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Project management issues: vulnerability management assessment

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Abstract

Purpose – The purpose of this paper is to investigate the vulnerability of projects implemented in enterprises. The paper focuses on the issue of vulnerability assessment in the planning stages of a project, before its realization.

Design/methodology/approach – In this paper, the realization of the project has been analyzed through the phases of delivery, and the fuzzy approach has been deployed for mathematical modeling of uncertainties. An appropriate expert and management team has assessed the variables of the project's vulnerability by using linguistic expressions, as this way of assessment is close to the human way of thinking. The model of project's vulnerability assessment has been verified on real life data by means of an illustrative example.

Findings – A very significant part of business operations in enterprises all over the world is realized through the practice of project management. In daily business practice, project activities may be exposed to different risk sources. These risks may be studied from different perspectives, but without reevaluation, risk sources increase the vulnerability of projects as well as of the whole enterprise.

Originality/value – The results of the analysis of the obtained data gives good direction to future research in the scope of vulnerability management in the enterprises oriented to long-term sustainability.

Keywords Project management, Vulnerability, Risk management, Uncertainties

Paper type Research paper

1. Introduction

The increasing application of project management practices generates the need for research and decision-making analysis of the overpowering existing and new challenges. The current trends show that development and application of project management, as well as risk management, is in expansion. This is visible in different areas of life and business, and markets have a constant demand for project managers (Shimizu *et al.*, 2014).

The emerging challenges and issues that are introduced to project managers are various and hard to predict, so the emerging conditions may adversely affect the desired and planned outcomes (Cerpa *et al.*, 2016) of the project. The most commonly occurring issues are related to breaking the budget and time schedules, as well as non-standardized processes within the operating system, as certain processes and activities are not always necessarily put into a standardized format of management (Ilie, 2015). A major problem may be a bad definition of the role of project management activities and insufficient support from the top management (Hermano and Martín-Cruz, 2016). When the project comes into the final phase, any delay will increase the total cost of the project, so awareness of project managers has to be focused on project management methods (Kostalova *et al.*, 2015), with a goal to enable

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faster and more efficient implementation while taking resources into account (time, money, human resources, material resources, etc.).

The issues mentioned above may be analyzed as potential weakness of the system leading to its increased vulnerability, which covers several connotations directed to the sensitivity (susceptibility) of a system to harm (Adger, 2016). In terms of strategy, vulnerability management may be associated with a goal to minimize the negative consequences that arise from changes in the organization's or supply chain activities, so that business performance may be recovered (Chowdhury and Quaddus, 2015). Exposure to negative consequences can induce new possible incidents, so it is important to handle vulnerabilities and respond to them effectively and quickly. To provide long-term sustainability (Afgan *et al.*, 2009), organizations need to be flexible, striving to develop their staff and to provide better competences so that they can develop increased static adaptive capacity. In this way, organizations can respond to changes and possible perturbations by resetting their own performance and recover from stress. Generally, vulnerability can be presented as a multidimensional concept that consists of exposure, sensitivity and adaptive capacity (Turner *et al.*, 2003). There are different vulnerability assessment tools, software and procedures that cover different factors (informational, etc.). However, when it comes to the area of project management, very few papers deal with vulnerability (Vidal and Marle, 2012), although this is a very important issue for enterprises all over the world.

The motivation for this paper is derived from the desire of the author to depict the disadvantages and vulnerabilities of project management that are currently befalling different companies in Serbia. To assess the vulnerability of project management in enterprises, the problem is treated through the following steps:

- definition of project phases;
- assessment of project phases' sensitivity to potential risks;
- enterprise's static ability to recover its business performances (adaptive capacity); and
- assessment of project phases' exposure to risks (susceptibility) that may occur during project delivery.

The aim of this paper is to present a model for assessment of the vulnerability of different projects, originating from one type of possible risks in their planning stages, before their realization. The vulnerability of the project could be analyzed through all the phases of the project, taking into account the analysis of the risk factors. The risks are evaluated from different angles, encompassing different areas (BS 6079-3). They could be common/general as well as those observed specifically from the aspect of human factors, politics, society, law, economy, finance, technology, commerce, etc.

In the problem being treated here, there are a lot of imprecise and uncertain data values related to constituents of vulnerability – such as susceptibility, exposure and adaptive capacity. Having this in mind, it seems more realistic to use linguistic variables (Zadeh, 1975) instead of numerical values for describing them. These uncertainties are modeled by applying the fuzzy sets theory (Zimmermann, 2001). The theory of fuzzy sets is a suitable mathematical tool, the application of which makes linguistic expressions quantitatively easy to introduce (Zadeh, 1975). An assessment of the projects' vulnerability is based on the fuzzy logic and according to the obtained results, the organizations could acquire a chance to improve their implemented business practice in the field of project management. This model has been verified by the illustrative example of one enterprise in Serbia.

