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CONTROLLING THE COST OF RISK MANAGEMENT BY UTILISING A PHASE PORTRAIT METHODOLOGY

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Abstract. The methodology developed in this study presents an approach to the concurrent evaluation of Risk Management (RM) effectiveness during project execution. The method proposed is an adaptation of an approach developed and advocated by Khlebopros *et al.* (2007) for the mathematical modelling of complex systems, namely the analysis and effects of natural catastrophes. Hence, the method utilizes a phase portrait approach to identify the Prime Cost (PC) of RM of a project. Furthermore, the method provides an approach for comparing the individual identified risks with this PC, and subsequently highlighting a way of classifying and prioritising risks into a rank order for RM attention. The MERA (Multiple Estimating Risk Analysis) approach was utilized for the quantification of risk impact and ultimately the creation of the phase portrait. Besides being accurate and intuitively understandable, the methodology is relatively simple to implement and provides a rapid visualisation of the overall risk extent of a project.

Keywords: risk analysis; risk management; risk monitoring; project management; construction industry; cost control; phase portraits.

Introduction

Risks in a project, in the broad sense, can simply be expressed as ‘internal or external events that may affect the expected outcome of the project’. Thus, the Project Management Institute defines risk as ‘an uncertain event that, if it occurs, has an undesirable effect on at least one project objective (e.g., time, cost, scope, quality)’ (PMI 2004). Hence, every project has some amount of risk, which in turn necessitates the systematic and sound treatment of the potential risks, namely Risk Management (RM), for the success of the project. In lieu of this fact, RM is an implicit activity of any successful project implementation. On the contrary, poor and ineffective RM can have catastrophic consequences, and may lead to a project’s failure.

To further deepen the discussion, RM is not only about predicting the future, but also understanding a project and making better decisions regarding the management of that project tomorrow (Smith *et al.* 2014). Hence, effective RM can help to reduce, absorb and transfer risk and exploit potential opportunities (Liu *et al.* 2003). From all indications, the use of risk assessment techniques is going to increase in the coming years (Touran 2006; Molenaar 2005).

In this study, a methodology is developed for the concurrent evaluation of RM effectiveness during project execution. It does so by presenting a ‘phase portrait’ to identify the ‘Prime Cost of Risk Management’ of a project and then a method of comparing individual identified risks with this Prime Cost (PC), and hence highlighting a way of classifying and prioritising risks into a rank order for RM attention. The phase portraits are graphical representations of a dynamical system in two-dimensional space, namely phase plane. It is a very powerful tool especially for the visualization of rate of change. The method proposed is an adaptation of an approach developed and advocated by Khlebopros *et al.* (2007) for the mathematical modelling of complex systems, namely the analysis and effects of natural catastrophes. This method reverses their approach and utilises it as a ‘maximising’ rather than ‘minimising’ approach. This is a novel approach and the authors are not aware of any similar work in the field of RM in the Built Environment.

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The paper is organized under seven section titles. Following the introduction section, a brief presentation on RM and current methodologies followed is made. Afterwards, in sections 1 through 4, a detailed presentation of the proposed method is made. A worked example is also presented in section 5. In the final section, concluding remarks are presented about the proposed methodology.

1. Risk Management: Scope, Guidelines and Methodologies

Eaton (2010) states that effective RM primarily has two important missions:

- to identify the risks, which comprises analysis of the likelihood of each risk event and determination of how serious the consequences might be;
- to identify the risk mitigation options; where in each case there will be an inconvenience or cost factor and a decision will have to be made on whether mitigation is worthwhile.

Thus, RM is a structured approach of *identifying*, *assessing* and *controlling* risks that may emerge during the course of a policy, program or project (Mills 2001). Hence the entities having a large number of programs or projects, i.e. governments often times lead the subject devising or establishing RM systems/methodologies as well as the organizations of professionals such as institutes and societies.

In the UK HM Treasury defines RM as a process of 'identifying the significant risks to a project, devising tactics to reduce exposure to these risks, and then monitoring the effectiveness of RM actions undertaken'. Effective RM ensures an organization makes cost-effective use of a process that has a series of well-defined steps to support better decision-making through good understanding of the risks inherent in a proposal and their likely impact (HM Treasury 2003, 2004; CUP 1993).

