COMP(TQC) - A NEW WAY FOR INTEGRATING TIME, QUALITY AND COST PERSPECTIVES WHEN DOING QUALITATIVE RISK ANALYSIS

Tugra Demir[1], David J. Bryde, Damian Fearon and Edward G. Ochieng

School of Built Environment, Peter Jost Enterprise Center, Liverpool John Moores University, Byrom Street, Liverpool, L3 3 AF, UK.

One of the most widely documented tools for 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 the Iron-Triangle of cost, time and quality. P-I Tables are typically used to help assess the downside of risk i.e. threats, rather than the upside of risk i.e. opportunities and the focus of this paper is on dealing with threats. Whilst there are numerous adaptations of the P-I Table, they all consistent in their approach to dealing with the cost, time and quality objectives in that the objectives are treated as independent and unrelated variables. This is a limitation of the P-I Table and reduces its 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 for analysing risk that uses vector theory to enable a single calculation of the overall probability and impact incorporating all three objectives in the Iron-Triangle to be made. The tool is exemplified through a practical application to a real case construction project, with the tool being used to support the analysis of threats to the project.

Keywords: iron-triangle, probability-impact tables, risk, vector theory.

INTRODUCTION

The construction industry has been plagued by high levels of risk (Tah and Carr, 2001), yet those involved in the management of risk in the construction industry have traditionally 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). 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 in respect of the uncertainties inherent in construction projects. 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

[1] S.T.Demir@2009.ljmu.ac.uk

Tugra Demir, T, Bryde, D J, Fearon, D and Ochieng, E G (2011) Comp(TQC) - A new way for integrating time, quality and cost perspectives when doing qualitative risk analysis *In:* Egbu, C. and Lou, E.C.W. (Eds.) *Procs 27th Annual ARCOM Conference*, 5-7 September 2011, Bristol, UK, Association of Researchers in Construction Management, 1013-1022.

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, and 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.

The current project management [PM] literature shows different ways of performing qualitative risk analysis on (construction) projects. One of the most used tools in practice is the Probability-Impact [P-I] table, which helps 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 typically treated independently for each risk. This paper argues that a separation between cost, time and quality objectives when analysing risks in a qualitative way is not desirable, due to the fact that they are interrelated. This problem has been highlighted in the latest Body of Knowledge of the Project Management Institute, though a tool providing a solution is not presented (PMI, 2008). Clearly there are numerous methods developed to support risk analysis in projects. However there is an opportunity to add to the current suite of methods by developing a tool for qualitative risk analysis that treats cost, time and quality objectives as independent rather than related variables in a P-I table. The development of such a tool provides the rationale for this paper.

CONCEPTUAL FRAMEWORK AND PROBLEM DEFINITION

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
    a. Risk Identification
    b. Risk Analysis
    c. Risk Evaluation
3. Risk Treatment

The focus of the tool developed in this paper is on 2.b Risk Analysis, which is the second 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).

A common thread connecting the definitions of project risk, the objectives of PRM and the process of performing qualitative risk analysis is the two-dimensionality of risk management i.e. a focus on the dimension of probability of occurrence of an event and on the dimension of its potential impact on the project. The PMI (2008) suggests besides the P-I table 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, which will be not described in detail due to the limited word count. But in comparison with the P-I table these tools do not have the same transparency which is the reason why the P-I table is the most common tool in construction practice (Gleissner *et al*. 2007). The reason for the high transparency provided by the tool is related to the consideration, of the two dimensions of risks when analysing them qualitatively, where the probability and impacts of each risk are assessed against defined scales, and plotted on a two-dimensional grid (Hillson, 2001). The qualitative and linear values are provided through defined impact scales for individual project objectives (PMI, 2008).A P-I table typically has three elements, which are as follows: risks which have to be treated, risks which need to be decided, if treatment is required or not, risks which do not need any treatment, but need to be monitored (Schelle *et al*. 2005; Fabri, 2008; Patzak and Rattay, 2009). 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). Therefore current literature provides tools which treat cost, time and quality risks independently and, despite the calls for methods that provide an overall rating for cost, time and quality risk, for example, see PMI (2008), there are no such tools related to constructing a P-I table that consider them as interrelated variables in respect of risk analysis. This limitation is addressed through the new tool for qualitative risk analysis.

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.

