Article

MANAGING PROJECT RISKS USING A CROSS RISK BREAKDOWN MATRIX

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Abstract

Projects are complex undertakings involving a unique set of tasks and activities conducted within a set of constraints to meet defined objectives. Risk in projects is also complex, arising from a wide range of sources and having a broad scope of possible effects on the project. Given these two dimensions of project complexity, the management of the relationship between project work and project risk is a key success factor for every project. This paper develops a method for understanding and managing risk on a project, using a combination of the Work Breakdown Structure (WBS) and Risk Breakdown Structure (RBS), resulting in the Risk Breakdown Matrix (RBM). An example is used to demonstrate how to measure risk concentration within the RBM using a "risk score" based on the scale or size of individual risks. It is also possible to combine different levels of the WBS and RBS into a pyramidal structure where each of the layers is an RBM.

Keywords

risk management; risk analysis; Work Breakdown Structure; Risk Breakdown Structure; Risk Breakdown Matrix

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Using the Risk Breakdown Structure

Since it was first described (Hillson, 2002a, b, 2003), the Risk Breakdown Structure (RBS) has been recognized as a useful tool for structuring the risk process, and has been included in several risk standards and guidelines (for example, Association for Project Management, 2004; Project Management Institute, 2004). The RBS is defined in similar terms to the Work Breakdown Structure (WBS), as "A source-oriented grouping of project risks that organises and defines the total risk exposure of the project. Each descending level represents an increasingly detailed definition of sources of risk to the project" (Hillson, 2002a). The RBS is therefore a hierarchical structure of potential risk sources, which can be an invaluable aid to understanding the risks faced by the project. It can act as a framework to structure and guide the risk management process, in the same way that the WBS can structure the project management process because it scopes and defines the work of the project (Project Management Institute, 2001).

A generic RBS might seem to be useful, but it would be unlikely to include the full scope of possible risks to every project. An alternative is therefore to produce a specific RBS structure relating either to a given industry or to the types of project undertaken by a particular organization. Once the RBS has been defined, it can be used in a variety of ways. Some of these facilitate the risk management process on a particular project, while others are relevant across projects. The main uses and benefits of the RBS are as follows (Hillson, 2002a, b):

- *Risk identification aid* – The higher levels of the RBS can be used as a prompt list to ensure complete coverage of risk identification, or lower levels can be used as a checklist. In addition the RBS can be used to structure lists of risks identified by other methods. This enables gaps or blind spots in risk identification to be seen and addressed, and reveals any double-counting or duplication.
- *Risk assessment* – Identified risks can be mapped into the RBS and categorized by source. This exposes the most significant sources of risk to the project, and indicates areas of dependency or correlation between risks. Risk response development can then be focused on high-risk areas, with generic responses for root causes or dependent groups of risks.
- *Comparison of alternatives* – Risks associated with competing bids and tenders can be compared directly if the same RBS is used to structure their associated risks. This can also provide input to trade-off studies examining alternative development options or investment decisions. Risk exposure on different projects within a programme or portfolio can also be directly compared since the RBS presents a common structure and terminology to describe the risks. This can help in development of a risk-balanced portfolio.
- *Risk reporting* – Different project stakeholders need different levels of reporting, and the RBS can be used to roll-up risk information to a higher level for senior management, as well as drilling down into the detail required to report on project team actions. It also provides a consistent reporting language for risk, reducing the potential for misunderstanding, especially when used for cross-project reporting.

- *Lessons learned for future projects* – Risk elements of post-project reviews on completed projects can be captured using an RBS as a common framework. This can reveal common or generic risks, allowing development of preventative responses, and feed-forward of effective actions into future projects.

Successful and effective risk management requires a clear understanding of the risks faced by the project and business. This involves more than simply listing identified risks and prioritizing them by their probability of occurrence and impact on objectives. The large amount of risk data produced during the risk process must be structured so that we can understand it and use it as a basis for action. A hierarchical RBS framework similar to the WBS provides a number of benefits, by decomposing potential sources of risk into layers of increasing detail. The RBS is a powerful aid to risk identification, assessment and reporting, and the ability to roll-up or drill-down to the appropriate level provides new insights into overall risk exposure on the project. It also provides a common language and terminology to facilitate comparison of alternatives, cross-project reporting and lessons learned.

