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A tool for integrating time, cost and quality perspectives in Probability Impact (P-I) Tables

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Abstract: One widely documented tool for project risk analysis is the Probability-Impact (P-I) Table, which assesses the probability of occurrence of a risky event and its likely impact on the project objectives, which are typically articulated in terms of cost, time and quality. Whilst there are numerous adaptations of the P-I Table, they are all consistent in treating the project objectives as independent and unrelated variables. This is a major limitation of the tool and reduces the P-I Table's practical applicability, as in most project contexts the probabilities and impacts of a risky event on the project objectives will be inter-related. To address this limitation, this paper presents a new tool that uses vector theory to enable a single calculation of the overall probability and impact, incorporating the perspective of all three objectives. The tool is illustrated through a practical application to a real case construction project.

Keywords: risk management; vector theory; probability-impact tables; construction.

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1 Introduction

The construction industry has traditionally been plagued by high levels of risk (Tah and Carr, 2001), yet traditionally those involved in the management of risk in the construction industry have not performed risk management in a systematic way (Al-Bahar and Crandall, 1990). Rather, they have tended to eschew formal risk management tools and techniques and use their knowledge and experience of working on past projects to make decisions related to risk identification, analysis and response (Bryde and Volm, 2009). The assumption has been that the more experience one has the better one will be able to deal with risks. In the UK this approach might, in part, be related to the structure of the construction industry, which is dominated by medium and small-sized companies (Office for National Statistics, 2010). With such a high degree of fragmentation and lots of different parties involved in the production of the end product, many of those involved do not see formalised risk management tools and techniques as useful in addressing the day-to-day challenges of dealing with the risks they face in respect of the uncertainties inherent in construction projects. A commonly heard sentence amongst those involved in construction projects is ‘we have always done it this way and it has always worked’. This fundamental approach or philosophy is one of the reasons why the construction industry has been criticised for the slow development or take-up of new management methods or techniques, resulted in the perception that it lags behind other sectors, such as manufacturing (Egan, 1998).

However, whilst informal approaches to managing project risk may have been sufficient in the past, the current and future environment in which construction projects are undertaken presents fresh challenges for those involved in the management of risk. These challenges include: increased globalisation of construction supply chains; the drive to more efficient ways of working i.e., lean, just-in-time, standardisation and off-site fabrication, increased client expectations in terms of meeting cost, time and quality objectives. Given these changes it is vital that project practitioners involved in managing construction project risk have tools and techniques to support them that are both efficient to use and effective in aiding the decision-making processes. If such tools are present then it is more likely that they will be perceived as both useful and worth adopting, to complement the existing, often experience-based approaches, currently used.

The current project management (PM) literature shows different ways in performing qualitative risk analysis on (construction) projects. One of the most used tools in practice is the Probability-Impact (P-I) Table, which helps the PM to refine the identified risks through considering the relationship between the probability and the impact of the risk on a two-dimensional gird. The project objectives, cost, time and quality are treated independently for each risk. The authors have the view on risk that a separation between cost, time and quality when analysing risks in a qualitative way is not possible, due to the fact that the Iron-Triangle of PM is related to each other. This problem has been addressed already through the Project Management Body of Knowledge (PMBoK) in its last edition, but an overall rating scheme has not been presented (PMI, 2008). The need for such tools provides the rationale for this paper, which aims to develop a tool for qualitative risk analysis that addresses a limitation of current tools; namely, the treatment of the cost, time and quality objectives as independent rather than related variables.

The paper has four sections. The first section provides the conceptual framework, with a focus on qualitative risk analysis, which specifically relates to the purpose of the new tool. It also presents the definition of the problem and highlights the incongruity between project risk analysis theory and tool development, in terms of the treatment of the interdependence of the project objectives. The second section covers the theoretical derivation of the new tool for construction project risk analysis. Next, the tool is demonstrated by applying it to a real construction project example. Finally, some conclusions are drawn and potential further work highlighted.