DISCUSSION AND DERIVATION OF THE TOOL FOR RISK ANALYSIS

The rationale for the new tool is to address current limitations of P-I tables, which typically treat the Iron-Triangle objectives separately and independently (PMI, 2008). 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). The rationale of the tool presented in this paper articulates the effect of a risky event on the Iron-Triangle as a single value, which can support objective decision making for the parties involved in construction. For instance a risky event could be a supplier of materials going bankrupt. This single event, if it materialises, could have cost implications (it might be more expensive to source materials from alternative suppliers), time (it might lead to delays) and quality (there is no time to carry out the usual quality checks and inspections on the supplier). The event may have implications on other success criteria, such as client satisfaction, but here we are focusing on cost, time and quality and reflecting the integration of the individual impacts in one value. 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.

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 Table: 1).

Table 1: Impact and Probability Project Risk Objectives

Impact					Probability		
Cost	Time	Quality	Impact	Linear score	Qualitative Scale	Quantitative Scale	Linear Score
insignificant cost increase	insignificant time increase	quality degradation barely noticeable	very low	0,05	Implausible	1-19%	0,1
< 10% cost increase	< 5% time increase	only very demanding applications are affected	low	0,1	once in a blue moon	20-39%	0,3
10-20% cost increase	5-10% time increase	quality reduction requires sponsor approval	moderate	0,2	Uncommon	40-59%	0,5
20-40% cost increase	10-20%time increase	quality reduction unacceptable to sponsor	high	0,4	Possible	60-79%	0,7
> 40% cost increase	> 20% time increase	project end item is effectively useless	Very high	0,8	Common	> 79%	0,9

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 table seems like that it transfers qualitative data to quantitative data, but the basis is related to subjective opinions (experience, mood etc) and not to objective numbers (calculations, measures etc) and therefore the authors will speak about qualitative data when talking about the table. 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 problem with this traditional approach is that the impact of a risk is analysed separately for each element of the Iron-Triangle.

Therefore a new method is required, which 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. This overall rating scheme is derived by the use of vector mathematics, which has been linked previously to the treatment of risk. The basis for this approach has been articulated by Hubbard (2009), who argued that risks are vectors, which have two components, the probability and the impact. Mathematically a vector is defined as follows:

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

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

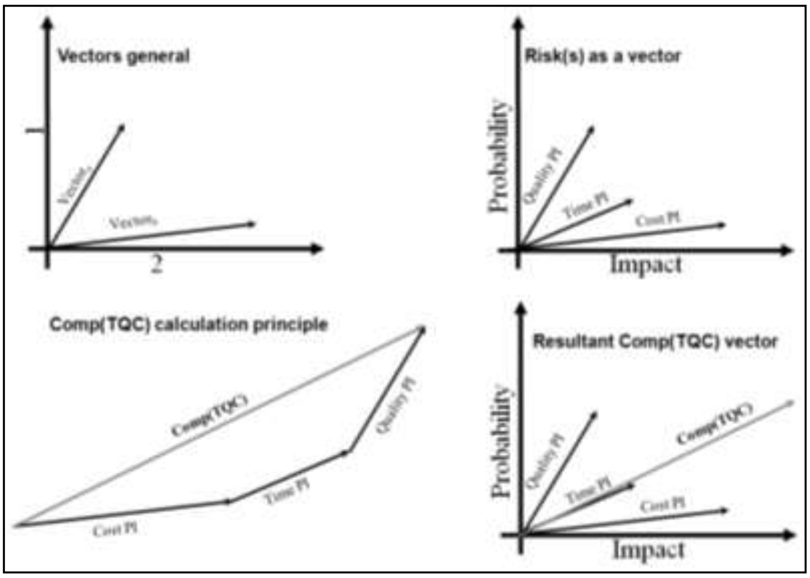
$$\begin{pmatrix} C_P \\ C_I \end{pmatrix} = Cost_{PI}\ ,\ \begin{pmatrix} T_P \\ T_I \end{pmatrix} = Time_{PI}\ ,\ \begin{pmatrix} Q_P \\ Q_I \end{pmatrix} = Quality_{PI}$$

In which P stands for probability and I for impact and therefore PI for probability impact i.e. the risk vector. This is illustrated graphically in figure 1. 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 2. The overall factor, which is a composite of the individual costs, time and quality vectors, is called the 'Composite of Time Quality and Cost', in short "Comp(TQC)". Comp(TQC)-value is calculated as:

$$\sqrt{(\sum Probabability)^2 + (\sum Impact)^2} = \mathrm{Comp(TQC)}$$

And can be illustrated through figure 1.

