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A RISK-ASSESSMENT METHODOLOGY IN TUNNELLING

Anita Cerić, Danijela Marčić, Krešo Ivandić

Original scientific paper

This paper introduces a process-driven risk-assessment methodology in tunnelling. This methodology considers the construction process as a whole and covers all aspects of risk-management process, from risk identification to risk response. The application of the proposed methodology has been demonstrated on two phases of the construction project and was applied to tunnel construction. Risk assessment should follow the construction process. Each phase of the project has a goal that must be achieved. The goal of each phase depends on some activities that affect the phase realisation. These activities are potential sources of risk and a cyclical risk assessment should be repeated for each phase of the project. It is necessary to take into account that executing a construction project is a process, and that risk management must follow that process.

Keywords: *risk management, methodology, early project phases*

Metodologija procjene rizika u tunelogradnji

Izvorni znanstveni članak

U radu se uvodi metodologija procesom vođene procjene rizika u tunelogradnji. Ova metodologija podrazumijeva da je građevinski proces cjelina te da pokriva sve aspekte procesa upravljanja rizicima, od identifikacije rizika do odgovora na rizik. Aplikacija predložene metodologije prikazana je kroz dvije faze građevinskog projekta i primijenjena je u u tunelogradnji. Procjena rizika slijedi građevinski proces. Svaka faza projekta ima svoj cilj koji mora biti postignut. Cilj svake faze građevinskog projekta ovisi o aktivnostima koje utječu na realizaciju te faze. Te aktivnosti su potencijalni izvori rizika i ciklička procjena rizika treba se ponavljati za svaku fazu projekta. Neophodno je uzeti u obzir da je realizacija građevinskog projekta proces te da upravljanje rizicima mora slijediti taj proces.

Ključne riječi: *upravljanje rizikom, metodologija, rane projektne faze*

1 Introduction

Every construction project passes through a number of phases. Hughes [1] compared nine plans of work and concluded that there are five basic phases through which each construction project must pass. These phases are: defining the project, design work, contract formation, construction work and completion of the project. As every project passes through several common phases and there is a set of common activities that should be performed in order to achieve successful project realisation, this suggests that there is a generic way of looking at risk, as well. According to Smith [2], the management of risk is a continuous process and should span all the phases of the project.

A risk-assessment methodology in tunnelling is proposed here, where cyclical risk management is performed in each phase of the construction process. Risk management is a dynamic process because it is carried out continuously through each project phase in accordance with the changeable circumstances in which the process runs.

The proposed methodology is demonstrated on two early phases of the Process Protocol [3]. The Process Protocol divides the design and construction process into ten phases. The reason why the first two phases - Demonstrating the Need and Conception of Need - are chosen here for special attention is that uncertainties and risk are the greatest in early phases of the project [2, 4]. As the project advances toward completion, the number of unknowns decreases. The level of uncertainties is inversely proportional to the progression of the project. Godfrey et al. [5] stated that as a project progresses, cost assumptions become facts and cost uncertainty thus reduces. Therefore, early phases can be crucial for the stakeholders' strategic business decisions about the project's engagement or abandonment. Some projects will be terminated as soon as the initial risk review has been completed because risk-reward ratio is not deemed to be sufficiently attractive, and other projects will be terminated before the end of life-cycle because of adverse developments [6].

To begin with, risk probability and risk impact are determined for each identified key risk in each project phase, and thus also risk exposure. Then a risk priority list is formed and a risk response strategy defined, depending on risk acceptability. If the project manager lacks sufficient experience with a particular identified risk, it is suggested here how to make decisions about risk acceptability by taking into account the calculated risk exposure. If the risk response leads to the appearance of new risks, a new cycle of risk identification, analysis and response is undertaken.

The methodology proposed here can be applied to all project phases. However, it is demonstrated here on two early phases only. These phases are of special importance to all projects, including those that do not involve any activity specific to tunnelling according to the Process Protocol.

2 The cyclical risk-management process

Fig. 1 shows the cyclical risk-management process, which is part of the proposed methodology, and which is carried out independently for each phase of the construction project. Risk identification follows project phases. The goal of each phase depends on activities that affect phase realisation. These activities are potential sources of risk – if they are not completed, the entire phase is in jeopardy.