The paper is organized as follows:

- In the first section, the basic considerations to be kept in mind about projects' vulnerability and the importance of project management for organizations are discussed;
- The second section presents an overview of the literature dealing with the mentioned problems;
- In the third section, an evaluation framework is discussed. Section four is designated for modeling of uncertainties. The section five defines the model for the assessment of projects' vulnerability and the section six explains an illustrative example for model testing; and
- Section 7 sets the conclusion, the paper's contribution and future directions in research.

2. A literature review

Project management covers a wide area of industrial engineering and management, and deals with many open issues (Vidal and Marle, 2012). Almost all significant issues in project management are oriented towards performance assessment (Chen, 2015), risk management (Marcelino-Sádaba *et al.*, 2014), critical success factors (Taherdoost and Keshavarzsaleh, 2016) and project system vulnerability (Deng *et al.*, 2014). Choosing the critical success factors in linking project management performance and project success through different conceptual frameworks (Mir and Pinnington, 2014) sets focus on important areas and enables project managers to set the right priorities across different project elements. On the other hand, all these factors carry a certain amount of risk and may cause vulnerability of the project management team as well as vulnerability in realization of the project.

The term 'vulnerability' is used in different aspects in relation to various areas such as information systems (Patel *et al.*, 2008), supply chains (Wagner and Neshat, 2010), monitoring systems (Pingue *et al.*, 2011), etc.; however, at the same time, very few papers treat vulnerability in business organizations. Emerging insights into organizational vulnerability can significantly add to the research agenda of organizational risk management (Liu *et al.*, 2013), as vulnerability may be presented as a multidimensional concept that consists of exposure, sensitivity and adaptive capacity (Turner *et al.*, 2003) to the manifested scenarios of potential risks. The conceptualization of risk may be analyzed through the ideas of Kaplan (1997) concerning the risk triplet, which includes a scenario, the likelihood of the manifestation of that scenario and the consequences of events within that scenario.

Risk management is involved in all phases of a project and has the task of identifying risks and explaining their impact and effects with the goal to propose measures of protection, usually in the form of change in the project itself or in the reserved project funds. In risk management, it is recommended to use a procedural approach that has been defined by a standard, like the BS 6079-2:2000, BS 6079-3 (BS 6079-2:2000, 2000; BS 6079-3:2000, 2000). It describes the risk management process as a basic in any organization, regardless of size, sector of activity and action. It defines good practice for risk management, which includes risk identification, risk analysis, assessment and control of risks. The motivation for usage of standard BS 06079-3-2000 lies in the Annex E of this standard which gives a list of some common types of business-related risks. It lists general risks, human resource-related issues that are associated with business risk, political/social environmental risks, legal risks, economic/financial risks and commercial and technical/operational risks. It also lists major technical considerations which can affect business risk. Technical/operational risks are used for model verification in this paper.

Literature review indicates that vulnerability in different research domains may be treated by applying the fuzzy sets theory (Tran *et al.*, 2002; Akgun *et al.*, 2010). It is known that the human way of thinking implies making decisions through predefined linguistic expressions, rather than through numerical values. According to Zadeh (1975), a linguistic variable is a variable whose values are expressed in linguistic terms. By applying the fuzzy sets theory (Zimmermann, 2001), linguistic expressions may be modeled in an appropriate manner. In general, the membership function shapes can be very different, such as the Gaussian curve, logistic curve, triangular function, trapezoidal function etc. The determination of the shape of a membership function can be considered as a task in itself. In the literature, different uncertainties are modelled by triangular fuzzy numbers (TFNs) such as (Tadić *et al.*, 2013; Paskoy *et al.*, 2012; Aleksić *et al.*, 2013), (b) trapezoidal fuzzy numbers (TrFNs) (Sadi-Nezhad and Damghani, 2010; Tadić *et al.*, 2014) and two-level fuzzy numbers (Liu and Teng, 2014). It may be noticed that triangular fuzzy numbers offer a good compromise between descriptive power and computational simplicity. During the process of decision-making, different numbers of linguistic variables for describing of uncertainties may be used. In the literature, there is no guideline as to how to determine the number of linguistic expressions, the lower bound, upper bound and modal value/values of any fuzzy numbers which are used for modelling of pre-defined linguistic expressions. Most authors used five (Zheng *et al.*, 2012; Tadić *et al.*, 2016) or seven (Arsovski *et al.*, 2015) linguistic expressions for describing uncertainties. The domains of fuzzy numbers are defined on the real sets which belong to the different intervals. In many papers found in literature, the domain of fuzzy numbers is defined into interval [1-9] (Zheng *et al.*, 2012) or into interval [0-1] (Sadi-Nezhad and Damghani, 2010). Fuzzy numbers can be presented symmetrically on the presented measurement scale or they may be presented in compliance with the decision makers' judgments.

