment of dams in construction phase using a multi-criteria decision-making (MCDM) method. Human and Ecological Risk Assessment: An International Journal. 2015;21:1-16.

[54] Karim NAA, Rahman IA, Memmon AH, Jamil N, Azis AAA. Significant risk factors in construction projects: Contractor's perception. In: Ismail Z, Hamzah MK, Hashim H, editors. IEEE Colloquium on Humanities, Science and Engineering (CHUSER). Sabah, Malaysia: IEEE; 2012. p. 347-50.

[55] Kuo Y-C, Lu S-T. Using fuzzy multiple criteria decision making approach to enhance risk assessment for metropolitan construction projects. International Journal of Project Management. 2013;31:602-14.

[56] Li J, Zou PXW. Fuzzy AHP-Based Risk Assessment Methodology for PPP Projects. Journal of Construction Engineering and Management. 2011;137:1205-9.

[57] Li HX, Al-Hussein M, Lei Z, Ajweh Z. Risk identification and assessment of modular construction utilizing fuzzy analytic hierarchy process (AHP) and simulation. Canadian Journal of Civil Engineering. 2013;40:1184-95.

[58] Liu H-T, Tsai Y-l. A fuzzy risk assessment approach for occupational hazards in the construction industry. Safety Science. 2012;50:1067-78.

[59] Liu WF, Feng W, Zhen WL. The Application of Fuzzy-AHP on Risk Assessment of Construction Project. In: Lin Y, editor. International Conference on Computer and Management (CAMAN). Wuhan, China: IEEE; 2011. p. 1-3.

[60] Lu W, Liang C, Ding Y. A Method for Risk Assessment in IT Project with Incomplete Information. In: Shaeffer JM, editor. International Conference on Management and Service Science. Wuhan, China: IEEE; 2010. p. 1-4.

[61] Manalif E, Capretz LF, Nassif AB, Ho D. Fuzzy-ExCOM Software Project Risk Assessment. In: Wani MA, Khoshgoftaar T, Zhu XH, editors. 11th International Conference on Machine Learning and Applications. Boca Raton, FL, USA: IEEE; 2012. p. 320-5.

[62] Meier SR. Causal inferences on the cost overruns and schedule delays of large-scale US federal defense and intelligence acquisition programs. Project Management Journal. 2010;41:28-39.

[63] Mostafavi A, Karamouz M. Selecting Appropriate Project Delivery System: Fuzzy Approach with Risk Analysis. Journal of Construction Engineering and Management. 2010;136:923-30.

[64] Mousavi SM, Tavakkoli-Moghaddam R, Hashemi H, Mojtahedi SMH. A novel approach based on non-parametric resampling with interval analysis for large engineering project risks. Safety Science. 2011;49:1340-8.

[65] Murphy ME, Perera S, Heaney G. Innovation management model: a tool for sustained implementation of product innovation into construction projects. Construction Management and Economics. 2015;33:209-32.

[66] Neves SM, da Silva CES, Salomon VAP, da Silva AF, Sotomonte BEP. Risk management in software projects through knowledge management techniques: cases in Brazilian incubated technology-based firms. International Journal of Project Management. 2014;32:125-38.

[67] Nieto-Morote A, Ruz-Vila F. A fuzzy approach to construction project risk assessment. International Journal of Project Management. 2011;29:220-31.

[68] Peibin G, Baojiang SUN, Gang LIU, Yong W. Fuzzy Comprehensive Evaluation in Well Control Risk Assessment Based on AHP: A Case Study. Advances in Petroleum Exploration and Development. 2012;4:13-8.

[69] Perera B, Rameezdeen R, Chileshe N, Hosseini MR. Enhancing the effectiveness of risk management practices in Sri Lankan road construction projects: A Delphi approach. International Journal of Construction Management. 2014;14:1-14.

[70] Pinto A, Nunes IL, Ribeiro RA. Qualitative Model for Risk Assessment in Construction Industry: A Fuzzy Logic Approach. In: Camarinha-Matos LM, Pereira P, Ribeiro L, editors. Emerging Trends in Technological Innovation. Berlin, Heidelberg: Springer Berlin Heidelberg; 2010. p. 105-11.