2 Conceptual framework and problem definition

The term ‘risk’ is based on the Italian word ‘risico’ or ‘risco’ (today ‘rischio’) from the sixteenth century (Girmscheid, 2006). Risico historically meant to sail around cliffs or dangerous rocks (ibid.). The derivation of the word clarifies dictionary definitions of the term ‘risk’, such as “the possibility of meeting danger or suffering harm or loss, exposure to this” [Oxford Dictionary, (1984), p.545]. However, classic and dictionary definitions do not include the positive opportunities which can arise out of risky situations (Ward and Chapman, 2003). Therefore, the ISO standard 31000 of the International Organisation for Standardisation (2009, p.1) has defined the term ‘risk’ as the “effect of uncertainty on objectives”, which describes it more neutrally. This is reflected in the defintions of risk from the respective professional bodies, such as the Association of Project Management and the Project Management Institute, who, respectively, define risk as:

- the combination of the probability or frequency of occurrence of a defined threat or opportunityand the magnitude of the consequences of the occurrence (APM, 2000)
- an uncertain event that, if it occurs, has a positive or negative effect on at least one project objective, such as time cost, scope or quality (PMI, 2008).

The characteristic of risk is desribed by two components, which is the impact and the probability (PMI, 2008; International Organisation for Standardisation, 2009; Hubbard 2009). Hubbard (2009, p.87) is aguing that risks are vector quantities, because “Vector quantities are quantities that can be described only in two or more dimensions [...]”. Therefore, can a risk kept in its separate components and can be seen as vector quantity (Hubbard, 2009). The definition of Hubbard (2009, p.88) “[...] simply states that risk is both probability and the consequence and doesn’t say that they should necessarily be multiplied together”.

In the case of construction projects there are many potential sources of risk, some related to the entrepreneurial tasks of undertaking a development, as well as those related to the construction tasks themselves (Girmscheid, 2006). That the construction industry is subjected to high levels of risk has long been recognised (Tah and Carr, 2000). Specific reasons related to the construction tasks have been long-understood and include: the uniqueness of each project; changing design teams consisting of architects and engineers which are formed only for one particular project; awarding of unknown contractors, where decisions were only made because of the lowest tender price; uncertainty about the qualitative, quantitative and physical performance of successful tenderers and their staff; ground conditions; changing material costs and weather conditions (Roesel, 1987). Given that there is the potential for events and consequences that constitute opportunities for benefit (upside) or threats to success (downside) means that both have to be taken into account when undertaking a project (Institute of Risk Management et al., 2002).

The objectives of project risk management (PRM) are “[…] to increase the probability and impact of positive events, and decrease the probability and impact of negative events in the project” [PMI, (2008), p.273]. The ISO Standard 31000 defines the risk management process in terms of the following steps [International Organisation for Standardisation, (2009), p.14]:

1 Establishing the context

2 Risk Assessment

   2.1 Risk identification

   2.2 Risk analysis

   2.3 Risk evaluation

3 Risk treatment.

The focus of the tool developed in this paper is on 2.2 Risk analysis, particularly on qualitative risk analysis, which is the 2nd step in the Risk assessment process, after Risk identification. Risk analysis involves consideration of the causes and sources of risk, their positive and negative consequences, and the likelihood that those consequences can occur (International Organisation for Standardisation, 2009). Risk analysis can be done in a quantitative and/or qualitative manner (Wang et al., 2004, ibid.). Performing risk analysis in a qualitative manner is the process of "[…] prioritizing risks for further analysis or action by assessing and combining their probability of occurrence and impact" [PMI, (2008), p.289]. The focus of such qualitative risk analysis is to refine the identified risks, because these can be many (Hillson, 2001; Fischer et al., 2007) and categorise them for further actions.

The PMI (2008) describes other tools such as risk probability and impact assessment, risk data quality assessment, risk categorisation, risk urgency assessment or expert judgement for performing qualitative risk analysis. But in comparison with the P-I Table, these tools do not enable a systematic qualitative analysis of risks and do not provide the same high amount of transparency, which might be the reason why the P-I Table, also known as P-I Matrix or Risk Matrix is the most common tool in construction practice (Gleissner et al., 2007). In a P-I Table the probability and impacts of each risk are assessed against defined scales (see Table 1), and plotted on a two-dimensional grid [Hillson, (2001), p.237]. The basical qualitative and linear values are provided through defined impact scales for individual project objectives (PMI, 2008). A P-I Table typically consists on three areas, which are:

1 risks which have to be treated

2 risks which need to be decided, if treatment is required or not

3 risks which do not need any treatment, but need to be monitored (Schelle et al., 2005; Fabri, 2008; Patzak and Rattay, 2009).