Linking WBS and RBS

The interconnection between the Work Breakdown Structure (WBS) of a project and its RBS is a useful technique to associate risks to the activities of a project (Aleshin, 2001).

The WBS uses a hierarchical structure to define the major tasks, minor tasks and work packages (WPs) necessary to reach the final objectives of a project (Project Management Institute, 2001), while the RBS classifies project risks using a hierarchical system of sources of risk (Hillson, 2002a, 2003). Both WBS and RBS commonly have three or four levels of increasing detail. There are evident analogies between WBS and RBS: WBS constitutes the basic framework for the management of a project; likewise, RBS can be used as a tool to structure the risk management process (Hillson, 2002b).

The combined use of WBS and RBS can be used to generate a matrix structure, which allows the project team to manage the risk at a level of detail appropriate to the specific business context.

To produce such a combined framework, risk analysis is first performed identifying and classifying risks using the RBS, either directly or to support other methods of identification such as brainstorming or interviews. The lowest levels of the RBS are then linked to the WPs in the WBS, producing a two-dimensional matrix. Obviously, a link is created only if a particular risk can affect a specific WP. A WBS–RBS matrix is generated which we call the “Risk Breakdown Matrix” (RBM) (Rafele *et al.*, 2005), as illustrated in Figure 1.

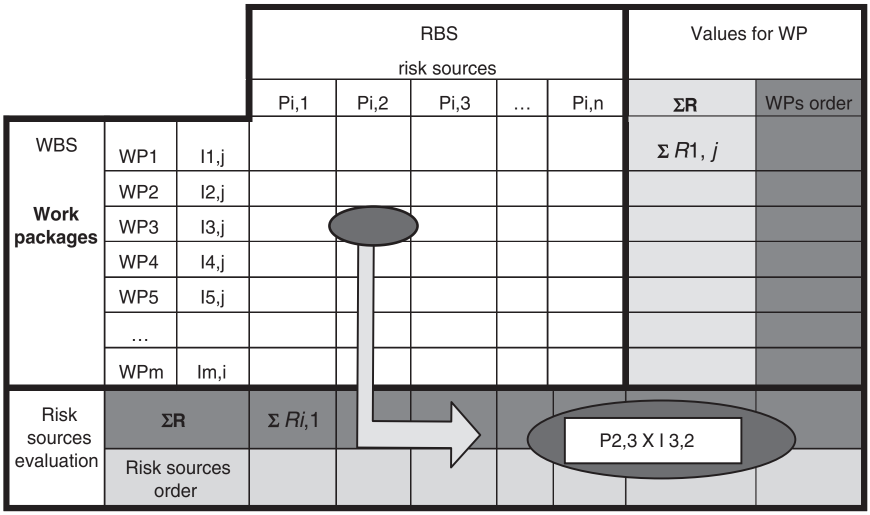

Figure 1 Risk Breakdown Matrix (RBM) with sample evaluation.

For every RBM cell containing risks, the value of each risk is calculated using two components: the probability of occurrence (*P*) and the degree of impact (*M*). Probability is related to the presence of a risk in the RBS, and impact refers to the effect of that risk in the WBS. The calculation of the value of each risk can be determined in various ways, depending on the availability of data, as follows (Grimaldi and Rafele, 2002; Project Management Institute, 2004):

- using an "ordinal scale" approach, the degree of impact (M) and the index of occurrence (P) are assessed using descriptive labels (Franceschini, 2001): for instance, very low, low, medium, high, and very high;
- using a "cardinal scale" approach, both the degree of impact and the index of occurrence are divided into classes, distinguished with numerical values included in dimensionless preset scales (for example from 1 to 9) (Misani, 1994);
- using a "quantitative approach", in which the degree of impact is related to the parameter directly influenced by the risk (e.g. time delay, increase of costs or other), whereas the probability of occurrence is usually described as a percentage (from 1 to 99%).

Considering the risks for every WP, an evaluation of the level of criticality for a single WP can be obtained, either in absolute terms or relative to other WPs. The degree of criticality is determined by adding the risk values for each row in the RBM matrix (Figure 1) (Grimaldi and Rafele, 2002). This can be expressed by the formula:

$$R_{WP,\ i} = \sum_{j=1}^{n} P_{i,j} * M_{i,j}$$

where $R_{WP,i}$ is the global incidence of risks in WP-*i*; $P_{i,j}$ is the probability of occurrence of risk-*j* in WP-*i*; $M_{i,j}$ is the impact of risk-*j* in WP-*i*.