According to the Process Protocol, the first two phases are demonstrating the Need and Conception of the Need. The goal of the first is to establish the need for a project to satisfy the client's business requirements, whereas the goal of the second is to identify potential solutions to the need and plan for feasibility [3]. The risks identified in

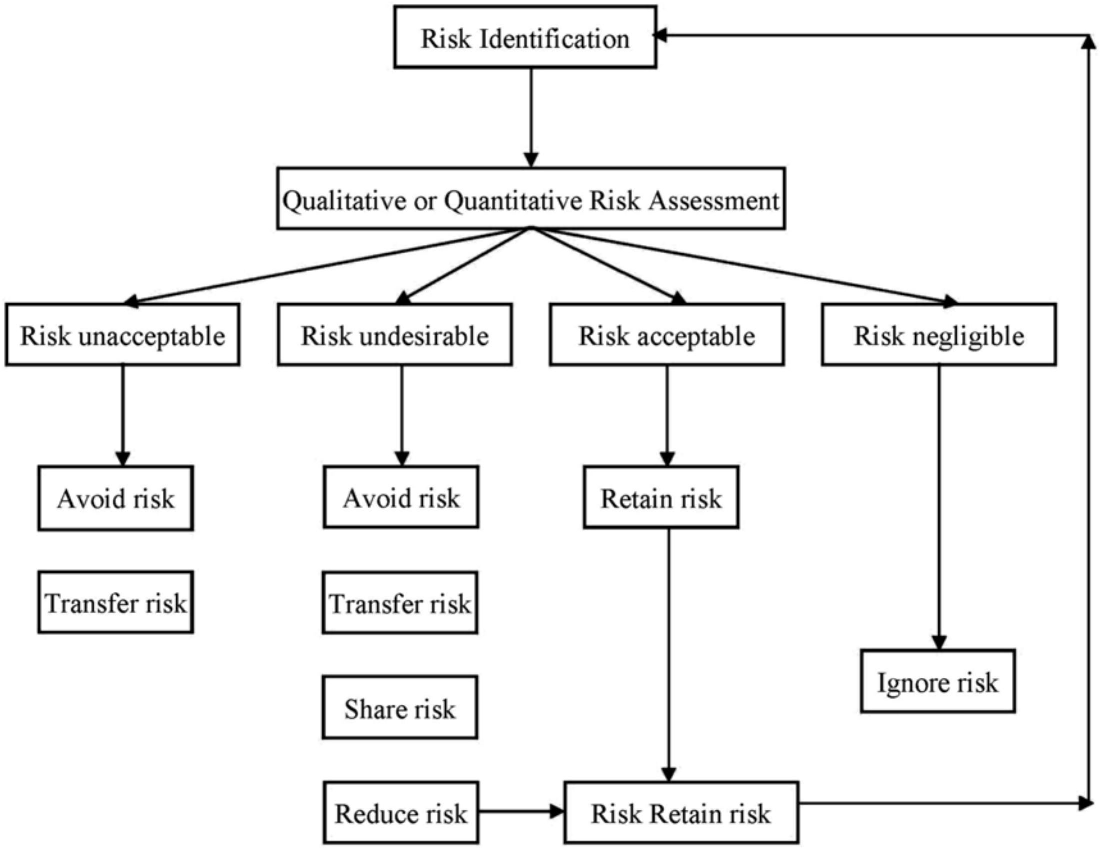

Figure 1 Cyclical risk management process [3]

connection with the first phase are unsatisfactory market research, ill-defined initial statement of need, incomplete stake-holder list, no historical data analysis of similar projects, and poor communication; and the risks identified in connection with the second phase are ill-defined statement of need, changes in the stake-holder list, poor assessment of stake-holder impact, poor communication, and incomplete identification of potential solutions [3].

The early phases of a project are of particular interest because the level of influence on total project costs is highest early on, whereas the impact of early decisions on total project costs is the highest [8]. The potential influence of stake-holders is also highest in the early project phases, before a detailed agenda is set and the cost for making changes is low [4].

Following risk identification, the analysis turns to risk probabilities and impacts. It is necessary to determine risk probability and risk impact for each identified risk in a particular phase, calculate the corresponding risk exposure, and, depending on risk acceptability, define a strategy of risk response. The procedure is repeated for each successive phase.

For each identified risk it is necessary to determine the associated risk exposure, and, depending on it, risk acceptability. Risk exposure is the product of risk probability and risk impact. Determining the risk exposures of all the identified risks in a particular phase and placing them in an interrelationship allows the formation of a risk-priority list. The position of the risk in this list—that is, the relative value of its exposure with reference to that of the other risks in the phase—determines which resources will be engaged in the planned risk response. The risk priority list can be determined using a quantitative, qualitative or mixed approach.