[71] Rodger JA, Pankaj P, Gonzalez SP. Decision making using a fuzzy induced linguistic ordered weighted averaging approach for evaluating risk in a supply chain. The International Journal of Advanced Manufacturing Technology. 2014;70:711-23.

[72] Shi Q, Zhou Y, Xiao C, Chen R, Zuo J. Delivery risk analysis within the context of program management using fuzzy logic and DEA: A China case study. International Journal of Project Management. 2014;32:341-9.

[73] Tang A-g, Wang Rl. Software project risk assessment model based on fuzzy theory. In: Luo Q, editor. International Conference on Computer and Communication Technologies in Agriculture Engineering. Chengdu, China 2010. p. 328-30.

[74] Taylan O, Bafail AO, Abdulaal RMS, Kabli MR. Construction projects selection and risk assessment by fuzzy AHP and fuzzy TOPSIS methodologies. Applied Soft Computing. 2014;17:105-16.

[75] Venkatesh VG, Rathi S, Patwa S. Analysis on supply chain risks in Indian apparel retail chains and proposal of risk prioritization model using Interpretive structural modeling. Journal of Retailing and Consumer Services. 2015;26:153-67.

[76] Wan J, Cao Y, Hou J. Case Study on H Corp. Software Project Risk Management with ISM. Technology and Investment. 2013;4:145-52.

[77] Wang YF, Xie M, Ng KM, Meng YF. Quantitative risk analysis model of integrating fuzzy fault tree with Bayesian Network. IEEE International Conference on Intelligence and Security Informatics. Beijing, China: IEEE; 2011. p. 267-71.

[78] Xiao N, Huang H-Z, Li Y, He L, Jin T. Multiple failure modes analysis and weighted risk priority number evaluation in FMEA. Engineering Failure Analysis. 2011;18:1162-70.

[79] Xu Y, Yeung JFY, Chan APC, Chan DWM, Wang SQ, Ke Y. Developing a risk assessment model for PPP projects in China—A fuzzy synthetic evaluation approach. Automation in Construction. 2010;19:929-43.

[80] Bi X, Wang G-l. Application of fuzzy comprehensive evaluation method based on entropy to evaluation risk of an EPC project. IEEE 18th International Conference on Industrial Engineering and Engineering Management. Changchun, China: IEEE; 2011. p. 55-8.

[81] Yang RJ, Zou PXW. Stakeholder-associated risks and their interactions in complex green building projects: A social network model. Building and Environment. 2014;73:208-22.

[82] Yao H-l, Lian C-g, Bai J-x. Application of analytic hierarchy process (AHP) in shipyard Project investment risk recognition. Canadian Social Science. 2009;5:17-25.

[83] Yazdani-Chamzini A. Proposing a new methodology based on fuzzy logic for tunnelling risk assessment. Journal of Civil Engineering and Management. 2014;20:82-94.

[84] Yu C-I, Chen H-G, Klein G, Jiang JJ. Risk dynamics throughout the system development life cycle. Journal of Computer Information Systems. 2013;53:28-37.

[85] Yu J-H, Lee S-K. A conflict-risk assessment model for urban regeneration projects using Fuzzy-FMEA. KSCE Journal of Civil Engineering. 2012;16:1093-103.

[86] Zacharias O, Panou E, Askounis DT, Vassilikopoulou A. Project risk ranking in large-scale programs: a Fuzzy Set based approach. Asia-Pacific Journal of Operational Research. 2014;31:1450020.

[87] Zeng SX, Tam CM, Tam VW. Integrating safety, environmental and quality risks for project management using a FMEA method. Engineering Economics. 2010;66:44-52.

[88] Zhang R, Li D. Development of risk assessment model in construction project using fuzzy expert system. 2nd IEEE International Conference on Emergency Management and Management Sciences. Beijing, China: IEEE; 2011. p. 866-9.