The column in Figure 1 titled "WPs Order" can be used to record a ranking of WPs, indicating which are most risky, determined by the total value of risks affecting each WP.

A similar reasoning can be applied to analysing risk sources by separately considering the columns of the RBM matrix. The sum of the values for each column identifies the relationship of all WPs of the project to a particular source of risk or the presence of risks in different WPs (Figure 1). In this case the formula is

$$R_{ris,\mathrm{i}} = \sum_{\mathrm{i}=1}^{m} P_{\mathrm{i,j}} * M_{\mathrm{i,j}}$$

where $R_{ris,j}$ is the total effect of risk source risk-*j* in the whole project.

The value obtained by summing columns using the second formula allows a classification of sources of risk in terms of their influence on the project.

The phase of risk evaluation is followed by the phases of monitoring and control, in which appropriate interventions are defined on the basis of the classification. The following alternatives should be considered:

1. Intervention aimed at the single most significant risk, as determined from the RBM, after having assigned the values of $P_{i,j}$ and $M_{i,j}$. Attention should be focused on the risk with the highest value of $R_{i,j}$ and continue in decreasing order to the lowest acceptable limit;
2. Evaluation of all the risks related to the element of the project identified as most critical (i.e. maximum value of $R_{WP,i}$), on the basis of adding the values for each row in the RBM (Figure 1). Risk responses should focus on execution of the WP or on the type of resources applied to that element of the project;
3. Evaluation of the influence of the single most significant source of risk on different WPs, considering the totals of RBM columns, based on a calculation of $R_{ris,j}$ (Figure 1). The response will address ways to reduce the risk source, decreasing its manifestation in the project.

The choice among the three options must be made with a special regard to the position of the risks in the RBM matrix and on the basis of the value in each cell. For instance, if risks are concentrated in specific WPs (the highest values occur on the rows related to the WPs), option 2 above is better, whereas if a single value is much higher than the others, it is useful to focus on the most critical risk (option 1).

Use of the RBM to analyse risk can be demonstrated using an example based on a software development project. The analysis starts with definition of WBS and RBS structures. For this example, both WBS and RBS have three levels. The first level of the WBS (Figure 2) divides the activities of the

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
Software implementation project WBS	Project Management	Planning	Develop Project Charter
			Define Scope
			Develop Resource Plan
			Develop Communication Plan
			Develop Risk Plan
			Develop Change Control Plan
			Develop Quality Plan
			Develop Purchase Plan
			Develop Cost Plan
			Develop Organization Plan
			Develop Project Schedule
		Meetings	Conduct Kickoff Meeting
			Weekly Status Meeting
			Monthly Tactical Meeting
			Project Closing Meeting
		Administration	Standards
			Program Office
	Product Requirements	Software Requirements	Create Draft Software Requirements
			Review Draft Software Requirements
			Update Draft Software Requirements
			Review Final Software Requirements
			Software Requirements Approved
		User Documentation	Create Draft User Documentation
			Review Draft User Documentation
			Update Draft User Documentation
			Review Final User Documentation
			User Documentation Approved
		Training Program Materials	Create Initial Training Requirements
			Review & Approve Training Requirements
			Create Initial Training Materials
			Review & Approve Training Materials
			Conduct Trial Course Delivery
			Updateand Finalize Training Materials
		Hardware	Create Draft Hardware Requirements
			Review Draft Hardware Requirements
			Hardware Requirements Approved
	Detail SoftwareDesign	Create Initial Software Design	
		Review Initial Software Design	
		Update Initial Software Design	
		Review Final Software Design	
		Software Design Approved	
	System Construction	Configure Software	
		Customize User Documentation	
		Customize Training Program Materials	
		Install Hardware	
		Implementation & Future Support	
	Integration &Test	Software	
		System Test Plan	
		System Test Cases	
		System Test Results	
		System Test Plan	
		System Test Cases	
		System Test Results	
		User Documentation	
		Training program Materials	
		Hardware	
		Implementation & Future Support	

Figure 2 WBS for software development.