Many scholars suggests that fuzzy rating of any type of uncertainties should be stated as a fuzzy group of decision-making problem. Aggregation of decision-maker opinions can be performed by applying different operators. The fuzzy averaging method is a widely used operator in the literature (Kaya and Kahraman, 2011) as well as in this paper.

3. Evaluation of framework

The evaluation framework for vulnerability assessment of each project phase is proposed in Figure 1.

Step 1. This paper focuses on projects which are realized in production enterprises with partner relations within a supply chain.

Step 2.. A project may be defined as a set of phases which are successively implemented (PMBOK Guide, 2015). Generally, project phases are denoted with the set $\phi = \{1, \ldots, f, \ldots F\}$. The total number of phases of the project is denoted by F, and f is the index of project phases f, $f = 1, \ldots, F$. The number of phases is determined in compliance with project management methodology (PMBOK Guide, 2015) as:

- Project conception and initiation ($f = 1$);
- Project definition and planning ($f = 2$);
- Project launch or execution ($f = 3$);
- Project performance and control ($f = 4$); and
- Project close ($f = 5$).

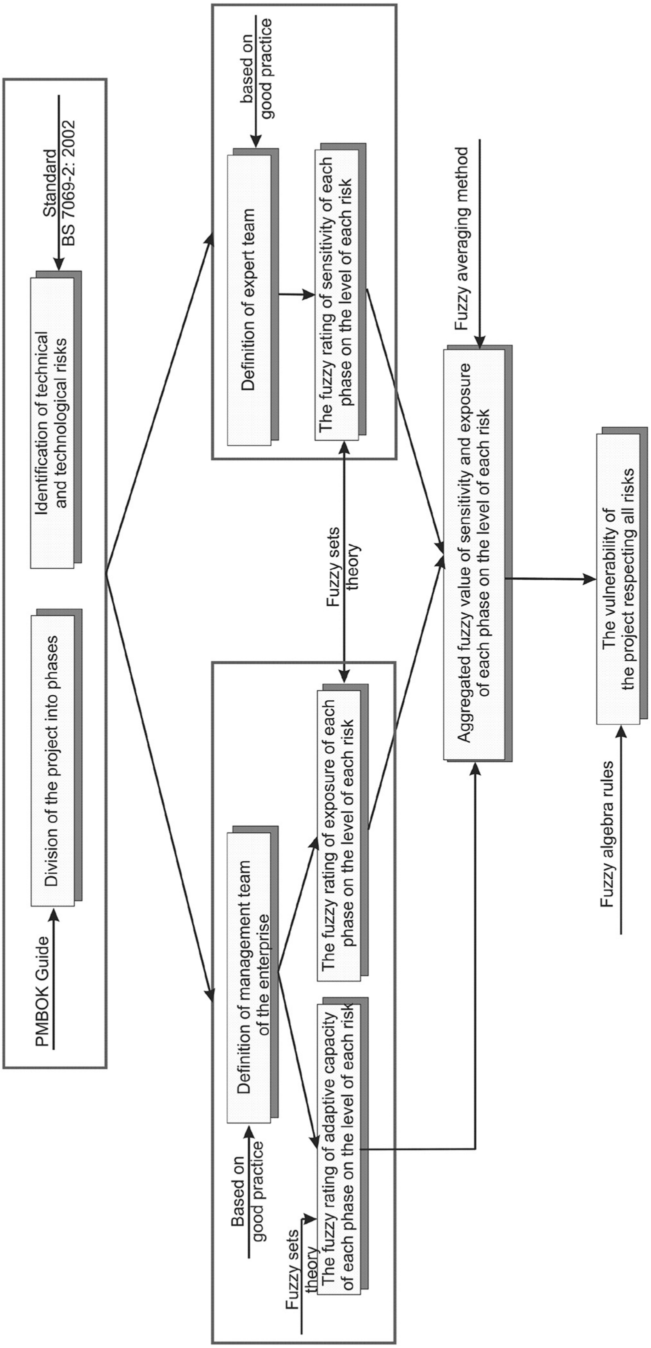

Figure 1.
Evaluation framework for project vulnerability assessment

Step 3. As it is known, during project realization, different risks that may be classified under various aspects, may occur (BS 6079-3:2002). This paper treats the group of technical and technological risks, as it has significant impact on the type of treated enterprises. Formally, those risks may be presented by the set $\rho = \{1, \ldots, r, \ldots R\}$.