In the US, Continuous Risk Management (CRM) has been developed through a research funded by the Department of Defence (Dorofee *et al.* 1996). Similar to the approach in the UK, CRM involves identification, analysis, planning, tracking and control regarding the potential risks in a given project (Fig. 1). In this approach a cost-benefit analysis is used as a decision support tool regarding the risks. The CRM approach was also adopted and used by the National Aeronautics and Space Administration, NASA together with a complimentary management tool named 'Risk-Informed Decision Making' (RIDM) in their projects including space missions (NASA 2008, 2010).

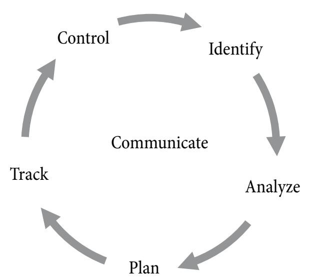

Fig. 1. Continuous risk management

In Canada, an Integrated Risk Management Framework (IRMF) (TBCS 2001) referring to managing and communicating risk from an organization-wide level was adopted by the Canadian Government. The subtle difference between CRM and Integrated Risk Management (IRM) is that the strategic decisions regarding risks are made in accordance with the organization's corporate objectives. Hence, the IRMF has 4 main elements (TBCS 2004):

- development of the corporate risk profile;
- establishment of an IRM function;
- practicing IRM;
- ensuring CRM learning.

The organizations of professionals such as the Project Management Institute and the Institute of Risk Management published their recommendations and guidelines on the issue of RM (PMI 2008; IRM 2002).

Internationally ISO, International Organization for Standardization, observing the needs on the subject have issued two standards, namely ISO 31000:2009 (Risk Management. Principles and Guidelines) and IEC 31010:2009 (Risk Management. Risk Assessment Techniques). It is foreseen to be used by an organization of any size, activity and/or sector. In ISO 31000:2009, as its title recalls, the principles, framework and the process for managing risk are set in three main clauses of the standard (Clauses 3 through 5). Fig. 2 summarizes the steps and the flowchart of the framework and process stages of RM as proposed in ISO 31000:2009. As can be seen from the figure, the RM process set forth by ISO 31000:2009 is also a continual procedure. Namely, one of the important tasks in the process is monitoring and review of the effectiveness of the system set.

As a concluding remark for this general preview, RM can be described as the performance of activities designed to minimize the negative impacts of risk regarding possible losses. Hence, management must decide among alternative methods to balance risk and cost, and the alternative chosen will depend upon the organization's risk characteristics (Schmit, Roth 1990). In lieu of this fact, RM is expected to produce reliable information in a timely manner regarding the residual risk status of the organization. Thus, the RM system needs to be re-evaluated periodically as well as each time a significant risk is identified/materialized that was not foreseen. Consequently, the approach followed must assure that the risks are identified in a timely manner, fairly assessed and appropriate, as well as, cost effective measures are taken. Yet all of the RM approaches presented above and others not presented here rely on the decision makers at various levels in the organization for the determination of the effectiveness of the RM. This might be partially due to the fact, that very little research has been presented on how to continuously evaluate the effectiveness of RM within a project environment.

In the literature there are numerous case studies demonstrating effective organisational structures to tackle the task of RM. However, oftentimes case studies present examples of RM successes and failures, but