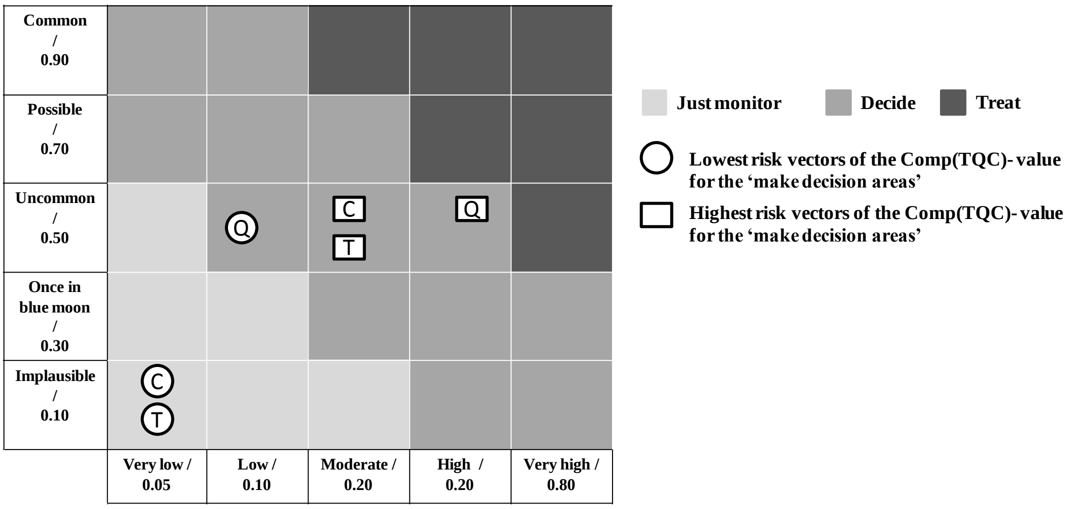
Figure 1: From Vector calculation to Comp(TQC)



This is a conceptual formula, which is based on Hubbard's (2009) research findings, in which he defined risk as a vector. 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 2). 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 2.

Figure 2: Risk vectors of the Comp(TQC)- value



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

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

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.

$$Cost_{PI} + Time_{PI} + Quality_{PI} = \begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} + \begin{pmatrix} 0.1_P \\ 0.05_I \end{pmatrix} + \begin{pmatrix} 0.5_P \\ 0.4_I \end{pmatrix} = \begin{pmatrix} 0.7_P \\ 0.5_I \end{pmatrix}$$

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

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

When defining the highest value for the ‘decide’ area the focus is on the lowest common denominator for the ‘treat’ area in figure 2. 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:

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

In which again it is not important which of these vectors has the Quality PI value. Adding the vectors gives the following:

$$Cost_{PI} + Time_{PI} + Quality_{PI} = \begin{pmatrix} 0.5 \\ 0.2_I \end{pmatrix} + \begin{pmatrix} 0.5_P \\ 0.2_I \end{pmatrix} + \begin{pmatrix} 0.5_P \\ 0.4_I \end{pmatrix} = \begin{pmatrix} 1.5_P \\ 0.8_I \end{pmatrix}$$

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

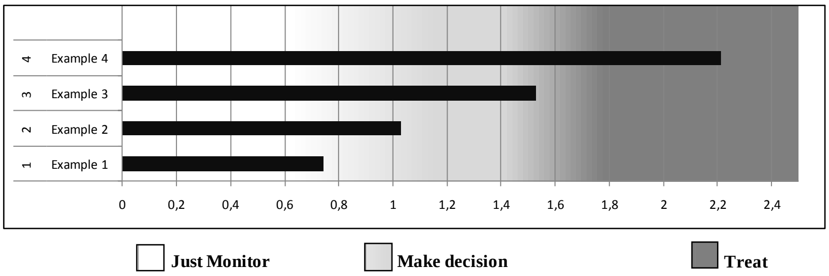
$$\sqrt{(1.5)^2+(0.8)^2} = Resultant\ vector = \text{Comp(TQC)} = 1.7$$

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 = $\text{Comp(TQC)} < 0.86$
Decide = $0.86 \leq \text{Comp(TQC)} \leq 1.7$
Treat = $\text{Comp(TQC)} > 1.7$

The findings with the Comp(TQC)-value can be summarised in the Comp(TQC)-diagram (figure 3) where a short bar means low risk (Monitor), and a wide bar means high risk (Treat).