The total number of risks is denoted as R, and r is the index of risks r, $r = 1, \ldots, R$. The following list notes the major technical considerations that can affect business risks (BS 6079-3:2002):

- inadequate design ($r = 1$);
- professional negligence ($r = 2$);
- human error/incompetence ($r = 3$);
- structural failure ($r = 4$);
- operation lifetime lower than expected ($r = 5$);
- residual value of assets lower than expected ($r = 6$);
- dismantling/decommissioning costs ($r = 7$);
- performance failure ($r = 8$); and
- residual maintenance problems ($r = 9$).

Step 4. In the treated problem, the sensitivity of each project phase, i.e. the quality or condition of being sensitive to accidents, arises from potential risks. The value of sensitivity of each project phase f, $f = 1, \ldots, F$, for each treated risk r, $r = 1, \ldots, R$, is based on the evaluation of the expert team. In this case, the expert team consists of the project manager, risk manager, quality manager, top manager and financial manager, who are employees of production enterprises with partner connections within the supply chain. Formally, the expert team is presented by the set of indices $\lambda = \{1, \ldots, j, \ldots J\}$. The total number of experts is denoted as J, and e is the index of a decision-maker j, $j = 1, \ldots, J$. In this case, the expert team consists of the project manager, risk manager, quality manager, top manager and financial manager, who are employees of production enterprises with partner connections within the supply chain. Decision makers articulate their assessment through pre-defined linguistic expressions which are modelled by TFNs, $\tilde{R}_i$, $i = 1, \ldots, I$.

The total number of linguistic expressions is I and is defined by the expert team with respect to the project size. The aggregation of their opinions is given by using fuzzy averaging method. The value of sensitivity of each project phase f, $f = 1, \ldots, F$ for each treated risk r, $r = 1, \ldots, R$ is denoted by TFN, $\tilde{e}_{rf}$.

Step 5. Exposure of each project phase is defined as the state of having no protection from something harmful – accidents occur from potential risks. Exposure of each project phase f, $f = 1, \ldots, F$ to risk r, $r = 1, \ldots, R$, if it is manifested through the possible accident, is assessed by each member of the management team on the level of the enterprise where the analyzed project should be realized. The aggregation of their opinions is given by using fuzzy averaging method. The value of exposure of each project phase f, $f = 1, \ldots, F$ for each treated risk r, $r = 1, \ldots, R$ is denoted by TFN, $\tilde{e}_{rf}$.

Step 6. Static adaptive capacity of each project phase f, $f = 1, \ldots, F$ if risk r, $r = 1, \ldots, R$, is manifested, is seen as a level of existing procedure plans or strategies that are supposed to be implemented if accident occurs. Its value is based on the assessment of the management team on the level of the enterprise p, $p = 1, \ldots, P$. The management team makes its decision through consensus by using pre-defined linguistic expressions that correspond to TFNs $\tilde{R}_j$, $j = 1, \ldots, J$. Fuzzy assessment of static adaptive capacity is denoted as $\tilde{A}_{rf}$, $r – 1, \ldots, R$; $f = 1, \ldots, F$.

Step 7. Vulnerability of each project phase *f*, $f = 1, \ldots, F$ for each risk *r*, $r = 1, \ldots, R$, $\tilde{V}_{rf}$ is calculated as a product of aggregated values of its sensitivity, $\tilde{s}_{rf}$, exposure, $\tilde{e}_{rf}$ and normalized value of static adaptive capacity, $\tilde{a}_{rf}$. In this case, it can be approximated that fuzzy number $\tilde{V}_{rf}$ is triangular (Kahraman *et al.*, 2006).

Step 8. By using the method of maximum possibility (Dubbois and Prade, 1986), the representative scalar of fuzzy number $\tilde{V}_f,\ v_f,\ f = 1, \ldots, F$ is given.

Step 9. At the first place in the rank, the phase *f*, $f = 1, \ldots, F$ which is associated with the highest value of vulnerability, is placed. It may be assumed that the vulnerability of the analyzed project is equal to the vulnerability of the first-ranked project phase.

4. Modelling of uncertainties

This section provides an insight into modeling of uncertainties related to sensitivity, exposure and adaptive capacity of project phases when technical and technological risks are analyzed.

4.1 Modelling of sensitivity and exposure of project phases

Sensitivity and exposure of each project phase in the general case is different for various considered risks. The value of these parameters may vary in different project phases, although the manifested risk is the same. So the assessment of sensitivity and exposure should be performed on the level of each project phase and each risk.

The value of sensitivity and exposure of each project phase *f*, $f = 1, \ldots, F$ which originates from manifested risk *r*, $r = 1, \ldots, R$ is assessed by the expert team and the management team, respectively. They use pre-defined linguistic expressions which are modelled by TFNs, as shown below:

- very low sensitivity/exposure (VL) – (x; 0, 0, 0.25);
- low sensitivity/exposure (L) – (x; 0.1, 0.3, 0.5);
- medium sensitivity/exposure (M) – (x; 0.3, 0.5, 0.7);
- high sensitivity/exposure (H) – (x; 0.5, 0.7, 0.9); and
- very high sensitivity/exposure (VH) – (x; 0.75, 1, 1).