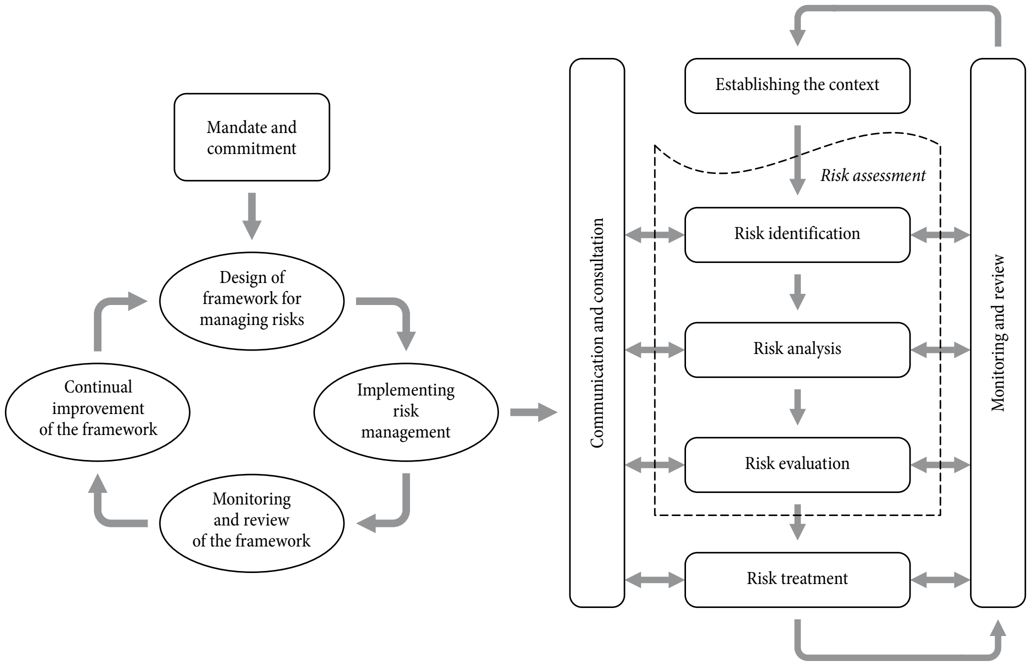

Fig. 2. ISO 31000:2009 principles, framework and process (adapted from: TSO 2013)

do not provide an explicit approach to evaluating the internal effectiveness of RM of a current project. It is however quite obvious that due to the inherent unique character of the processes involved in a project; it will be very difficult, if not impossible to devise an ideal organizational structure that will serve the RM needs of all the projects. The cost of performing CRM must be balanced against the expected benefits and the cost of not doing RM (Charette 1989). The cost-benefit analysis is quite useful in assessing individual risks momentarily but will be limited when it is necessary to see the full picture of the risk registry especially at different instances during the course of a project. Consequently, there is a need for a tool to monitor the process numerically. This is essential for the assessment of the effectiveness of the system and retuning the process as the project progresses.

2. Proposed Method

As presented above, in the RM of a project the initial steps involve the identification and the analysis of potential risks in a project. This can be performed by any industry-accepted methodology and a risk register can be formed. In this respect, information on risks can be assembled through well-known techniques such as brainstorming, checklists (possibly based on the standard risk registers recommended by the official bodies) or the Delphi method (Ghazali, Kabir 2009; PMI 2008; Boussabaine 2006). For the analysis of the identified risks and determination of their quantum, the analyst can use methods such as Multiple Estimating Risk Analysis, MERA (MoD 1994), Estimating Range Analysis, ERA (Mak, Picken 2000) or any other method that is familiar. In this study as noted above the MERA method will be used. At this point, it is worth to note that the identification and analysis of risks is an iterative and continuous process, that takes place over the project life cycle (PMI 2008).

The PC of RM is defined within this method as the cost of management of the entire risk portfolio of a project (as identified in a risk register):

$$PC = \frac{R_E}{C}, \quad (1)$$

where: PC is the defined PC of RM; R_E is the total risk exposure of the project; C is the total cost of RM of the project, determined by the cost of RM staff and the associated overheads and expenditures of the contractor in managing the risks.

Hence, the PC value determined here is a ratio of risk exposure to management cost. In other words, it is the amount of risk exposure treated by unit management cost. The risk exposure and cost of RM has a convex relationship. Subsequently, assuming that both the cost of management and the risk exposure are properly calculated on the risk register, PC resulting from Eq. (1) will represent the lowest cost of management. In mathematical terms, R_E can be written as:

$$R_E = R_{E1} + R_{E2} + \ldots + R_{En}, \quad (2a)$$

or alternatively as:

$$R_E = \sum_{i=1}^{n} R_{Ei}, \quad (2b)$$

where: subscript n in the equations represents the total number of risks identified on the project risk register. On the other hand, the individual risk exposures, R_{Ei} are the products of the individual risk quantum and their associated probabilities, which can be presented as follows:

$$R_{Ei} = R_{Qi} \cdot R_{Pi}. \quad (3)$$

Inserting Eq. (3) into Eq. (2a), one can obtain:

$$R_E = R_{Q1} \cdot R_{P1} + R_{Q2} \cdot R_{P2} + \ldots + R_{Qn} \cdot R_{Pn}; \quad (4a)$$

$$R_E = \sum_{i=1}^{n} R_{Qi} \cdot R_{Pi}. \quad (4b)$$

The total risk exposure (R_E) of the project and the total RM cost (C) in Eqs (1–4) above, are known from the summation of the risk register and from the total tender budget allocation, respectively. At this point, it should be noted that, the proposed method only incorporates risks on the risk register and any contingency for uncertainty must be excluded from the total RM cost (C).