These areas or categories describe how to deal further with the risks, in which risks are typically analysed separately for each objective i.e., a cost-related risk, time risk, or quality risk (Schelle et al., 2005; PMI, 2008; Patzak and Rattay, 2009). As a result the P-I Table provides high visibility in a systematic way of analysing risks in a qualitative manner, but is not able to use multiple criteria in an overall rating scheme, i.e., to show the impact on time, quality and cost at the same time.

The P-I Table has been further developed by MITRE Cooperation, who developed a software package covering the functions of the P-I Table as well as a Borda index sorting method (Ni et al., 2010). The Borda index sorting method describes the application of the Borda algorithm (developed by the French mathematician Jean-Charles Chevalier de Borda in the 17th century) to risk management (Garvey, 2009). The Borda algorithm, also known as Borda Voting Method, was originally used in voting theory to rank candidates according to their votes (ibid). The need for a tool, such as Borda, came from a limitation of the P-I Table, which is the distinction of only three areas (treat, decide and monitor) as mentioned previously(Garvey and Lansdowne, 1998). Therefore the Borda tool compares the risks and ranks them relative to each other in order to prioritise which is the most important risk: where actions have to made now; the second risk, where actions have to be made next, and so on. The derivation of the forumula is articulated by Garvey and Lansdowne (1998, pp.19–20) as follows:

"Let N be the total number of risks […]. Let the index i denote a particular risk and the index k denote a criterion. The original Risk Matrix has only two criteria: the impact I denoted by $k = 1$ and the probability assesment […] denoted by $k = 2$. If r_{ik} is the rank of risk I under criterion k, the Borda count for risk i is given by $b_i = \sum_k (N - r_{ik})$. The risks are then ordered (ranked) according to these counts".

The extention of the Borda tool beyond the two criteria of probability and impact has been detailed by Garvey (2009) through the use of five criterion (probability, cost, schedule, technical performance and programmatics). One feature of the Borda tools is that it ranks several risks relative to each other. If one has only one risk – unlikely in practice, but theoretically possible – the Borda tool is not applicable as it need at least two risks to generate the comparator. Also, if there are two risks with the same values, the tool cannot be applied because it is not able to generate a distinctive ranking. Furthermore, the application of the Borda is a cyclic process, i.e., if a new risk has been identified the Borda Values of all risks will change or if a risk has been eliminated, the Borda Values of all risks will change again. Professional software support is needed to use the Borda tool in construction practice where a large number of risks exist, because the calculation of the Borda Value becomes increasingly more complex the more risks a project has.

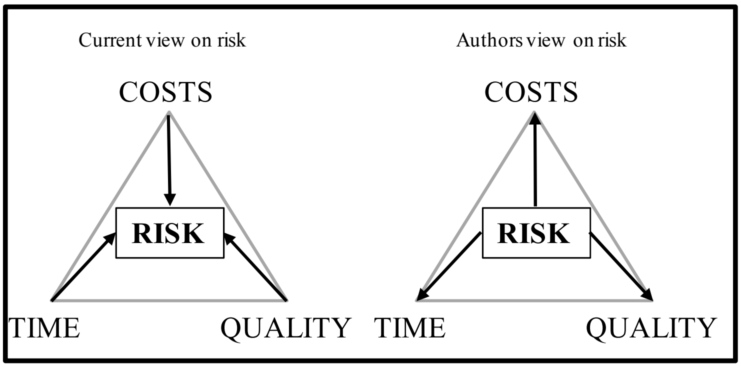
Table 1 Impact and probability project risk objectives

Impact				
Cost	*Time*	*Quality*	*Impact*	*Linear score*
Insignificant cost increase	Insignificant time increase	Quality degradation barely noticeable	Very low	0,05
< 10% cost increase	< 5% time increase	Only very demanding applications are affected	Low	0,1
10–20% cost increase	5–10% time increase	Quality reduction requires sponsor approval	Moderate	0,2
20–40% cost increase	10–20%time increase	Quality reduction unacceptable to sponsor	High	0,4
> 40% cost increase	> 20% time increase	Project end item is effectively useless	Very high	0,8

Probability		
Qualitative scale	*Quantitative scale*	*Linear score*
Implausible	1–19%	0,1
Once in a blue moon	20–39%	0,3
Uncommon	40–59%	0,5
Possible	60–79%	0,7
Common	> 79%	0,9