[89] Zhang S, Sun B, Yan L, Wang C. Risk identification on hydropower project using the IAHP and extension of TOPSIS methods under interval-valued fuzzy environment. Natural Hazards. 2013;65:359-73.

[90] Zhao J, Xin C, Yang R. Risk Assessment of Mine Shaft Construction Projects Based on Risk Matrix. In: Yang Y, Hu H, editors. 3rd International Conference on Information Management, Innovation Management and Industrial Engineering. Kunming, China: IEEE; 2010. p. 527-30.

[91] Zhao X, Hwang B-G, Yu GS. Identifying the critical risks in underground rail international construction joint ventures: Case study of Singapore. International Journal of Project Management. 2013;31:554-66.

[92] Zhou Z, Fang X-j. Application study on fuzzy influence diagram in highway tunnel construction safety risk assessment. International Conference on Management Science &

Engineering 17th Annual Conference Proceedings. Melbourne, Australia: IEEE; 2010. p. 272-9.

[93] Zhou H-b, Zhang H. Risk Assessment Methodology for a Deep Foundation Pit Construction Project in Shanghai, China. Journal of Construction Engineering and Management. 2011;137:1185-94.

[94] Zou PXW, Li J. Risk identification and assessment in subway projects: case study of Nanjing Subway Line 2. Construction Management and Economics. 2010;28:1219-38.

[95] Chan APC, Yung EHK, Lam PTI, Tam CM, Cheung SO. Application of Delphi method in selection of procurement systems for construction projects. Construction Management & Economics. 2001;19:699-718.

[96] Okoli C, Pawlowski SD. The Delphi method as a research tool: an example, design considerations and applications. Information & management. 2004;42:15-29.

[97] Markmann C, Darkow I-L, von der Gracht H. A Delphi-based risk analysis—Identifying and assessing future challenges for supply chain security in a multi-stakeholder environment. Technological Forecasting and Social Change. 2013;80:1815-33.

[98] Heiko A. Consensus measurement in Delphi studies: review and implications for future quality assurance. Technological forecasting and social change. 2012;79:1525-36.

[99] Ceric A. Minimizing communication risk in construction: a Delphi study of the key role of project managers. Journal of Civil Engineering and Management. 2014;20:829-38.

[100] Esmaeili B, Hallowell M. Integration of safety risk data with highway construction schedules. Construction Management and Economics. 2013;31:528-41.

[101] Culley JM. Use of a computer-mediated Delphi process to validate a mass casualty conceptual model. Computers, informatics, nursing: CIN. 2011;29:272-9.

[102] Hussein MM. Corporate social responsibility: finding the middle ground. Social Responsibility Journal. 2010;6:420-32.

[103] Schmidt RC. Managing Delphi surveys using nonparametric statistical techniques. decision Sciences. 1997;28:763-74.

[104] Fleiss JL. Measuring nominal scale agreement among many raters. Psychological bulletin. 1971;76:378-82.

[105] Landis JR, Koch GG. The measurement of observer agreement for categorical data. biometrics. 1977;33:159-74.

[106] Rowe G, Wright G. The Delphi technique as a forecasting tool: issues and analysis. International journal of forecasting. 1999;15:353-75.

[107] Jensen FV, Nielsen TD. Causal and Bayesian Networks. Bayesian Networks and Decision Graphs. New York: Springer; 2007. p. 23-50.

[108] van Gerven MAJ, Lucas PJF, van der Weide TP. A generic qualitative characterization of independence of causal influence. International Journal of Approximate Reasoning. 2008;48:214-36.

[109] Henrion M. Some Practical Issues in Constructing Belief Networks. In: Kanal LN, Levitt TS, Lemmer JF, editors.: North-Holland; 1989. p. 161-73.

[110] Lemmer JF, Gossink DE. Recursive noisy OR - a rule for estimating complex probabilistic interactions. IEEE Transactions on Systems, Man, and Cybernetics, Part B (Cybernetics). 2004;34:2252-61.