Figure 3: Comp(TQC)- Diagram



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 3 years

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. This potential impact on the schedule could also result in more costs (caused by the delay) and in quality loss of supplied reinforcement (because the supplier needs to speed up the production).

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

Using the defined scales of probability and impact (see table 1) results with the following

Table 2: Qualitative Risk Analysis on the Case Study

	Impact				Probability	
Iron-Triangle Member	Qualitative Scale	Impact	Linear Score	Qualitative Scale	Quantitative Scale	Linear Score
Cost	10-20% cost increase	Moderate	0,2	possible	60-79%	0,7
Time	10-20%time increase	High	0,4	possible	60-79%	0,7
Quality	only very demanding applications are affected	Low	0,1	once in a blue moon	20-39%	0,3

Using vector calculations results in the following:

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

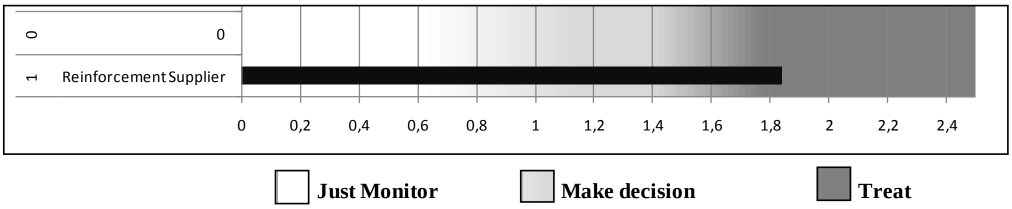
Comp(TQC)- value:

$$\sqrt{(\sum Probabability)^2 + (\sum Impact)^2} = \sqrt{(1.7)^2 + (0.7)^2} = \mathrm{Comp(TQC)} = 1.8$$

As a result:

$1.84 = \mathrm{Comp(TQC)} > 1.7 \rightarrow$ ‘Treat’ area, as shown in the Comp(TQC) diagram (figure 4):

Figure 4: Comp(TQC)- Diagram using the provided Example



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. However PM theory stresses that a risk has a potential impact on each PM objective (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 proposed in this paper. The tool utilises vector mathematics and is simple to apply, requiring no complex software to derive the values. By considering the interrelations between the project objectives the tool provides a solid and fast base 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, facilitates communication of the project risks between the key stakeholders.

Whilst this paper has presented a tool for qualitative risk analysis, on the basis that the probabilities and impact figures are generated based on subjective opinion, it has to be recognised that in a small number of situations elements of a P-I table contain quantitative information. For example, if an organisation holds a repository of historical data on the past performance of a supplier i.e. in terms of on-time delivery and number of defects, on a large number of prior projects then the P-I figures can be generated with a high level of confidence as to their accuracy. Therefore, in parallel with the use of the tool there is also a need for improving the quantification of risk information which will give the values generated from the P-I table more reliability and validity. Such quantification will enhance the risk analysis process.

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. Furthermore, it only considers PM risks, focused just on potential risky events and their impact on the Iron-Triangle and is limited to the qualitative analysis of project risks. 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 of other project environments. When using the tool or the value, one is adding the linear scores which result out of each PM objective. The resultant value helps in refining the risks which have been identified previously, to consider for quantitative risk analysis. However, the fact that practically seen the probability is added when calculating the Comp(TQC)-value might be considered as confusing by the users. The domain of definition can be adapted to the specific project or organisational environment and is easy to define, which is on the hand in today's globalised project environment an advantage for the practicability of the tool. However, further studies are required to identify a universal response decision scales on several similar construction project types.

REFERENCES

Al-Bahar, J. F. and Crandall, K. C. (1990), “Systematic Risk Management Approach for Construction Projects”, *Journal of Construction Engineering and Management*, **23**(1), 533-546.

APM (2000), *APM Body of Knowledge*, 4th ed, Association of Project Managers, High Wycombe, UK.

Atkinson, R. (1999), “Project management: cost, time and quality, two best guesses and a phenomenon, it's time to accept other success criteria”, *International Journal of Project Management*, **17**(6), 337-342.