3 Risk priority list

The quantitative approach to forming the priority list implies that risk probability and risk impact can be explicitly calculated using one of the known quantitative risk-analysis methods. Many methods of quantitative risk analysis are in use today, the best-known being simple assessment, probabilistic analysis, sensitivity analysis, decision-tree analysis and Monte Carlo simulation [9, 10]. For each of the above, a relevant database must be available to form the probability distribution required, i.e. to enable the direct calculation of impact on time, cost and quality. In each case, a completely determined and consistent procedure can be used to determine the priority list.

Most of the past research in risk management has focused on introducing new models [11]. What happens most often in actual practice is that the risk-management team does not have the relevant database about earlier projects that could be used to form the probability distribution function and determine the risk probability. It does not have, either, all the necessary indicators for directly calculating the effects—that is, the impact the risky event would have on time, cost and quality. In such cases the risk-priority list is determined by using some of the techniques for qualitative risk analysis that various authors have already used in risk management. These include Multi-attribute Utility Theory, Fuzzy Analysis, Analytical Hierarchy Process, etc. [12].

The most usual case in practice is a combination of the quantitative and qualitative approaches. For some risks in a particular phase, there will be a database for assessing their probability—that is, their impact on time, cost or quality. For others this will not be available. If risk probability can be calculated for all the risks in any phase, then the normalisation method should be used, i.e. the quantitative approach. If it cannot be calculated for at least one risk, then the risks for which calculation is possible should be normalised, and the qualitative approach used for the interdependency of the probabilities of those risks and the one for which calculation is not possible. The same procedure should be used for risk impact on time, cost or quality.

4 Risk acceptability

An acceptability assessment is made for each identified risk in any phase, depending on its risk exposure, and methods are defined for managing it. Godfrey [5] proposed a risk classification and the corresponding risk management for each category:

UNACCEPTABLE: Intolerable, must be eliminated or transferred.

UNDESIRABLE: To be avoided if reasonably practicable, detailed investigation and cost-benefit justification required, top-level approval needed, monitoring essential.

ACCEPTABLE: Can be accepted provided the risk is managed.

NEGLIGIBLE: No further consideration needed.

The link between risk acceptability and risk exposure results from the policy of the risk management team. It depends on the type, character and complexity of the facility, and on the experience gained in constructing similar facilities. Depending on the success of project realisation, this link may be changed from phase to phase.

In the case of lack of sufficient experience, the starting link may be as shown in Tab. 1. The range of values in each part of the table is explained below. In each case, the risk probability and risk impact are given convenient hypothetical values, such as 1/2, 1/3, and 1/10.

Table 1 Risk evaluation depending on risk exposure

Risk Acceptability	Risk Exposure
Unacceptable risk	0,25 – 1,00
Undesirable risk	0,11 – 0,25
Acceptable risk	0,01 – 0,11
Negligible risk	0,00 – 0,01

Unacceptable risk: If risk probability and risk impact are greater than 1/2, then risk acceptability is greater than 0,25 (0,5·0,5 = 0,25) and, of course, smaller than 1. This means that the risk has a high probability and a great impact, which means that this risk is more probable than all the other risks of the phase put together and that it has a greater impact than all the other risks of the phase put together. If risk probability falls below 0,5 by 20 % (0,8·0,5 = 0,4), then risk impact must grow over 0,5 by 25 % (1,25·0,5 = 0,625) for risk acceptability to remain within this category. The opposite is also true. If the risk satisfies all these conditions then it is unacceptable and the response to it may be risk avoidance or risk transfer.

Undesirable risk: If risk probability and risk impact are greater than 1/3 and smaller than 1/2, then risk acceptability is between 0,11 and 0,25 (0,333·0,333 = 0,11). This means that the risk has a mean value and mean impact, and that this risk has between one third and one half probability and impact of all the other risks of the phase put together. Similarly as in the preceding category, if risk probability changes by, for example, 20 % with reference to the values of 1/3 and 1/2, risk impact must change by 25 % for the risk to remain in this category. Of course, the opposite is also true. If the risk satisfies all these conditions then it is undesirable and the risk response may be risk avoidance, risk transfer, risk reduction or risk sharing with the necessary risk monitoring.

Acceptable risk: If risk probability and risk impact are greater than 1/10 and smaller than 1/3, then risk acceptability is between 0,01 and 0,11 (0,1·0,1 = 0,01). This means that the risk has a small probability and small impact, and it has between one tenth and one third probability and impact of all the other risks in the phase put together. Similarly as in the preceding categories, if risk probability changes by, for example, 20 % with reference to 1/3 and 1/2, risk impact must change by 25 % for the risk to remain in this category. Of course, the opposite is true, as well. If the risk satisfies these conditions then it is acceptable and the response to it may be risk retention with the necessary risk monitoring.