[111] Barker GC, Talbot NLC, Peck MW. Risk assessment for Clostridium botulinum: a network approach. International Biodeterioration & Biodegradation. 2002;50:167-75.

[112] Jones B, Jenkinson I, Yang Z, Wang J. The use of Bayesian network modelling for maintenance planning in a manufacturing industry. Reliability Engineering & System Safety. 2010;95:267-77.

[113] Zadeh LA. Fuzzy sets. Information and Control. 1965;8:338-53.

[114] Schjaer-Jacobsen H. Representation and calculation of economic uncertainties: Intervals, fuzzy numbers, and probabilities. International Journal of Production Economics. 2002;78:91-8.

[115] Detyniecki M, Yager RR. Ranking fuzzy numbers using α-weighted valuations. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems. 2000;08:573-91.

[116] Basuki M, Manfaat D, Nugroho S, Dinariyana AAB. Improvement of the Process of New Business of Ship Building Industry. Journal of Economics, Business, and Accountancy/Ventura. 2012;15:187-204.

[117] McManus TN, Haddad AN. Use of Methanol as a Coolant During Machining of Aluminum in a Shipbuilding Environment: A Failure to Assess and Manage Risk. In: Zhao J, Wang A, Li X, Wang X, editors. 2014 International Conference on Energy and Environmental Protection (ICEEP 2014). Xi'an, China: Trans Tech Publications; 2014. p. 1061-4.

[118] Pérez-Garrido C, González-Castano FJ, Chaves-Diéguez D, Rodríguez-Hernández PS. Wireless remote monitoring of toxic gases in shipbuilding. Sensors. 2014;14:2981-3000.

[119] Lee E, Shin JG, Park Y. A statistical analysis of engineering project risks in the Korean shipbuilding industry. Journal of Ship Production. 2007;23:223-30.

[120] Yue W, Zhang Q. Research on the shipbuilding supply chain risk control. IEEE International Conference on Automation and Logistics. Qingdao, China: IEEE; 2008. p. 2205-8.

[121] Lu BZ, Tang AST. China shipbuilding management challenges in the 1980s. Maritime Policy & Management. 2000;27:71-8.

[122] Yun J-M, Park P. Development of Industrial Safety Management System for Shipbuilding Industry Using RFID/USN. In: Apduhan BO, Hsu C-H, Dohi T, Ishida K, Yang LT, Ma J, editors. 9th International Conference on Ubiquitous Intelligence and Computing and 9th International Conference on Autonomic and Trusted Computing. Fukuoka, Japan: IEEE; 2012. p. 285-91.

[123] Nowinski EH, Kohler RJ. The lost art of program management in the intelligence community. Journal of Intelligence Studies. 2006;50:33-46.

[124] National Audit Office. Allocation and management of risk in Ministry of Defence PFI projects (Report HC 343 Session 2007-2008). London. https://www.nao.org.uk/wp-content/uploads/2008/10/0708343.pdf.2008.

[125] Department of Defence. Liability Risk Assessment Template V1.1. Australia. http://www.defence.gov.au/casg/DoingBusiness/ProcurementDefence/ContractinginCASG/LiabilityRiskManagementProcess/. Department of Defence; 2011.

[126] Nicoll A, Delaney J. UK air force may have its wings clipped. Strategic Comments. 2010;16:1-4.

[127] Nicoll A, Delaney J. Deal saves Europe's transport aircraft plans. Strategic Comments. 2010;16:1-4.

[128] Tuunanen T, Vartiainen T, Ebrahim M, Liang M. Continuous Requirements Risk Profiling in Information Systems Development. In: Bui TX, Sprague Jr. RH, editors. 48th Hawaii International Conference on System Sciences (HICSS 2015). Kauai, HI, USA: IEEE and CPS; 2015. p. 4019-28.

[129] Keith M, Demirkan H, Goul M. Service-oriented methodology for systems development. Journal of Management Information Systems. 2013;30:227-60.

[130] Karvetski CW, Lambert JH. Evaluating deep uncertainties in strategic priority-setting with an application to facility energy investments. Systems Engineering. 2012;15:483-93.