The domains of these TFNs are defined into a real set with the interval [0-1]. Values 0 and 1 denote that the sensitivity and exposure of the project phase *f*, $f = 1, \ldots, F$ for risk *r*, $r = 1, \ldots, R$ is at the lowest value and the highest value, respectively.

4.2 Modelling of static adaptive capacity level of project phases

As it has been mentioned, reduction of the vulnerability of each project phase may be achieved through appropriate procedure, instruction or manual with a guide on how to react if risk *r*, $r = 1, \ldots, R$ occurs and leads to an accident. The existence and quality of these documents, with preparedness for their implementation, may be treated as static adaptive capacity. The value of static adaptive capacity should be determined on the level of the enterprise. Its value may be assessed in an exact way by the opinion of the management team, whose decisions are formed by consensus.

It is assumed that adaptive capacity can be adequately described by three linguistic expressions which are modelled by TFNs and that are given in the following way:

- very low satisfactory (VS) – (y; 1, 1, 4.5);
- moderate satisfactory (S) – (y; 2, 5, 8); and
- highly satisfactory (SS) – (y; 5.5, 9, 9).

The domains of these TFNs are defined to a common measurement scale [1-9]. Values 1 and 9 denote that static adaptive capacity for the project phase f, $f = 1, \ldots, F$ at the level risk r, $r = 1, \ldots, R$ is at the lowest value and the highest value, respectively. The vulnerability of each project phase with respect to each treated risk is inversely proportional to the adaptive capacity. In other words, with regard to a project's vulnerability, it may be assumed that static adaptive capacity is a cost-type variable.

5. The proposed model

The proposed model can be shown through further steps.

Step 1. Fuzzy rating of each project phase's sensitivity f, $f = 1, \ldots, F$ on the level of each risk r, $r = 1, \ldots, R$ is performed by decision-maker j, $j = 1, \ldots, J$, who uses pre-defined linguistic expressions $\tilde{R}_i$, $i = 1, \ldots, I$.

Step 2. Fuzzy rating of the exposure of each project phase, $f = 1, \ldots, F$ on the level of each risk, $r = 1, \ldots, R$ is obtained by each member of the management team, $k = 1, \ldots, K$, $\tilde{R}_i^k, i = 1, \ldots, I; \; = 1, \ldots, K.$

Step 3. Fuzzy rating of static adaptive capacity for each project phase on the level of each risk is assessed by the management team at the enterprise level:

$$\tilde{A}_{fr} = \left(y; L_{fr}, M_{fr}, U_{fr}\right),\ f = 1, \ldots, F;\ r = 1, \ldots, R.$$

Step 4. The aggregated value of sensitivity, $\tilde{s}_{fr}$, and the exposure, $\tilde{e}_{fr}$, of each project phase, $f = 1, \ldots, F$ on the level of each risk, $r = 1, \ldots, R$ is calculated by using the fuzzy averaging operator:

$$\tilde{s}_{fr} = \frac{1}{E} \cdot \sum_{e=1}^{E} \tilde{R}_i^k,\ f = 1, \ldots, F;\ r = 1, \ldots, R;\ e = 1, \ldots, K;\ i = 1, \ldots, I$$

$$\tilde{e}_{fr} = \frac{1}{K} \cdot \sum_{k=1}^{K} \tilde{R}_i^k,\ f = 1, \ldots, F;\ r = 1, \ldots, R;\ k = 1, \ldots, K;\ i = 1, \ldots, I$$

Step 5. All cost-type linguistic variables, $\tilde{A}_{fr},\ f = 1, \ldots, F;\ r = 1, \ldots, R$ are transformed by applying the expression (Shih *et al.*, 2007):

$$\tilde{A}_{fr} = \left(\frac{L_{fr}^{-}}{U_{fr}}, \frac{L_{fr}^{-}}{M_{fr}}, \frac{L_{fr}^{-}}{L_{fr}}\right)$$

where: $L_{fr}^{-} = \min_{r=1,\ldots,R; f=1,\ldots,F} L_{fr}$

Step 6. The vulnerability of each phase of the project with respects to all identified risk is calculated as:

$$\tilde{V}_f = \frac{1}{R} \sum_{r=1}^{R} \tilde{s}_{fr} \cdot \tilde{e}_{fr} \cdot \tilde{a}_{fr}$$

Step 7. The representative scalar, V_f of TFN $\tilde{V}_f$ is determined by using the method of maximum possibility (Dubbois and Prade, 1986):

Step 8. Project phases in the treated enterprise are ranked with respect to their vulnerability. Placed at the first place in the rank is a phase which is denoted as f^*, $f = 1, \ldots, F$, with the greatest value of V_f, $f = 1, \ldots, F$.