Both R_{Qi} and R_{Pi} can be estimated using the average and maximum risk allowance values obtained from MERA calculations as follows:

$$R_{Qi} = \frac{RQ \text{ at } ARA + RQ \text{ at } MRA}{2}; \quad (5a)$$

$$R_{Pi} = \frac{RP \text{ at } ARA + RP \text{ at } MRA}{2}, \quad (5b)$$

where: *ARA* and *MRA* are the MERA average and maximum risk allowances respectively; *RQ* is risk quantum; *RP* is risk probability.

The ARA represents a risk allowance for a 50% probability of not being exceeded while the MRA has the estimated risk allowance that has a 95% probability of not being exceeded. Note that, R_Q is set thus to give a representation of the accuracy of the pre-tender estimate based on empirical evidence and the application of statistical theory relating to a triangular distribution.

Higher sensitivity can be achieved by increasing the MRA probability, however this is not deemed necessary in most projects because of the inherent limit of accuracy in the initial project estimates. A lower MRA probability could be considered but the statistical analysis necessary to estimate these values is significantly more complicated than the 95% threshold, which in the adoption of a triangular distribution utilised in MERA is represented by 1σ (1 standard deviation above the mean – a simple mathematical calculation).

The individual cost of each risk exposure can either be calculated in detail using actual values to the best extent or can simply be estimated by either intuition and experience or some means of proportioning.

Subsequently, each of the *n* number of risks on the risk register has an associated cost value, C_i and a risk exposure value, R_{Ei} (per Eqs (2–4)). So analogous to Eq. (1), the cost of a particular risk can be calculated as follows:

$$P_i = \frac{R_{Ei}}{C_i}. \quad (6)$$

Hence, this means that P_i is the geometrical slope of a line from the origin to the *i*-th point, simply point *i*, (having coordinates (R_{Ei}, C_i)) from the vertical *C* axis (Fig. 3). This is also the *R–C* coordinate ratio at the point *i*, namely (R_{Ei}/C_i). These become the coordinates of the vertical and horizontal axes of the 'phase portrait' as defined by Khlebopros *et al.* (2007).

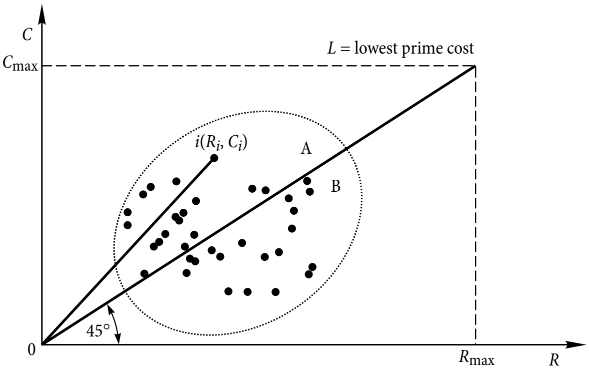

Fig. 3. Phase portrait of original PC of RM

3. Phase Portrait Creation

Assuming that, at any point in time *t*, when the RM strategy for the project is being reviewed, the risk register has been determined and the quantum R_{Qit} and exposure probability R_{Pit} for each risk item in the register have been determined by any appropriate risk assessment method, the 'phase portrait' will be a two dimensional graphical representation of variables RM cost (C_t) and risk exposure (R_{Et}) at the pre-determined point in time *t*.

The scales of the horizontal and vertical axes *C* and *R* are constructed such that at any point on the bisector (a line drawn from the origin at 45° to the axes, namely line *O–L* as shown in Fig. 3) has the ratio of $R/C = 1$. This is also the second differential of the data set.