Negligible risk: If risk probability and risk impact are smaller than 1/10, then risk acceptability is between 0,0 and 0,01. This means that the risk has a negligible probability and negligible impact, and that this risk has less than one tenth probability and impact of all the other risks in the phase put together. Similarly as in the preceding categories, if risk probability changes by, for example, 20 % with reference to the values of 1/3 and 1/2, risk impact must change by 25 % for the risk to remain in this category. Of course, the opposite holds true, as well. If the risk satisfies these conditions then it is negligible and no response to it is needed.

This kind of risk analysis is performed for each phase separately. If some activities, or some causes of risk, are carried from one phase to another, the corresponding risk is also transferred. Therefore it is necessary, after every phase, to once more single out all the risks that will be analysed in the next phase.

5 Risk response

Each identified risk, depending on the level of risk exposure, is classed as unacceptable, undesirable, acceptable or negligible. This classification affects the decision about how to respond to it [13]. If a risk is classed as unacceptable, the response to it may be risk avoidance or risk transfer. If a risk is classed as undesirable, the response to it may be risk avoidance, risk transfer, risk reduction or risk sharing with the appropriate risk monitoring. If a risk is classed as acceptable, the response to it may be risk retention with the appropriate risk monitoring. If the risk is classed as negligible, no response to it is necessary. The above is illustrated in Fig. 1.

Risk avoidance: In practice, risk avoidance means refusing to accept the risk at all [14]. Qualitative assessment has shown that the risk should simply be eliminated in the case of such high-risk exposure. To eliminate the risk, research is necessary into whether the potential source of risk can be eliminated, the unfavourable event in which the risk is inherent. The most drastic way of avoiding risk is not to accept the contract, to give up the project. Risks can also be avoided by introducing a contract clause whereby some risks, that is their consequences, shall not be accepted.

Risk transfer: This response means transferring the risk to any other participant in the project but the investor through contracting [15]. The investor can transfer the risk to the contractor or the designer; the contractor to his sub-contractors; or the investor, contractor or sub-contractors to the insurance company, and the contractor and sub-contractors to their guarantee. When choosing a risk-transfer strategy through contracting, account should always be taken of which participant in the project can best control events that may lead to the appearance of the risk. Account should be taken of which participant can best control the risk if it occurs, or assume a risk that cannot be controlled.

Risk sharing: When a project participant cannot control risk exposure, then he can share it with other participants [16]. Part of the risk may be transferred, but part should be assumed and one of the risk responses applied.

Risk retention: When a project participant estimates that the risk probability is small, or that its impact is acceptable, the risk is simply retained and no response is made [17]. This does not mean that the risk is ignored; it is monitored and controlled, and its exposure is constantly checked.

Risk reduction: Most risks need not be avoided or transferred, they need not be shared with other project participants, nor need they simply be retained and not responded to [13]. Certain measures can be undertaken to reduce risk exposure—that is, to decrease the probability of an event with adverse effects, or decrease the impact of these effects on the project. Risk reduction demands certain initial investment. It goes without saying that this investment should be smaller than the expenses entailed by the occurrence of the adverse event. For example, tunnel excavation in weak rock mass is subject to the risk of rock-mass stability loss due to inadequate sub-structuring or water penetration. Additional research is an expense, but it considerably decreases these risks. The costs of additional research should be smaller than the costs of repair if caving does occur. Risk reduction also provides new knowledge about the project and the conditions under which it is being performed. An attempt to reduce risk may lead to more detailed designing plans, an alternative contracting strategy or some other method for executing the project.

6 Application of the risk-assessment methodology in tunnelling

Tunnel construction is exposed to a wide variety of risks, many of which are well known [18]. Dudeck [19] and John [20] performed important research on risk in tunnel construction. Smith [2] gave a case study showing risk assessments and analysis performed during preparations to design, construct and operate the Channel Tunnel Rail Link.

The proposed methodology was applied on a highway tunnel in Croatia. Carbonate karst formations from the Jurassic and Cretaceous period are present on over 50 % of the total coastal area of the Republic of Croatia [21, 22]. Road construction is of special importance in the Republic of Croatia because of tourism, which is one of the main industrial branches, so the Government made it an investment priority. In the case of the tunnel chosen for methodology testing, the experts involved had extensive experience on similar projects.

The proposed methodology was applied to all project phases according to the Process Protocol, but only Phases Zero and One are presented here. The methodology and its application to Phase Zero was presented elsewhere [23]; however, it is only summarised here.