Table I. Fuzzy rating of project phases' sensitivity

Project phases/ technical-operational risk factors	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$	$r = 7$	$r = 8$	$r = 9$
$f = 1$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$
$f = 2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}\tilde{R}_2,\tilde{R}_{2,3}\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$
$f = 3$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$
$f = 4$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_4,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$
$f = 5$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_2,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_2,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$

Table II.
Fuzzy rating of project phases' exposure

Project phases/ technical-operational risk factors	$r=1$	$r=2$	$r=3$	$r=4$	$r=5$	$r=6$	$r=7$	$r=8$	$r=9$
$f=1$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$
$f=2$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_5,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_3,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_2,\tilde{R}_4,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5$
$f=3$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_4,\tilde{R}_5$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_3$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4$	$\tilde{R}_3,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5$	$\tilde{R}_3,\tilde{R}_4,\tilde{R}_5$	$\tilde{R}_4,\tilde{R}_5,\tilde{R}_5$
$f=4$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_4,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_3,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_3,\tilde{R}_3,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_2$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_3$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_5$
$f=5$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$	$\tilde{R}_2,\tilde{R}_3,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_3,\tilde{R}_4$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_2$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$	$\tilde{R}_1,\tilde{R}_1,\tilde{R}_1$	$\tilde{R}_1,\tilde{R}_2,\tilde{R}_4$	$\tilde{R}_2,\tilde{R}_2,\tilde{R}_2$

6. Illustrative example

The proposed model is tested on real life data from one small production enterprise from Serbia. In the treated enterprise, one research project was analyzed. The group of technical and technological risks from standard (BS 6079-3:2000) were analyzed after sensitivity, exposure and static adaptive capacity had been assessed.

Fuzzy ratings of sensitivity, exposure and static adaptive capacity for each phase of the project at the risk level r, $r = 1, \ldots, R$ are presented in Table I to Table III (Step 1 to Step 3 of the proposed algorithm). These data present input data for the proposed model.

Applying the proposed algorithm (Step 4), the aggregated value of sensitivity and exposure of each project phase are calculated. The proposed procedure is illustrated by the following example (phase $f = 1$ on the level of risk $r = 1$):

$$\tilde{s}_{11} = \frac{1}{5} \cdot \left(2 \cdot \tilde{R}_2 + 2 \cdot \tilde{R}_3 + \tilde{R}_4\right) = (0.30,\ 0.48,\ 0.70)$$

$$\tilde{e}_{11} = \frac{1}{3} \cdot \left(\tilde{R}_1 + \tilde{R}_2 + \tilde{R}_3\right) = (0.13,\ 0.27,\ 0.48)$$

The aggregated values of sensitivity and exposure for reach project phase at the risk level r, $r = 1, \ldots, R$ are calculated and presented in Tables IV and V.

Following the procedure (Step 5 of the proposed algorithm), the normalized values of adaptive capacity are presented in Table VI.

The vulnerability of each project phase is obtained by the application of the proposed algorithm (Step 6 to Step 7). By illustrating the developed procedure on example of vulnerability of phase one on risk $r = 1$:

$$\begin{aligned} \tilde{V}_{11} &= \tilde{s}_{11} \cdot \tilde{e}_{11} \cdot \tilde{a}_{11} = (0.13,\ 0.27,\ 0.48) \cdot (0.20,\ 0.30,\ 1) \cdot (0.30,\ 0.48,\ 0.70) \\ &= (0.008,\ 0.04,\ 0.34) \end{aligned}$$

Vulnerability of phase one with respect to all identified risks is given as:

$$\tilde{V}_1 = \frac{1}{9} \cdot \left\{ \begin{array}{l} (0.008,\ 0.04,\ 0.34) + (0,\ 0,\ 0.10) + (0.002,\ 0.02,\ 0.23) \\ +(0.002,\ 0.06,\ 0.20) + (0.01,\ 0.06,\ 0.43) + (0.001,\ 0.01,\ 0.13) \\ +(0.003,\ 0.02,\ 0.27) + (0,\ 0,\ 0.16) + (0,\ 0,\ 0.16) \end{array} \right\}$$

$$\tilde{V}_1 = (0.005,\ 0.02,\ 0.22)$$

The representative scalar of TFN $\tilde{V}_1$ is given by the method of the maximum possibility (Step 7 of the proposed algorithm) and it is $V_1 = 0.02$.