As a mathematical consequence of the adopted methodology, the lowest PC of RM lies along this bisector line *O–L*. If point *i* lies along this line then the ratio of *R/C* is the R_0/C_0 ratio. This is then independent of the choice of point on *O–L*. This can easily be demonstrated by the theorem of similar triangles. Every risk point can subsequently be compared to the PC line *O–L* for effective analysis of RM approaches. This will be elaborated later in the interpretation of the results section.

The easiest method of constructing the scale is to enter the total cost of RM (C) onto the vertical axis at a suitable point on the phase portrait. Then draw a line from (C_{max}), parallel to the *R* axis. Then draw a bisector (45°) to each axis. Where these cross, draw a line from this point to cross the *R* axis at the perpendicular. Where it crosses this is the position of R_{max}. This method is demonstrated in Fig. 3.

Then each individual risk item is plotted using the Eqs (3–4). Thus, when all of the risk items are plotted on the phase portrait (shown as dots in Fig. 3) a 'cloud' of dots appear, both above and below the bisector *O–L*. These have been surrounded by a phase envelope (shown as an ellipse in Fig. 3).

4. Interpreting the Phase Portraits

4.1. The Initial Phase Portrait

Having established the PC; (*O–L*) the original bisector of the phase portrait; RM interventions can be inferred from the location of individual risks in relation to the target PC.

Any dots appearing along the phase bisector (obscured by the bisector line *O–L*) are effective and efficiently managed risks, (since the individual ratio of risk exposure to RM cost is unity – as a function of the definition of the phase portrait). In other words again considering the convex relationship of the risk exposure versus cost of managing the individual risks, the lowest cost cases by definition should line on the bisector. Thus it can be inferred, that on this project, these risks cannot be ameliorated by any further RM interventions.

Any dots appearing in area A – above the bisector, indicate risks that have a management cost in excess of the PC. These are individual risks that can (and should) be more efficiently managed on a project. These are risk items with the highest PC and they can be monitored for changes in their PC, the PC of the *i*-th item. Thus interventions (RM tactics) to reduce the quantum or probability of the risk occurring should be tested to see if the phase ratio can be moved closer to unity. If a particular intervention (including any additional costs of the management of that risk) shows that the phase ratio improves towards unity, then that risk tactic is preferable to the current risk policy for that risk.

Any dots appearing in area B – below the bisector, indicate risks that have a RM intervention cost that is smaller than the P – hence the risk could be better managed by having further management attention given to the current approach. This indicates that a risk has had a 'satisficing' management tactic applied, rather than identifying and applying the most effective management tactic.

Efficiency in this context is that the total RM cost allocation to the project is minimised.

The extent and position of the phase envelope in relation to the bisector also reveal information about the management of risk. A phase envelope divided in half by the bisector indicates rational RM decisions have been made. Whilst an unbalanced phase envelope (areas A and B have a very unequal area), indicates more irrational RM of the entire risk portfolio.

A small phase envelope indicates that the risks are generally of a similar scale, whilst a larger envelope indicates a much larger variation in the scales of the individual risks.

The position of the phase envelope to the origin also indicates information about the total risk portfolio. The nearer to the origin the smaller is the total risk exposure of the project and vice versa.

The perfect RM phase portrait would thus have all the individual 'dots' attached to points on the bisector *O–L* and in Fig. 3 all such risks would be obscured by the line *O–L*.

4.2. Further Phase Portraits

Since RM is an iterative process and current research is showing that risk quantum and risk exposure probabilities vary through time, further phase portraits can be constructed at appropriate time intervals and further visual appraisals can be conducted, following the identical procedure described above.

However, since the scales of *R* and *C* are established on the initial data set, further 'bisectors' (the term is used here for clarity – but it is recognised by the authors that such lines are not 'true' bisectors) can be calculated and phase portraits of the 'dots' can be plotted.

The phase portraits can be plotted and P_n (the *n*-th phase portrait) PC can be plotted against P_0 (the original PC). This is a cost control mechanism to ensure that the costs of RM are being managed efficiently.

Fig. 4 shows two additional phase portraits superimposed onto the original scale, namely P_1 shown as 'bisector OL_1' and P_2 shown as 'bisector OL_2'.