To summarise, current literature provides tools which treat cost, time and quality risks independently or provides tools which consider multiple criteria but work by generating rankings with no fixed domain of definition, where decisions can be made based on a particular risk. The new tool for risk analysis developed by the authors, which is conceptualised through Figure 1, builds on these existing tool by specifically addressing the need for a perspective that reflects the inter-relationship between the criteria of cost, time and quality:

Figure 1 Current vs. author's view on risk



A project risk is defined as "[...] an uncertain event or condition that, if it occurs, has an effect on at least one project objective" [PMI, (2008), p.275] which, ultimately impacts on project success. However, project success means different things to different people (Chan and Chan, 2004). There are different ways of conceptualising project success in the PM literature. deWit (1988) differentiates between PM success and project success. PM success focuses on the management of the 'Iron-Triangle', which is meeting cost, time and quality objectives (Atkinson, 1999). PM success can be seen as a part of the project success. But the project success considers more factors than the Iron-Triangle, such as stakeholder satisfaction, performance of the end product or service, and motivation (deWit, 1988; Chan and Chan, 2004). The focus of the risk analysis tool in this paper is on the PM success, specifically the meeting of the time, cost and quality objectives, as these are related to the end product, i.e., a constructed facility, and are fundamental to managing construction project risk.

3 Discussion and derivation of the tool for risk analysis

Given that project objectives are related to each other (Atkinson, 1999; PMI, 2008; El-Rayes and Kandil, 2010), it follows that any treatment of project risk ought, in some way, to reflect their inter-relationships. For example, a risk may have the greatest impact on the time objective, such as the late delivery of materials, but there may also be an influence on cost, such as expenses occurred in expediting delivery and an impact on quality, such as a decline in workmanship due to pressure to make up the lost time on the job (Atkinson, 1999). Therefore the rationale of the tools presented in this paper articulates the effect of a risk on the Iron-Triangle (ibid) as a single value, which can support objective decision making for the parties involved in construction. Such a value will give transparency of the impact of a risk to the project, as the derivation of a single value will allow ranking of risks based on a holistic view of effect on objectives. Once ranks have been constructed priorities can be set, which risks are to be monitored identified, and what decisions have to be made and what strategies to implement can be chosen.

To know the expected aims and the objectives of the project they have to be defined. This is normally done in practice with a kick-off workshop. In this workshop key stakeholders with high salience, such as the PM and the owner (in some cases also the user of the building) define the aims and objectives of the project. During that workshop the strategic objectives of the project in regard to risks have to be taken into account (Institute of Risk Management et al., 2002), for instance by defining the risks' probabilities and impacts.

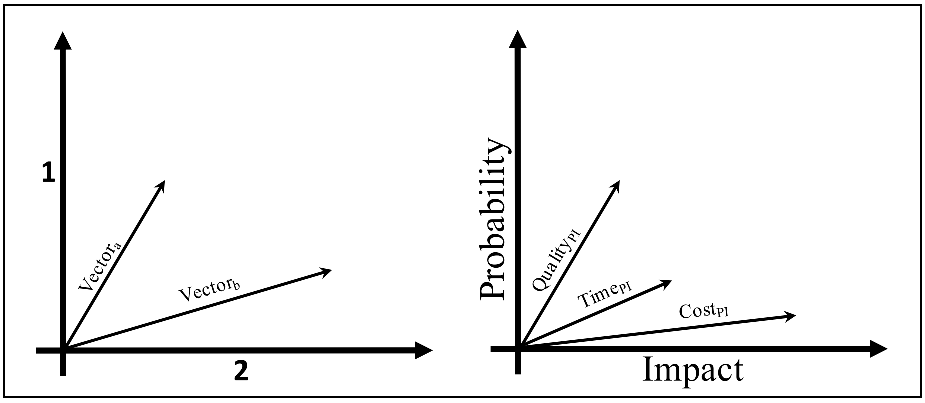
The derivation of the tool adapts the definition of the risk probabilities and impacts as shown in the latest PMBoK of the Project Management Institute (PMI, 2008). The difference is that the row scope in the tool is deleted, as everything in scope can be articulated through the Iron-Triangle elements. Furthermore, rows have been added for the probability (see Table1). The client has to define, for example, what has a low impact on the schedule i.e., the client may determine that a < 2% increase in schedule is classed as 'low impact'. The parameters will be set for each objective in respect of both impact and probability. There will be flexibility in the setting of such parameters and the classification may vary from project to project. The same process will be followed for opportunities as well as threats. Defining these qualitative measures is one of the most important steps in the risk management process, because it sets the framework for the use of the tool during the subsequent risk analysis. Table 1 shows a linear score to each piece of qualitative data. After the linear score has been defined, the risk is located in the P-I Table and one sees if a risk needs to be monitored, decisions have to be made, or if a risk needs to be treated.