project into *Project Management, Product Requirements, Detail Software Design, System Construction,* and *Integration & Test*. Similarly, the first level of the RBS divides the sources of risk into *Product engineering, Development environment*, and *Program constraints* (Figure 3). The RBM analysis method proceeds with relating risks in the lowest level of the RBS to the work-packages of the project in the corresponding lowest level of the WBS. (For simplicity in this example we only show the *Program*

LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3
Project risk	Product engineering	Requirements	Stability
			Completeness
			Feasibility
		Design	Functionality
			Interfaces
			Testability
		Code& unit test	Feasibility
			Testing
			Coding/Implementation
		Integration test	Environment
			Product
			System
		Engineering specialities	Maintainability
			Reliability
			Security
	Development environment	Development process	Formality
			Process control
			Product control
		Development system	Capacity
			Reliability
			System support
		Management process	Planning
			Project organisation
			Management experience
		Management methods	Monitoring
			Project organisation
			Management experience
		Work environment	Cooperation
			Communication
			Morale
	Program constraints	Resources	Staff
			Budget
			Facilities
		Contract	Type of contract
			Restrictions, dependencies
		Program interfaces	Customer
			Subcontractors

Figure 3 RBS for software development.

constraints branch of the RBS and the *Project Management* branch of the WBS.)

This produces a matrix (Figure 4), which allows classification of the risks, in this example using a cardinal scale. Based on the numerical values in the matrix, various conclusions can be drawn, including:

- identifying which activities have more associated risks (in the example this is the activity *Develop Project Charter*);

		From RBS (Program constraints)							WPs evaluation	
		Staff	Budget	Facilities	Type of contract	Restrictions/ Dependencies	Customer	Subcontractors	R	WPs order
From WBS	Develop Project Charter			I =3, p=2: R=6	I =6, p=5: R=30	I =7, p=7: R=49	I =7, p=5: R=35		120	1
	Define scope	I =8, p=6: R=48	I =7, p=4: R=28					I =4, p=4: R=16	92	3
	Develop Resource Plan	I =7, p=5: R=35				I =4, p=3: R=12			47	5
	Develop Communication Plan	I =5, p=3: R=15				I =3, p=2: R=6			21	9
	Develop Risk Plan	I =7, p=5: R=35							35	7
	Develop Change Control Plan								0	6
	Develop Quality Plan					I =4, p=3: R=12			12	10
	Develop Purchase Plan								0	12
	Develop Cost Plan		I =8, p=4: R=32						32	8
	Develop Organization Plan								0	12
	Develop Project Schedule								0	12
	Conduct Kickoff meeting	I =7, p=5: R=35			I =3, p=2: R=6				41	6
	Weekly Status Meeting								0	12
	Monthly Tactical Meeting								0	12
	Project Closing meeting						I =3, p=2: R=6		6	11
	Standards	I =8, p=6: R=48					I =7, p=5: R=35	I =4, p=4: R=16	99	2
	Program Office					I =5, p=3: R=15	I =8, p=6: R=48		63	4
Risk sources evaluation	R	216	60	6	36	94	124	32		
	Risk sources order	1	4	7	5	3	2	6		

Figure 4 Matrix RBM for a software development with a cardinal scale approach.

- identifying the most important single source of risk, that is, with the highest value of $R_{WP,j}$ (in the example this is *Staff*)
- to single out the most significant relationship (in the example the link between *Restrictions* and *Develop Project Charter* is highlighted).

Such considerations will allow risk responses and actions to be planned, increasing the effectiveness of the interventions.

The matrix can be linked to the elements of a risk register, in which it is possible to insert for each cell a description of the risk, and the reduction and mitigation plans derived by considerations of the numeric values (Patterson and Neailey, 2002).

Using an WBS/RBS/RBM pyramid for layered risk analysis

Optimal analysis of risk identifies risks with a sufficient degree of detail to be able to determine the most vulnerable points in a project. Therefore, it is necessary not only to classify individual risks, but also to quantify their relationship with areas of the project, in order to understand the correct priority of intervention among the possible mitigation actions.

As a result, it is useful to analyse risk in a hierarchical manner at different levels within the project. This can be achieved by developing a pyramidal structure, linking the hierarchical levels of WBS and RBS into RBMs with increasing degrees of detail.