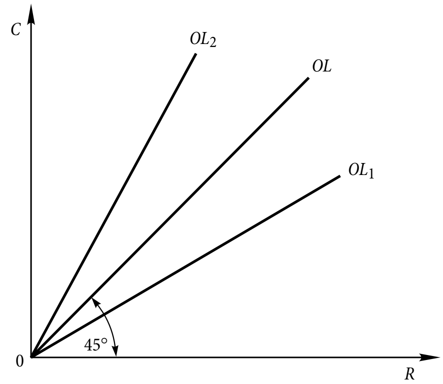

Fig. 4. Multiple phase portraits superimposed on the original phase portrait

OL_1 shows a 'picture' of 'improving' RM. The cost of managing each unit of risk exposure is reducing and the total risk exposure is reducing. It is possible to calculate the predicted savings of this improvement – but they are not shown in this paper.

OL_2 shows a deteriorating 'picture' of RM. The cost of managing each unit of risk exposure is increasing and the total cost of RM is increasing. Again, it is possible to calculate this increase – not shown in this paper.

5. A Worked Example

The method has been tested on several UK infrastructure projects, including 2 highway, a motorway and two bridge contracts. These projects where commenced between 2007 and 2011, and where executed by different clients and main contractors. The risk registers for these projects were provided to the authors on a commercially confidential basis. Therefore, the authors have created an exemplar project combining the most salient elements of these projects to provide the exemplar presented in the paper and to illustrate the essential features and utility of this new methodology. Only 10 risks have been analysed – to aid clarity in the presentation of the data. The project has a risk free estimate of £216M and a dual range estimate of ‖£231M – £285M‖. Other data is shown in Tables 1–2 to illustrate the project. The most basic MERA technique has been applied to the data.

The risk exposure (R_E) is calculated using the Eqs (3–4) above. The individual cost of each risk exposure can either calculated assuming a quantum proportionate distribution of the cost of management of individual risks, in which case for the i-th item on the risk register C_i can be calculated as follows:

$$Ci = \frac{R_{Qi} \cdot C}{\sum_{i=1}^{n} R_{Qi}}, \quad (7)$$

where: $1 \le i \le n$.

The results are tabulated in the last two columns of Table 1.

When constructing the scales to provide the values of C (in monetary values – £) calculate them per £1000000 of risk exposure. This is a mathematical convenience and simplifies the size of the numbers appearing in the scales. Hence, £1000000 is an arbitrary selection – it should be any convenient unit to suit the overall scope of total risk on the project. The results are demonstrated in Fig. 5.

In the exemplar one risk (identified as point 1 in Fig. 5) appears on the bisector. This indicates that in terms of the RM policy for this project this risk is being efficiently managed.

In the exemplar only one risk (identified as point 3 in Fig. 5) appears in area A – above the bisector, indicating a risk that has a management cost in excess of the PC. This risk can (and should) be more efficiently managed on the project. This risk item has a high PC and can be monitored over time for changes in PC. RM tactics to reduce the quantum or probability of the risk occurring should be tested to see if the phase ratio can be moved closer to unity. If a particular intervention (including any additional costs of the management of that risk) shows that the phase ratio improves towards unity, then that risk tactic is preferable to the current risk policy for that risk.

Table 2. Exemplar basic data (£M)

		Risk estimate	
		Average (50%)	Maximum (95%)
Works	165.00	–	–
M&E	30.50	–	–
External	14.00	216.00	216.00
Client sup.	0	15.03	72.38
Fees	6.5	–	–
SUM	216.0	231.03	288.40
R/U	–	£231.00	£285.00
Dual range estimate ‖231M – 285M‖ @95% probability			

In the exemplar, most of the risks appear in area B – below the bisector. This is indicated by the typical risk 2 (shown in Fig. 5), which shows a risk that has a RM intervention cost that is smaller than the PC – hence the risk could be better managed by having further management attention given to the current approach. This indicates that a risk has had a 'satisficing' management tactic applied, rather than identifying and applying the most effective management tactic.

It is also recognised that in the exemplar the risks below the bisector are all clustered near to the origin, which indicates risks that have a much lower significance than those further from the origin. Thus, it is most appropriate to start with the risk identified by point 2 since this is furthest from the origin.

The phase envelope is relatively small and appears oriented along the bisector. The small phase envelope indicates that the risks are generally of a similar scale (with one exception for risk 3). The orientation of the phase envelope indicates rational RM decisions have been made.