The proposed tool by the authors is able to reduce the three components down to one number, which can be used to inform decisions about the kind of treatment a risk requires. Such a method is derived by the use of vector mathematics, which has been linked previously to the treatment of risk. Hubbard (2009) argued that risks are vectors, which have two components, the probability and the impact. Mathematically a vector is defined as follows:

$$\begin{pmatrix} a_1 \\ a_2 \end{pmatrix} = vector\ a \text{ or } \begin{pmatrix} b_1 \\ b_2 \end{pmatrix} = vector\ b$$

An example vector is shown in Figure 2.

Figure 2 Vectors general and risk as a vector



Considering each of the Iron-Triangle elements – cost, schedule and quality – as vectors gives the following definitions:

$$\begin{pmatrix} C_P \\ C_I \end{pmatrix} = Cost_{PI} \quad \begin{pmatrix} T_P \\ T_I \end{pmatrix} = Time_{PI} \quad \begin{pmatrix} Q_P \\ Q_I \end{pmatrix} = Quality_{PI}$$

In which *P* stands for probability and *I* for impact and therefore *PI* for probability impact i.e., the risk vector. This is illustrated as well in Figure 2. Based on the framework of the PMI and the authors' own knowledge and experience of project environments the areas of the P-I Table are shown in Figure 4. The overall factor, which is a composite of the individual time, quality and cost vectors, is called the 'Composite of time quality and cost', in short 'Comp(TQC)'. Applying resultant vector calculations to risk management, results in the following formula for the Comp(TQC)-value

$$\sqrt{\left(\sum Probability\right)^2 + \left(\sum Impact\right)^2} = \text{Comp(TQC)}$$

And can be illustrated through Figure 3.

This is a conceptual formula, which is based on Hubbard's (2009) research findings, in which risk is defined as vector quantity. Therefore when calculating the Comp(TQC)-value one is not adding the probabilities or the impacts, the numerical values which are added are linear scores out of the PI-Table. The result is a resultant value which will describe how to deal with the risk.

To enable decision making it is necessary to focus attention on the lowest common denominator within the Comp(TQC) (see Figure 4). For example if one of the Iron-Triangle objectives is in the 'decide' area and the other two objectives are in the 'monitor' area, the Comp(TQC)-value is defined as 'decide', which is the lowest common denominator. To enable this process the researchers have tested several scenarios, which has resulted in the values shown in Figure 4.