The application of the proposed methodology was tested in several steps. The first step was the choice of experts to participate in testing. In the second step, all experts chosen were given the list of key risks, upon which they agreed on the proposed list for initial analysis, given that other risks could be added in later stages of analysis. The third step was to calculate risk exposures. As there was no historical data available, a qualitative approach was chosen for risk analysis, which was carried out in the following three steps:

Step One: Questionnaire-type forms made for each phase separately were distributed to all the experts. The forms were adapted to the Analytic Hierarchy Process or AHP method [24] and enabled making a series of judgments about interrelationships among the identified risks with reference to probability, time, cost and quality, and defining the mutual significance of time, cost and quality in each phase.

Step Two: The comparison results were entered in the database of the PP-Risk computer programme [25, 26] and after calculation of risk exposure; the experts were requested to provide the appropriate risk response.

Step Three: Finally, the project manager made judgments and risk responses for all the project phases, taking into account all the judgments made by the experts, as well as the exposures and the appropriate risk responses obtained.

The list of key risks identified and analysed for phase zero *Demonstrating the Need* and phase One *Conception of Need* are shown in Tab. 2 and 3 [7] and results of risk analysis obtained by PP-Risk computer programme are shown in Fig. 2 and 3.

Appropriate risk responses are shown in Fig. 1 and explained in Section 5 above. As can be seen from Tabs. 2 and 3, poor communication in tunnelling is common to both phases. In general, poor communication is one of the most common project risks [7]. Available collaboration technologies are yet to be properly employed in integrating communications among all project participants in practice [27].

The risk exposure of a particular risk may be directly correlated with the assets available to manage that risk in a particular phase by calculating the participation of its risk exposure in the total risk exposure of that phase. The total risk exposure is obtained by adding up all the exposures in a phase except the exposures of negligible risks, because these risks are disregarded, so no investment is necessary to respond to them. For example, Risks 2 and 3 for Phase One in Tab. 3 are negligible, and their risk exposures need not be considered any further. Therefore, the total risk exposures for Risks 1, 4 and 5 together would be 0,061 + 0,035 + 0,202 = 0,298. In the case of Risk 4, for example, this means that 0,035/0,298 = 0,117 or 12 % of the total assets available for risk management in this phase can be used to manage this particular risk. Complete risk responses for all key risks identified for phase zero *Demonstrating the Need* and phase One *Conception of Need* are shown in Tab. 4 and 5.

Table 2 The list of key risks for Phase Zero – Demonstrating the Need

Risk code	Risk name	Risk description
001	Unsatisfactory market research	In this earliest project phase it is necessary to research the market of existing structures which may help the client express his requirements or demands as clearly as possible. This is especially important as some of the stakeholders will be participating in the realisation of such a project for the first and only time. When they see what they could obtain, clients will be able to express what they really want much more clearly. Without market research and the presentation to clients there is a significant risk that the goals will not be fulfilled.
002	Ill-defined initial statement of need	All the client's needs, goals and demands should be described in as much detail as possible in a document according to Process Protocol called Statement of Need. In this early project phase it is very difficult to define all the demands and needs. In further project phases the elaboration and evaluation of potential solutions will lead to their reduction or may even extend the demands of the client, i.e. the stakeholder.
003	Incomplete stakeholder list	Each stakeholder has his needs and demands, depending on his investment in the project. An incomplete stakeholder list makes it impossible to form all sources of funding and means that demands differing from earlier ones may appear. An incomplete stakeholder list is a risk for the entire phase zero not fulfilling its basic goals.
004	No historical data analysis	In the earliest project phase, after the client's needs, goals and demands have been defined, it is necessary to analyse available data about all risk sources on similar projects that have already been executed. There is also a risk of leaving out of the risk list a risk that in the past showed significant risk exposure in a project phase. Analysing available data considerably contributes to a better understanding of the problem.
005	Poor communications	In the earliest project phase it is necessary to establish a communication strategy within the management team participating in the project phase (development, resources, facilities, project and process management) and between the management team and the client and stakeholders. Success in realising the goals of phase zero greatly depends on this communication.