Table 1. Exemplar Data for MERA calculation and phase portrait construction

Risk register	Fixed or variable (F or V)	Average risk			Maximum risk							
		Q_{av}	P_{av}	R_{Eav}	Q_{max}	P_{max}	R_{Emax}	Range	Deviation	Rank	R_E	C
Add'l staff parking	F	5.00	0.50	2.50	5.00	1.00	5.00	2.50	6.25	8	2.81	0.22
Add'l client parking	F	2.50	0.35	0.875	2.50	1.00	2.50	1.625	2.64	10	1.14	0.10
Add'l office accom.	V	1.50	0.50	0.75	10.00	1.00	10.00	9.25	85.56	6	4.03	0.32
IT connectivity	V	11.0	0.20	2.20	17.00	1.00	17.00	14.80	219.04	5	5.76	0.57
Atrium	F	4.00	0.50	2.00	4.00	1.00	4.00	2.00	4.00	9	2.25	0.18
Insolvency	V	9.50	0.10	0.95	17.50	1.00	17.50	16.55	273.90	4	5.07	0.55
Ground conditions	V	3.00	0.50	1.50	20.00	1.00	20.0	18.50	342.25	3	8.06	0.64
Design variations	V	8.00	0.20	1.60	25.00	1.00	25.00	23.40	547.56	2	7.98	0.79
Supplier default	V	4.50	0.20	0.90	9.00	1.00	9.00	8.10	65.61	7	2.97	0.29
Consultant default	V	35.0	0.05	1.75	43.50	1.00	43.50	41.75	1743.06	1	11.88	1.34
		ARAΣ	15.03					Σ	3289.88			
								√Σ	57.36			
								+ ARAΣ	15.03			
								MRA	72.38			

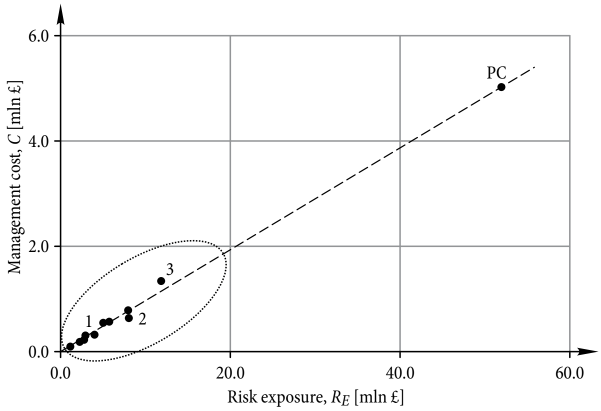

Fig. 5. Exemplar phase portrait diagram

Conclusions

The proposed phase portrait methodology based on the Khlebopros *et al.* (2007) work has a number of advantages, which makes it an effective RM tool.

Firstly, it is strongly based on quantitative data that is specific to the user. There is no averaging or approximating, it is explicitly dependent only on the data of a unique project. It will work on little or ample data as is available.

Secondly, the initial phase portrait is intuitively understandable. The phase 'cloud' above the bisector are initial targets for improving the RM tactics for a particular risk, either by reducing the quantum or probability of impact, utilizing standard techniques of RM.

Thirdly, the subsequent imposition of later phase portraits gives a very clear visual indication of the overall trend in RM – something that is not easily achieved by data alone.

The methodology is relatively simple to implement and provides a rapid visualisation of the overall risk extent of a project. In addition, though the example presented above was about a construction project, the proposed technique can easily be used in other sectors without any sector related modification and/or adaptation. Furthermore, though the methodology proposed applies the MERA approach to quantification of risk impact, other methods could be applied to replicate R_Q and R_P in this approach, but have been ignored in this paper.

References

Boussabaine, A. 2006. *Cost Planning of PFI and PPP Building Projects*. Routledge. 336 p. http://doi.org/10.4324/9780203018842

Charette, R. N. 1989. *Software Engineering Risk Analysis and Management*. McGraw-Hill. 325 p.

CUP. 1993. *Guidance Note No. 41: Managing Risks and Contingency for Works Projects*. HM Treasury Central Unit on Procurement (CUP), London, UK.

Dorofee, A. J.; Walker, J. A.; Alberts, C. J.; Higuera, R. P.; Murphy, R. L.; Williams, R. C. 1996. *Continuous Risk Management Guidebook*. Software Engineering Institute (SEI), Carnegie Mellon University. 562 p.