Figure 3 Comp(TQC)-vector

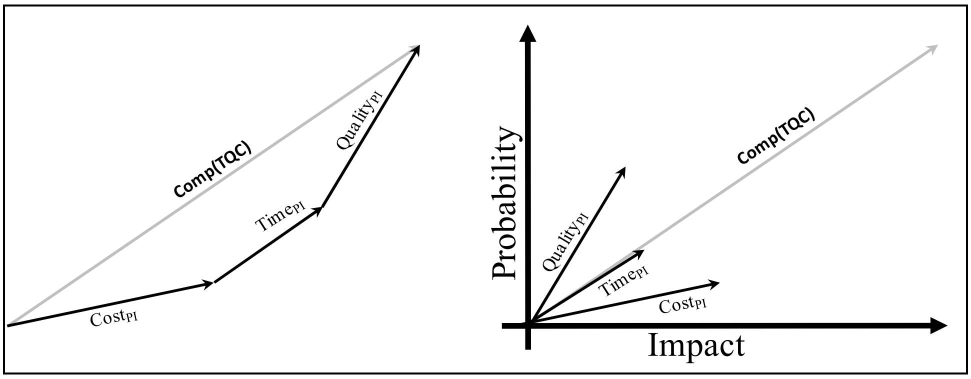
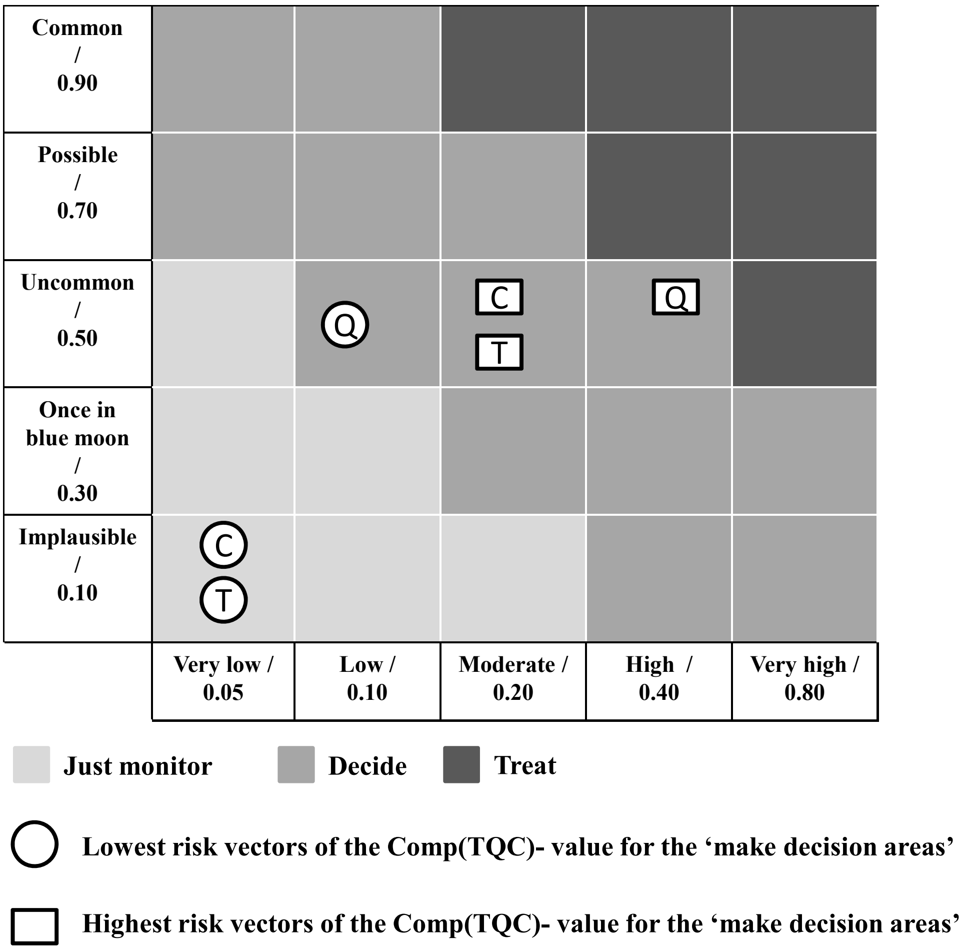


Figure 4 Risk vectors of the Comp(TQC)-value



Therefore the tool defines the lowest Comp(TQC)-value for the 'decide' areas through the following vectors:

$$\begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} = Cost_{PI} \quad \begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} = Time_{PI} \quad \begin{pmatrix} 0.5_P \\ 0.4_I \end{pmatrix} = Quality_{PI}$$

In which the $Quality_{PI}$ has a neutral impact on the different vectors. Using vector mathematics the individual risks can be added together, which results in the following.

$$Cost_{PI} + Time_{PI} + Quality_{PI} = \begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} + \begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} + \begin{pmatrix} 0.5_P \\ 0.04_I \end{pmatrix} = \begin{pmatrix} 0.7_P \\ 0.5_I \end{pmatrix}$$

The resultant vector will give the lowest value for the 'decide' area, as follows:

$$\sqrt{(0.7)^2 + (0.5)^2} = \text{Resultant vector} = \text{Comp(TQC)} = 0.86$$

When defining the highest value for the 'decide' area the focus is on the lowest common denominator for the 'treat' area in Figure 4. If two risk vectors are in the lowest 'decide' area and one risk vector is in the 'treat' area, the risk has to be classified as needing treatment.