Project phases/ Technical-operational risk factors	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$	$r = 7$	$r = 8$	$r = 9$
$f = 1$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$
$f = 2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$
$f = 3$	$\tilde{R}_2$	$\tilde{R}_{11}$	$\tilde{R}_1$	$\tilde{R}_2$	$\tilde{R}_1$	$\tilde{R}_1$	$\tilde{R}_1$	$\tilde{R}_1$	$\tilde{R}_1$
$f = 4$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$
$f = 5$	$\tilde{R}_1$	$\tilde{R}_3$	$\tilde{R}_3$	$\tilde{R}_3$	$\tilde{R}_3$	$\tilde{R}_3$	$\tilde{R}_2$	$\tilde{R}_2$	$\tilde{R}_2$

Table III.
Fuzzy rating of project phases' adaptive capacity

Table IV.
The values of sensitivity of project phases on the level of each risk

Project phases/ technical-operational risk factors	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$	$r = 7$	$r = 8$	$r = 9$
$f = 1$	(0.30, 0.48, 0.70)	(0.06, 0.18, 0.40)	(0.06, 0.18, 0.40)	(0.06, 0.18, 0.40)	(0.22, 0.42, 0.62)	(0.02, 0.06, 0.30)	(0.04, 0.12, 0.35)	(0.26, 0.46, 0.66)	(0.26, 0.46, 0.66)
$f = 2$	(0.52, 0.76, 0.86)	(0.22, 0.42, 0.48)	(0.22, 0.42, 0.48)	(0.65, 0.88, 0.96)	(0.65, 0.88, 0.96)	(0.04, 0.12, 0.34)	(0.38, 0.58, 0.78)	(0.42, 0.62, 0.82)	(0.38, 0.58, 0.78)
$f = 3$	(0.65, 0.88, 0.96)	(0.65, 0.88, 0.96)	(0.46, 0.66, 0.86)	(0.42, 0.60, 0.82)	(0.46, 0.66, 0.86)	(0.70, 0.94, 0.98)	(0.70, 0.94, 0.98)	(0.70, 0.94, 0.98)	(0.70, 0.94, 0.98)
$f = 4$	(0.04, 0.12, 0.35)	(0.38, 0.58, 0.78)	(0.70, 0.96, 1)	(0.26, 0.46, 0.66)	(0.04, 0.12, 0.35)	(0.38, 0.58, 0.78)	(0.22, 0.42, 0.62)	(0.04, 0.12, 0.35)	(0.22, 0.42, 0.62)
$f = 5$	(0.02, 0.06, 0.30)	(0.02, 0.06, 0.30)	(0.04, 0.12, 0.25)	(0.04, 0.12, 0.25)	(0.02, 0.06, 0.30)	(0.15, 0.38, 0.58)	(0.08, 0.24, 0.45)	(0.04, 0.12, 0.25)	(0.04, 0.12, 0.25)

Table V. The aggregated value of exposure of each phase on the level of each risk

Project phases/ Technical-operational risk factors	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$	$r = 7$	$r = 8$	$r = 9$
$f = 1$	(0.13, 0.27, 0.48)	(0, 0, 0.25)	(0.17, 0.37, 0.57)	(0.10, 0.30, 0.50)	(0.30, 0.50, 0.70)	(0.07, 0.20, 0.42)	(0.37, 0.57, 0.77)	(0, 0, 0.25)	(0, 0, 0.25)
$f = 2$	(0.43, 0.63, 0.83)	(0.17, 0.37, 0.57)	(0.43, 0.63, 0.83)	(0.67, 0.90, 0.97)	(0.60, 0.83, 0.90)	(0.43, 0.63, 0.83)	(0.20, 0.33, 0.55)	(0.45, 0.67, 0.80)	(0.58, 0.80, 0.93)
$f = 3$	(0.58, 0.80, 0.93)	(0.52, 0.73, 0.87)	(0.58, 0.80, 0.93)	(0.17, 0.37, 0.57)	(0.37, 0.57, 0.77)	(0.60, 0.83, 0.90)	(0.583, 0.80, 0.93)	(0.583, 0.80, 0.93)	(0.52, 0.733, 0.87)
$f = 4$	(0.07, 0.20, 0.42)	(0.37, 0.57, 0.77)	(0.27, 0.40, 0.62)	(0.07, 0.20, 0.42)	(0.07, 0.20, 0.42)	(0, 0, 0.25)	(0.0,; 0.20, 0.42)	(0.23, 0.43, 0.63)	(0.38, 0.60, 0.73)
$f = 5$	(0, 0, 0.25)	(0.30, 0.50, 0.70)	(0.03, 0.10, 0.25)	(0.27, 0.40, 0.62)	(0.03, 0.10, 0.25)	(0, 0, 0.25)	(0, 0, 0.25)	(0.20, 0.33, 0.55)	(0.10, 0.50, 0.50)