Eaton, D. 2010. *Price Bidding, Bid Evaluation and Financial Management*: Lecture notes. School of Construction and Property Management (SCPM), University of Salford, UK.

Ghazali, F. E. M.; Kabir, S. 2009. Determination of risk identification process employed by NHS for a PFI hospital project in the UK, *Journal of Industrial Engineering and Management* 2(3): 558–568. http://doi.org/10.3926/jiem.2009.v2n3.p558-568

HM Treasury. 2004. *The Orange Book: Management of Risk – Principles and Concepts*. HMSO, London. 52 p.

HM Treassury. 2003. *The Green Book: Appraisal and Evaluation in Central Government*. HMSO, London. 118 p.

IRM. 2002. *Risk Management Standard*. Institute of Risk Management (IRM), London, UK. 16 p. Available from Internet: https://www.theirm.org/knowledge-and-resources/risk-management-standards/irms-risk-management-standard

IEC 31010:2009. *Risk Management. Risk Assessment Techniques*.

ISO 31000:2009. *Risk Management. Principles and Guidelines*.

Khlebopros, R. G.; Okhonin, V. A.; Fet, A. I. 2007. *Catastrophes in Nature and Society: Mathematical Modeling of Complex Systems*. World Scientific Publishing Company. 336 p.

Liu, J.; Flanagan, R.; Li, Z. 2003. Why does China need risk management in its construction industry?, in D. J. Greenwood (Ed.). *19th Annual ARCOM Conference*, 3–5 September 2003, Association of Researchers in Construction Management, University of Brighton, 1: 453–462.

Mak, S.; Picken, D. 2000. Using risk analysis to determine construction project contingencies, *Journal of Construction Engineering and Management* 126(2): 130–136. http://doi.org/10.1061/(ASCE)0733-9364(2000)126:2(130)

Mills, A. 2001. A systematic approach to risk management for construction, *Structural Survey* 19(5): 245–252. http://doi.org/10.1108/02630800110412615

MoD. 1994. *Defence Works Services Technical Bulletin 06/94 MERA: Multiple Estimating Risk Analysis*. Ministry of Defence (MoD), UK.

Molenaar, K. R. 2005. Programmatic cost risk analysis for highway megaprojects, *Journal of Construction Engineering and Management* 131(3): 343–353. http://doi.org/10.1061/(ASCE)0733-9364(2005)131:3(343)

NASA. 2010. *NASA Risk-Informed Decision Making Handbook*. NASA/SP-2010-576. Version 1.0. April 2010. National Aeronautics and Space Administration (NASA). 128 p. Available from Internet: http://www.hq.nasa.gov/office/codeq/doctree/NASA_SP2010576.pdf

NASA. 2008. *Agency Risk Management Procedural Requirements*. National Aeronautics and Space Administration (NASA). Available from Internet: http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPR&c=8000&s=4A

PMI. 2008. *A Guide to the Project Management Body of Knowledge*. 4th edition. Project Management Institute (PMI). 459 p.

PMI. 2004. *A Guide to the Project Management Body of Knowledge*. 3rd edition. Project Management Institute (PMI). 390 p.

Schmit, J. T.; Roth, K. 1990. Cost effectiveness of risk management practices, *The Journal of Risk and Insurance* 57(3): 455–470. http://doi.org/10.2307/252842

Smith, N. J.; Merna, T.; Jobling, P. 2014. *Managing Risk in Construction Projects*. Wiley. 252 p.

TBCS. 2004. *Integrated Risk Management: Implementation Guide*. Treasury Board of Canada Secretariat (TBCS), Government of Canada. Available from Internet: http://www.tbs-sct.gc.ca

TBCS. 2001. *Integrated Risk Management Framework*. Treasury Board of Canada Secretariat (TBCS), Government of Canada. Available from Internet: http://www.tbs-sct.gc.ca

Touran, A. 2006. *Owners Risk Reduction Techniques Using a CM*. Report presented to the Construction Management Association of America (CMAA). 55 p. Available from Internet: https://cmaanet.org/files/touran.pdf

TSO. 2013. *Management of Risk: Guidance for Practitioners and the international standard on risk management, ISO 31000:2009*. White Paper. The Stationery Office (TSO), London, UK.