Through doing several scenarios the tool defined the maximum Comp(TQC)-value for the 'decide' area, with the following vectors:

$$\begin{pmatrix} 0.5_P \\ 0.2_I \end{pmatrix} = Cost_{PI} \quad \begin{pmatrix} 0.5_P \\ 0.2_I \end{pmatrix} = Time_{PI} \quad \begin{pmatrix} 0.5_P \\ 0.4_I \end{pmatrix} = Quality_{PI}$$

In which again it is not important which of these vectors has the $Quality_{PI}$ value.

Adding the vectors gives the following:

$$Cost_{PI} + Time_{PI} + Quality_{PI} = \begin{pmatrix} 0.5_P \\ 0.2_I \end{pmatrix} + \begin{pmatrix} 0.5_P \\ 0.2_I \end{pmatrix} + \begin{pmatrix} 1.5_P \\ 0.8_I \end{pmatrix} = \begin{pmatrix} 0.7_P \\ 0.5_I \end{pmatrix}$$

The resultant Comp(TQC)-value is as follows:

$$\sqrt{(1.5)^2 + (0.8)^2} = \text{Resultant vector} = \text{Comp(TQC)} = 1.7$$

Considering the highest and lowest Comp(TQC)-values for the 'decide' areas results in the following definition of domains, though these are based on the authors' own simulation from their experience and can be modified and adapted to suit different organisational and project environments:

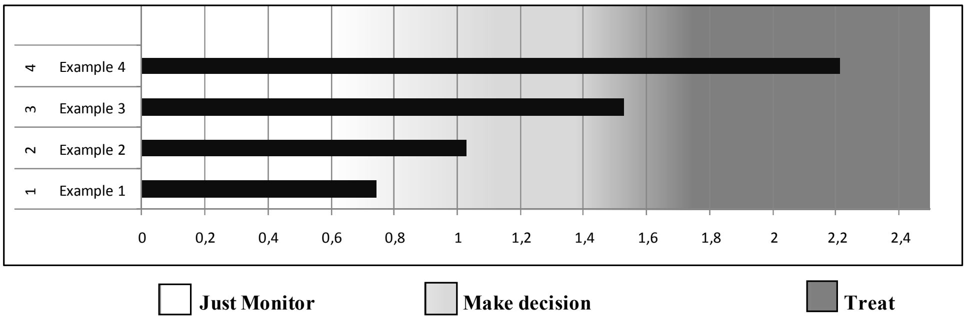
Monitor = Comp(TQC) < 0.86

Decide = $0.86 \leq$ Comp(TQC) ≤ 1.7

Treat = Comp(TQC) > 1.7.

The findings with the Comp(TQC)-value can be summarised in the Comp(TQC)-diagram (Figure 5) where a short bar means low risk (Monitor), and a wide bar means high risk (Treat).

Figure 5 Comp(TQC)-diagram



4 Presentation of the Comp(TQC) – a worked example

The application of the Comp(TQC)-value is demonstrated through a real example. Whilst this is a real project, to maintain confidentiality and anonymity the details of the case have been changed so that the actual construction project used is not identifiable. The specifics of the project are as follows:

Location: United Arabic Emirates (UAE)

Type: Civil Engineering structures

Project value: approximately 120 million Euros

Duration: approximately three years.

4.1 Specific project scenario and risk

There is a huge construction boom in the UAE, but there is also a shortage in steel in the market. The particular project has a diverse range of difficult shapes and a huge tonnage of steel with many small diameters. A supplier being overbooked due to the construction boom can affect the delivery of steel reinforcement in time. One reason for this is that the supplier gets paid per ton of reinforcement. As a result it might be that the supplier will prefer to deliver large quantities of big diameters to other projects, rather than the small diameters and difficult shapes of this project.

4.2 Analysis of the risk with the Comp(TQC)-value

As discussed previously the focus of the new tool is on the PM objectives, using the values in Table 1 results in the following qualitatively defined scales of impact and probability (Table 2).