[131] McLeod L, MacDonell SG. Factors that affect software systems development project outcomes: A survey of research. ACM Computing Surveys (CSUR). 2011;43:24-.

[132] Stanley D, Wilhite A. Technology Engineering: The Concurrent Development of Space Transportation Systems and Technology. Engineering Management Journal. 2010;22:55-63.

[133] Siemieniuch CE, Sinclair MA. Systems integration. Applied ergonomics. 2006;37:91-110.

[134] Moreland JD, Sarkani S, Mazzuchi T. Service-Oriented Architecture (SOA) Instantiation within a Hard Real-Time, Deterministic Combat System Environment. Systems Engineering. 2014;17:264-77.

[135] Radjenovic A, Paige RF. Behavioural interoperability to support model-driven systems integration. In: Bézivin J, Soley RM, Vallecillo A, editors. First Workshop on Model Driven Interoperability (MDI'2010). Oslo, Norway: ACM Digital Library; 2010. p. 98-107.

[136] Boehm B, Bhuta J. Balancing opportunities and risks in component-based software development. Software, IEEE. 2008;25:56-63.

[137] Schaefer R. Debugging debugged, a metaphysical manifesto of systems integration. ACM SIGSOFT Software Engineering Notes. 2008;33:1-20.

[138] Wang S, Xu Z, Cao J, Zhang J. A middleware for web service-enabled integration and interoperation of intelligent building systems. Automation in Construction. 2007;16:112-21.

[139] Philip A, Afolabi B, Adeniran O, Oluwatolani O, Ishaya G. Towards an efficient information systems development process and management: A review of challenges and proposed strategies. Journal of Software Engineering and Applications. 2010;3:983-9.

[140] Mane M, DeLaurentis DA. Network-level metric measuring delay propagation in networks of interdependent systems. In: Henshaw MJdC, Shing M-T, editors. 5th International Conference on System of Systems Engineering. Loughborough, UK: IEEE; 2010. p. 1-6.

[141] Marmier F, Gourc D, Laarz F. A risk oriented model to assess strategic decisions in new product development projects. Decision Support Systems. 2013;56:74-82.

[142] Cooke RM. Experts in Uncertainty: Opinion and Subjective Probability in Science (Environmental Ethics and Science Policy). 1991.

Appendix 1 – Guide of the interviews with experts (panel 2)

Objective	Question
Assess the perception of the interviewees about the difficulty of using the input tool (questionnaire)	1 - What is your opinion about the questionnaire applied in terms of clarity of the questions? 2 - Is the definition of the causes and risks presented clearly? 3 - Given the complexity of the diagram, which includes various cause and effect relationships, what is your opinion on how the issues are presented? 4 – Is the average length of time for completing the questionnaire adequate? 5 - Do linguistic variables help express the probability of occurrence of risk events and their relations? 6 - What is your opinion about the possibility that project managers and project teams use the questionnaire as an initial data (about possible risks and their causes in shipbuilding projects of the Brazilian Navy) entry tool?
Confirm that the results obtained with the model are in accordance with the reality surrounding projects X and Y	7 - What is your evaluation about the results obtained with the application of the model when compared with the reality observed during the execution of the project? 8 - If some of the results did not correspond to reality, what points do you consider that could have contributed to this difference, and what are your suggestions for correcting them?
Confirm that the risk network can be applied to other projects	9 - To what extent do you consider the possibility of using this network as a risk management tool in other projects of the same nature?
Assess the potential for future implementation of the framework as a tool for group decision-making in the risk management of shipbuilding projects	10 – What would be, in your opinion, the possible advantages/disadvantages of implementing the framework for risk analysis in Brazilian Navy shipbuilding projects? 11 - Do you consider that this model can contribute to group decision making by providing information for prioritization, elaboration of mitigation strategies, and control of risks and their possible causes? 12 - If you were the manager or a team member of a project to build a ship for the Brazilian Navy, would you apply the framework?