The WBS and RBS hierarchies can be visualized as two triangles, whose dimensions depend on the number of levels and the degree of detail in each level.

If the WBS and RBS have the same number of levels, it is possible to join the two triangles to form the faces of a pyramid, where the detailed RBM matrix between lowest levels of RBS and WBS constitutes the base. At each level another RBM is created, whose area depends on its position within the two triangles, that is, depending on the degree of detail of the WBS and RBS (Figure 5).

It follows that the number of layers in the pyramid will match the levels of detail in the WBS and RBS, and each layer represents an RBM matrix at a different level of detail.

The highest RBM matrix is defined by the intersection of the first levels of the WBS and RBS. This identifies the macro areas of risks in a project, because it crosses the main tasks or "aggregated deliverables" with generic types of risk. This first level of generic analysis therefore only allows identification of areas of risk within the main sectors of the project.

The next level of the WBS defines the main deliverables of the project (Villa, 2003) and if they are crossed with the second level of RBS, the possible vulnerability and criticality of each deliverable is exposed. At this level, an ordinal

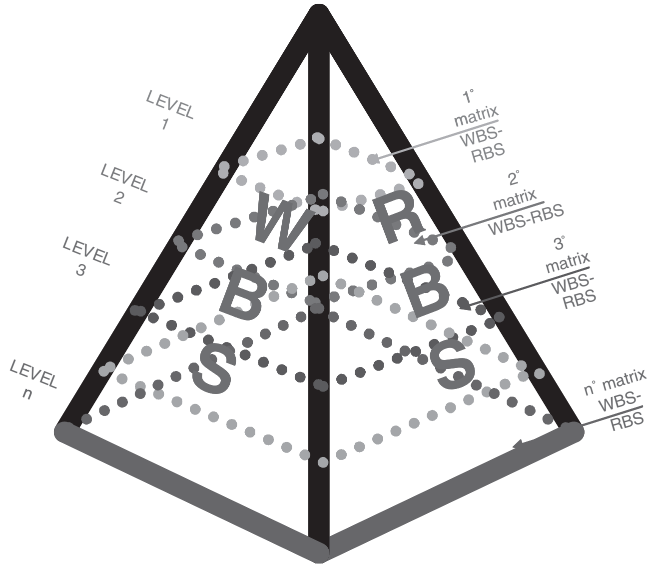

Figure 5 Risk pyramid.

scale could be used, with descriptive categories of impact and probability of occurrence.

If the detail of WBS and RBS is increased further, a more precise analysis of the risk can be undertaken, using the cardinal scale approach, or if the economic or time impacts are known, a quantitative analysis becomes possible.

In the construction of the pyramid, with a top-down approach from the vertex to the base, risks are defined and quantified at an increasing level of detail related to the elements of the project affected.

This is the most important phase of the risk evaluation, in which it is necessary to put the greatest energies in terms of knowledge, competence and ability of all the project resources with the purpose to get the best quantification of the risk. In this way, it is possible to understand which risks have the biggest impact, and also to establish where it is necessary to intervene and which are the priorities.

After the most detailed quantification of all the risks for every activity of the project, compiling the RBM matrix at the base of the pyramid, it is also useful to conduct a bottom-up assessment, going up the pyramid from a specific level of evaluation to a more general one. For instance, passing from a larger RBM matrix to a smaller, it is possible to aggregate the risks affecting particular areas of the project.

The pyramid representation clearly visualizes the hierarchical nature of the RBM matrixes. It also allows identification of the links that connect data on different levels, which can be used to structure management of risk information at different levels of RBM matrixes.

As we have developed the model thus far, the WBS and RBS have been used properly vis-à-vis driving the activities/deliverables to the lowest levels of the structure. At this level, an appropriate and detailed risk analysis and assessment could be made. However, by stratifying the pyramid according to the different levels of the matrices, practical analysis of the risks is diluted and the RBM is meaningful mostly at the lowest level of the two structures (WBS and RBS).

Nevertheless, useful information could be found also at the highest levels, in fact aggregate data could be compared across multiple projects. Range of risks for areas show the evolution of risk behaviour through the time for successive projects.