Table VI. The aggregated value of adaptive capacity of each phase on the level of each risk

Project phases/ technical-operational risk factors	$r = 1$	$r = 2$	$r = 3$	$r = 4$	$r = 5$	$r = 6$	$r = 7$	$r = 8$	$r = 9$
$f = 1$	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.40, 1, 1)	(0.20, 0.30, 1)	(0.40, 1, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)
$f = 2$	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.40, 1, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)
$f = 3$	(0.20, 0.30, 1)	(0.40, 1, 1)	(0.40, 1, 1)	(0.20, 0.30, 1)	(0.40, 1, 1)	(0.40, 1, 1)	(0.40, 1, 1)	(0.40, 1, 1)	(0.40, 1, 1)
$f = 4$	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)	(0.20, 0.30, 1)
f = 5	(0.40, 1, 1)	(0.70, 0.70, 1)	(0.70, 0.70, 1)	(0.70, 0.70, 1)	(0.70, 0.70, 1)	(0.70, 0.70, 1)	(0.20, 0.33, 1)	(0.20, 0.33, 1)	(0.20, 0.33, 1)

Similarly, vulnerability of all other phases is calculated, and the rank is determined. It is presented in Table VII.

By application of the proposed model, it is calculated that the most vulnerable phase of the project implementation is the executing phase. Based on the results of real life practice, it may be concluded that the obtained result is expected. This may be explained by the fact that this phase is impacted by the greatest influence of risk factors. The phases of Initiating, Monitoring, Controlling and Closing have similar values of vulnerability, which are relatively low, so the management team does not need to focus significantly on the vulnerability of these phases. This is important because obtaining the rank of vulnerability related to each phase is obtained leads to decreasing time, costs and other resources that are needed for the enhancement of project management practice activities in this state. The project may be realized but some measures for decreasing and managing vulnerability would be applicable.

7. Conclusion and research implications

An analysis of the existing literature sources indicates a lack of significant work in the area of project management vulnerability assessment of projects in an exact way (Vidal and Marle, 2012). This is a very significant issue, as project management represents a very important part of business activities within many organizations. Serious problems in organizations may arise from untreated vulnerability, which eventually may lead to overall business collapse or even a catastrophe.

The main practical implication to the research field is manifested through the proposed model, as it is known that the solution of any management problem which is obtained in an exact way is more precise as compared to qualitative methods (Wagner and Neshat, 2010), where the model for assessment of supply chain vulnerabilities is based on three indicator groups. This qualitative approach is dominantly focused on graphs which are used as visual maps that facilitate the understanding of vulnerabilities by analyzing the supply side, demand side and supply infrastructure. The calculated value of the project's vulnerability does not imply any significance to the enterprise's management team. That value is used for the calculation of the region of project's vulnerability (low, moderate, high), which is important information for decision-making. This way of problem solving is adopted from the existing literature in the field of chemical industry (literature). In that way, the management team is able to make important decisions, work toward decreasing the project's vulnerability or even stop the project's realization.

The main scientific implication to the research field is formalized thorough the modelling of existing qualitative data by application of the fuzzy sets theory.

The main contributions of the proposed model are further discussed below:

Project phases	$\tilde{V}_f$	V_f	The rank
$f = 1$	(0.005, 0.02, 0.220)	0.02	4
$f = 2$	(0.04, 0.14, 0.590)	0.14	2
$f = 3$	(0.12, 0.54, 0.81)	0.54	**1**
$f = 4$	(0.01, 0.04, 0.31)	0.04	3
$f = 5$	(0.002, 0.01, 0.12)	0.01	5

Table VII. The vulnerability of each project phase and their rank

- A tool for assessment of project management vulnerability in enterprises is obtained in a well-structured manner and is described by a mathematical model (this is important as this approach supports obtaining a solution by an exact method);
- The assessment is performed in the planning stages, before its realization, so it could be managed; and the modeling of uncertain and imprecise data is based on the fuzzy sets theory;
- The fuzzy averaging operator for obtaining group consensus has been deployed when various numbers of decision makers participated in the decision-making process; and
- All the possible changes, such as number of treated risks, or number of decision makers, can be easily incorporated into the model.

The main constraints of the proposed model are related to the scope of the model, as it covers only the vulnerability that originates from technical and technological risks. Also, there is a need for a structured project management practice which is in compliance with the PMBOK guide. Taking in account the contributions and the main constraints of the model, it may be concluded that it represents a solid base for further development of quantitative approaches in project management vulnerability assessment.

Further research should cover analysis of vulnerability originating from other sources of risks, such as human factors, economy, finance, etc., so that specific actions can be deployed for coping with project management vulnerability.

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