Bryde, D. and Volm, J. (2009), “Perceptions of owners in German construction projects: congruence with project risk theory”, *Construction Management and Economics*, **27**(11), 1059-1071.

Chan, A.P. and Chan, A.P. (2004), “Key performance indicators for measuring construction success”, *Benchmarking: An International Journal*, **11**(2), 203-221.

Demir, S. T. (2010), *Risk Management Perceptions and a Framework for Construction Projects in Germany*, Unpublished MBA Thesis, School of Business and Law, Liverpool John Moores University, UK.

deWit, A. (1988), “Measurement of project success”, *Project Management*, **6**(3), 164-170.

Egan, J. (1998) *Rethinking construction: the report of the Construction Task Force to the Deputy Prime Minister, John Prescott, on the scope for improving the quality and efficiency of UK construction*, Department of the Environment, Transport and the Regions Construction Task Force, London, UK.

El-Rayes, K. and Kandil, A. (2010), “Time-Cost-Quality Trade-Off Analysis for Highway Construction”, *Journal of Construction Engineering and Management*, **131** (4), 477-486.

Fabri, K. (2008), " 'Risikomanagement' als neue ganzheitliche Methodik", *Science and Technology*, 52-55.

Fischer, P., Maronde, M. and Schwiers, J. (2007), "Das Auftragsrisiko im Griff- Ein Leitfaden zur Risikoanalyse für Bauunternehmer", GWV Fachverläge, Wiesbaden, Germany.

Girmscheid, G (2006). *Strategisches Bauunternehmensmanagement- Prozessorientiertes integriertes Management für Unternehmen in der Bauwirtschaft*, Springer Verlag, Berlin, Germany.

Gleissner, W., Mott, B. and Schenk, M. (2007), "Risikomanagement in der Bauwirtschaft-Praktische Umsetzung am Beispiel der Bauer AG", *ZRFG-Zeitschrift für Risk*, Fraud and Governance, 179-185.

Hillson, D. (2001), "Extending the risk process to manage opportunities", *International Journal of Project Management*, **20** (3), 235-240.

Hubbard, D. (2009), "The Failure of Risk Management-Why It`s Brokenand How to fix it", John Wiley and Sons, New Jersey, USA.

Institute of Risk Management (2002), *A Risk Management Standard*, Institute of Risk Management, Association of Insurance and Risk Managers, National Forum for Risk Management in the Public Sector (2002, London, UK.

International Organisation for Standardisation (2009), *ISO 31000: Risk Management-Principles and Guidelines*, ISO, Geneva, Switzerland.

Office for National Statistics. (2010), Construction Statistics Annual, http://www.statistics.gov.uk/STATBASE/Product.asp?vlnk=284 [Date accessed 1 December 2010].

Oxford Dictionary (1984), *Griffin Savers Oxford Dictionary*, University Press of Oxford, UK.

Patzak, G. and Rattay, G. (2009), *Projektmanagement-Leitfaden zum Management von Projekten, Projektportfolios, Programmen und projektorientierten Unternehmen*, Linde Verlag, Wien, Austria.

PMI (2004), *A guide to the project management body of knowledege (PM Guide)*, 3rd ed., Project Management Institute, Pennsylvania, USA.

PMI (2008), *A guide to the project management body of knowledege (PM Guide)*, 4th ed., Project Management Institute, Pennsylvania, USA.

Roesel, W. (1987), *Baumanagement Grundlagen-Technik-Praxis*, Springer Verlag, Berlin, Germany.

Schelle, H., Ottmann, R. and Astrid, P. (2005), *ProjektManager*, GPM Deutsche Gesellschaft für Projektmanagement, Nürnberg, Germany.

Tah, J. and Carr, V. (2000), "A proposal for construction project risk assessment using fuzzy logic", *Construction Management and Economics*, **18** (4), 491-500.

Tah, J. and Carr, V. (2001), "Knowledge- Based Approach to Construction Project Risk Management", *Journal of Computing in Civil Engineering*, **15** (3), 170-177.

Wang, S., Dulaimi, M. and Aguria, Y. (2004), "Risk management framework for construction projects in developing countries", *Construction Management and Economics*, **22** (3), 237-252.

Ward, S. and Chapman, C. (2003), "Transforming project risk management into project uncertainty management", *International Journal of Project Management*, **21** (2), 97-105.