Table 3 The list of key risks for Phase One – Conception of Need

Risk code	Risk name	Risk description
101	Ill-defined statement of need	In this phase all the client's needs, goals and demands should be finally defined and the Statement of Need finalised. This will serve as the basis for defining potential solutions. There is a risk of leaving out potentially good solutions because all the client's needs were not sufficiently investigated.
102	Changes in stakeholder list	Since this is the phase when potential solutions are proposed any change in the stakeholder's list leads to the risk that introducing new stakeholders will change earlier demands and in fact lead to the rejection of some solutions already proposed.
103	Poor assessment of stakeholder impact	A stakeholder's investment in the project defines his impact. The greater a stakeholder's impact the higher his needs will rank over the needs of others. A poor assessment of stakeholder impact may lead to the stakeholders with a smaller impact having their needs satisfied and the stakeholders who consider they were assigned too small an impact in relation to their investment being dissatisfied and abandoning the project.
104	Poor communications	The communication strategy must be added in every project phase. In this phase there is a risk of bad communication between all the previous participants and the design management, which joins the project in this phase and proposes potential solutions on the basis of needs, investigations and environmental impact assessment.
105	Incomplete identification of potential solution	The design management should propose a sufficient number of potential solutions to be used as a basis for feasibility studies. All the proposed solutions must be as well defined as possible, must be practicable, contain a description of the necessary investigations and a preliminary analysis of possible environmental impact.

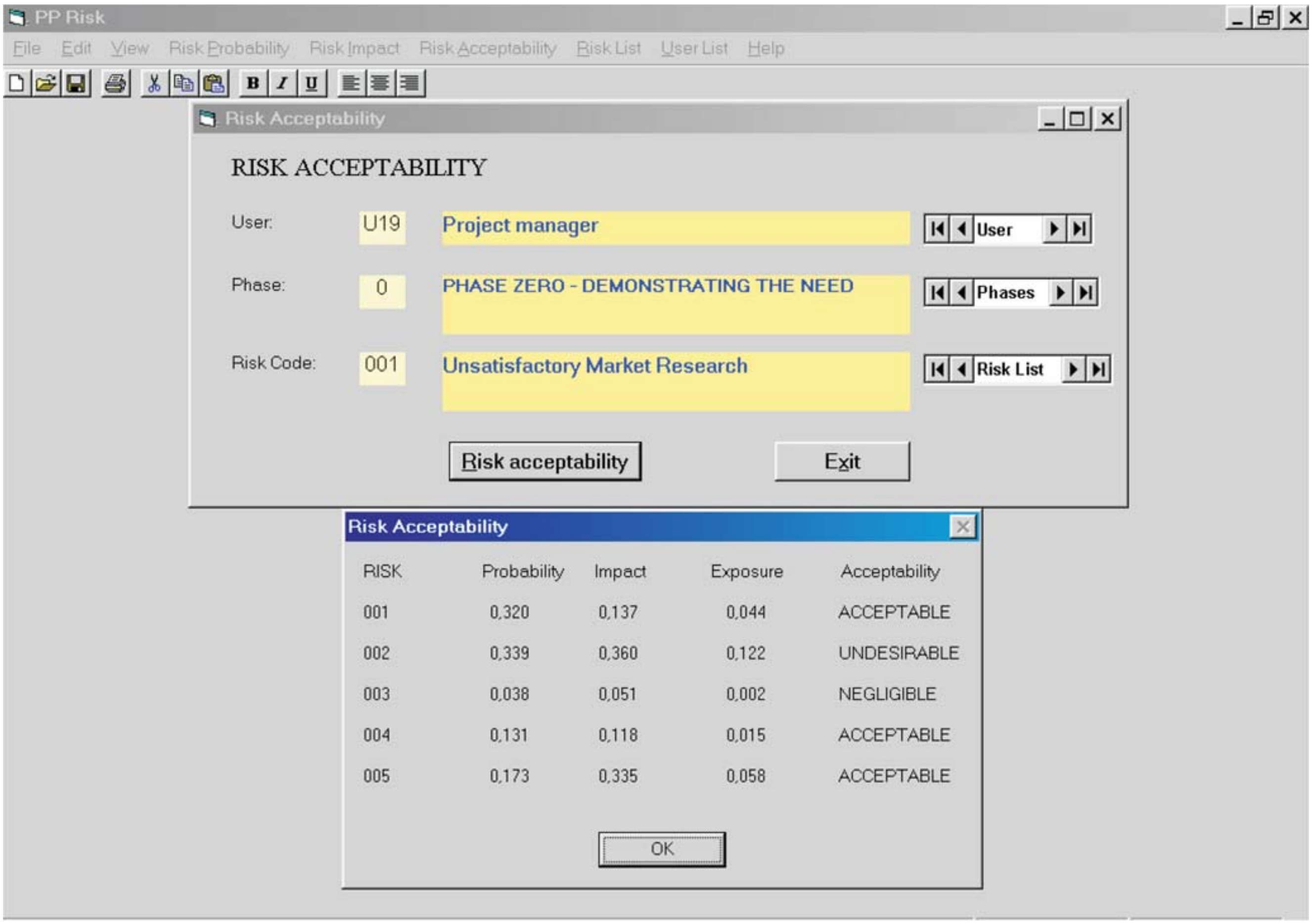

Figure 2: Phase 0: Risk exposure and risk acceptability obtained by PP-Risk for Phase Zero – Demonstrating the Need