Table 2 Qualitative risk analysis on the case study

Impact				
Iron-Triangle member	*Description*	*Qualitative scale*	*Impact*	*Linear score*
Cost	Late delivery can result in a project delay which results in more costs	10–20% cost increase	Moderate	0,2
Time	Supplier can deliver late, because he can prefer to supply big diameters and easy shapes instead of low diameters and difficult shapes	10–20%time increase	High	0,4
Quality	The delay of the supplier can result in quality loss of the supplied reinforcement, because he has to speed up	Only very demanding applications are affected	Low	0,1

Probability			
Iron-Triangle member	*Qualitative scale*	*Quantitative scale*	*Linear score*
Cost	Possible	60–79%	0,7
Time	Possible	60–79%	0,7
Quality	Once in a blue moon	20–39%	0,3

Using vector calculations results in the following:

$$Cost_{PI} + Time_{PI} + Quality_{PI} = \begin{pmatrix} 0.7_P \\ 0.2_I \end{pmatrix} + \begin{pmatrix} 0.7_P \\ 0.4_I \end{pmatrix} + \begin{pmatrix} 0.3_P \\ 0.1_I \end{pmatrix} = \begin{pmatrix} 1.7_P \\ 0.7_I \end{pmatrix}$$

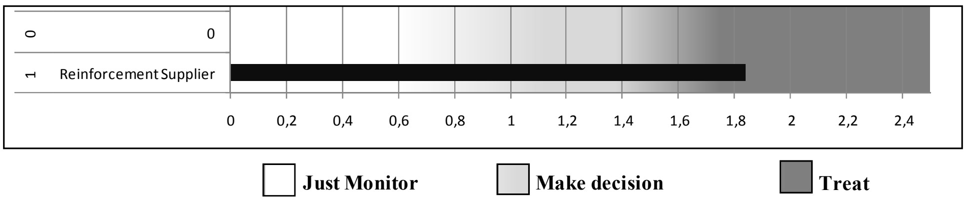
Comp(TQC)-value:

$$\sqrt{\left(\sum Probability\right)^2 + \left(\sum Impact\right)^2} = \sqrt{(1.7)^2 + (0.7)^2} = \text{Comp(TQC)} = 1.8$$

As a result:

1.84 = Comp(TQC) > 1.7 → 'Treat' area, as shown in the Comp(TQC) diagram (Figure 6):

Figure 6 Comp(TQC)-diagram using the provided example



With the specific risk analysed in a qualitative way through the new tool, the next step would be now to consider this risk for quantitative analysis to get the numerical values for the eventual consequences. Afterwards an appropriate treatment strategy can be developed.

5 Conclusions

The traditional approach to analysing risk in a qualitative way using the P-I Table, such as the method of the Project Management Institute (PMI, 2008), considers each project objective separately. PM theory stresses that a risk has a potential impact on all of the PM objectives (cost, time and quality) at the same time. To address this mismatch between theory and risk analysis approaches a new risk analysis tool, the Comp(TQC)-value, is developed and proposed in this paper. Multiple project objective criteria for analysing risks have been considered with the Borda Voting Method, which ranks the risks relative to each other, and provides a prioritised and sequenced order of risks. In comparison with the Comp(TQC)-value, the Border Voting Method does not result in a single value in a defined domain of definition, where conclusions can be drawn by the decision maker on which type of treatment is required.

By considering the interrelations between the project objectives the tool presented in this paper provides a relatively simple and easy to implement method to support decision making in construction risk management. The high level of transparency, which is provided by having a single Comp(TQC)-value, as well as the high level of visibility in the Comp(TQC)-diagram, has the added benefit of facilitating communication of the project risks between the key stakeholders.

The Comp(TQC)-value has the following formula:

$$\sqrt{\left(\sum Probability\right)^2 + \left(\sum Impact\right)^2} = \text{Comp(TQC)}$$

Based on the experience and knowledge of the authors, the following domains of definition are suggested as appropriate for distinguishing different classes of risk (though further research is required to gain a deeper understanding of the impact of changes in the parameters):

Monitor = Comp(TQC) < 0.86

Decide = $0.86 \leq$ Comp(TQC) ≤ 1.7

Treat = Comp(TQC) > 1.7.

(though the parameters can be adapted to specific organisation and project contexts).

This paper has focused on its use to construction projects, yet the Comp(TQC)-value is not limited to such projects and could be used to analyse risk other project environments. Finally, it ought to be emphasised that the tool would not be used in isolation; it is only one of a suite of tools which can be used during the Risk analysis stage of PRM. Another potentially fruitful avenue of further work is on the complementarily between the Comp(TQC) and the Borda method.

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