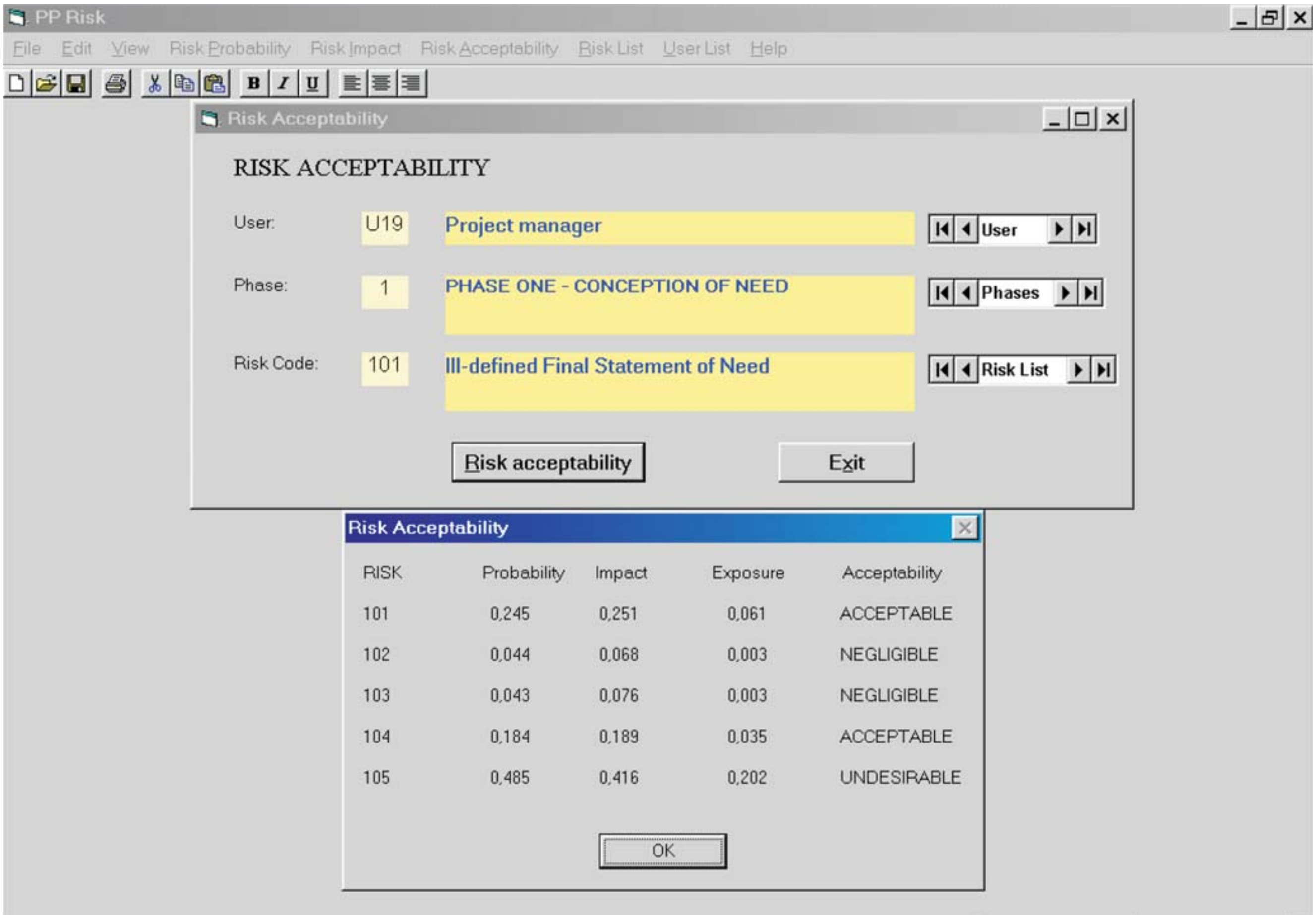

Figure 3 Phase 1: Risk exposure and risk acceptability obtained by PP-Risk for Phase One – Conception of Need

Table 4 Risk response for Phase Zero – Demonstrating the Need

Risk code	Risk name	Risk response
001	Unsatisfactory market research	Risk is acceptable. Response method: Risk retention. As the government founded several firms for infrastructure construction, the management team should avail itself of the opportunity (the same owner) of exchanging experiences with other firms that have already constructed similar facilities. No additional funds need be invested for managing this risk and the 19 % of the assets available should be used for further personnel training through seminars, study trips and other forms of further education.
002	Ill-defined initial statement of need	Risk is undesirable. Response methods: Risk sharing and reduction. Responsibility for a possible unfavourable outcome must be defined more precisely, that is, shared out between development, facilities and project managements, and measures taken for their additional training and including new people in management teams. Manage this risk using 51 % of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.
003	Incomplete stakeholder list	Risk is negligible. Response methods: No need. This result is expected because the government is the only stakeholder through the firms it founded.
004	No historical data analysis	No Historical Data Analysis. Risk is acceptable. Response methods: Risk retention. No systematised database about risk sources in earlier similar projects exists so it is impossible to do anything except continuous monitoring. Therefore this risk may be neglected. Still, the 6% assets available should be used for forming and continuously updating the database for this project.
005	Poor communications	Risk is acceptable. Response method: Risk reduction. Engage additional resources to establish a complete and efficient communication strategy within the management team participating in this project phase. Use 24 % of the total assets available in this phase for defining a communication strategy. Continuously monitor cost-effectiveness of investments in improving communications during the realisation of this phase.

Table 5 Risk responses for Phase One – Conception of Need

Risk code	Risk name	Risk response
101	Ill-defined statement of need	Risk is acceptable. Response method: Risk retention. Form an expert group to review the Final Statement of Need and assess whether the Government's needs, goals and demands have been completely defined. Use 20 % of the total assets available in this phase to manage this risk.
102	Changes in stakeholder list	Risk is negligible. Response methods: No need. The only stakeholder is the government, that is, the government-founded firm for managing infrastructure facilities. Thus this risk may be disregarded.
103	Poor assessment of stakeholder impact	Risk is negligible. Response methods: No need. This risk may be disregarded for the same reason as Risk 102.
104	Poor communications	Risk is acceptable. Response method: Risk retention. Include the design management team in the communication chain alongside all the project participants thus far. Continuously monitor and upgrade communications quality and level and communications infrastructure, using 12 % of the total assets available in this phase.
105	Incomplete identification of potential solution	Risk is undesirable. Response methods: Risk reduction. Reduce risk by engaging consulting firms and/or independent consultants with the necessary experience in designing similar facilities. This will help design management to propose a sufficient number of potential solutions as the bases for a feasibility study. Manage this risk using 68 % of the total assets available in this phase, including continuous monitoring and re-examination of the current value of exposure during phase realisation.

7 Conclusion

This paper proposes a methodology for process-driven risk management in tunnelling. Risk identification follows project phases. A cyclical risk-management process is part of the proposed methodology and should be carried out independently for each phase of the construction project.

For each identified risk in a particular phase it is necessary to determine risk probability and risk impact, and calculate the corresponding risk exposure. By determining risk exposure for all the identified risks, a priority list can be formed. Depending on the position of the risk in the risk-priority list—that is, on the relative value of its exposure with reference to the other risks in the phase—resources will be engaged for the anticipated risk response. The risk priority list can be determined using a quantitative, qualitative or mixed approach.

The proposed methodology was tested on tunnel construction in Croatia. Tests have shown that the methodology is applicable to this particular construction domain. Further tests are needed to assess wider application of the methodology.

In addition, further research should consider several aspects of the proposed methodology. First, the risk-acceptability guidelines offered in this paper require further investigation. This is especially important in the early project phases, which are crucial to project success. Second, the applicability of the proposed methodology to a wide variety of projects needs to be tested with special reference to the early project phases. And third, poor communication between project participants should be investigated in greater detail. All phases of risk management crucially depend on this issue.

8
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Authors' addresses

Prof. dr. sc. Anita Cerić, dipl .ing. građ.
Sveučilište u Zagrebu
Građevinski fakultet
Zavod za geotehniku
Kačićeva 26
10000 Zagreb, Croatia
E-mail: anita@grad.hr

Doc. dr. sc. Danijela Marčić, dipl. ing. građ.
Sveučilište u Zagrebu
Građevinski fakultet
Zavod za geotehniku
Kačićeva 26
10000 Zagreb, Croatia
E-mail: djk@grad.hr

Doc. dr. sc. Krešo Ivandić, dipl. ing. građ.
Sveučilište u Zagrebu
Geotehnički fakultet
Zavod za geotehniku
Hallerova aleja 7
42000 Varaždin, Croatia
E-mail: kreso.ivandic@gfv.hr