This approach can be used not only as a mean of risk analysis, but also as a way of facilitating communication between the different stakeholders in a project. For instance, project managers who understand the specific issues on their project can introduce detailed data on the risks in the lowest layers of the pyramid to form the base RBM, and at the same time top management can then obtain summary information on risk exposure from the higher-level RBM matrixes allowing them to make appropriate strategic decisions, as it happens for milestones representation in project schedule.

This pyramidal RBM approach can also support different levels of risk process dependent on the level of risk maturity of the organization (Hillson, 1997; Hopkinson, 2000; Hulett, 2001; McKenna, 2001). For example, it is likely that organizations with low-risk management capability and maturity might be able to complete only the first levels of the pyramid, whereas organizations with higher risk management maturity might be able to complete the whole pyramidal structure.

Example of WBS/RBS/RBM pyramid for software development

Going back to the software development example, we can complete the risk analysis using the pyramidal structure of the risk. At the highest level of WBS and RBS, it is possible to define the smallest matrix, which distinguishes 15 main areas of risk affecting the project (Figure 6a). Each of these areas must be expanded, to obtain a precise quantification of the risk. In this way, larger RBM matrixes would be produced.

A full analysis of the software development example at all RBM levels is beyond the scope of this paper: our analysis therefore expands only the single RBS branch of *Program constraints* in the WBS area of *Project Management*. This uses the second levels of the WBS and RBS: for the WBS area of *Project Management*, three subareas can be decomposed: *Planning*, *Meetings*, and *Administration*. For the RBS area *Program constraints* the defined groups are *Resources*, *Contract*, and *Program interfaces*. Their combination produces

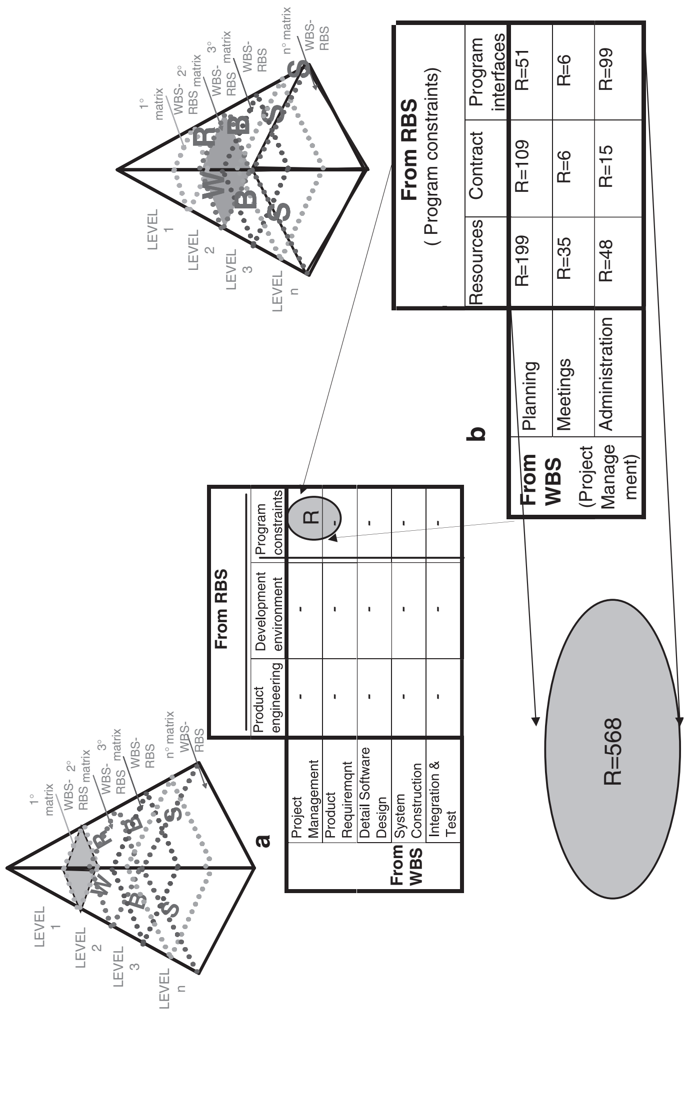

Figure 6 First (a) and second (b) matrix RBM.

a 3×3 matrix (Figure 6b), in which it is possible to associate more specific sources of risk to every single deliverable of the project. In this phase, the degree of detail of the matrix optimizes identification of the risks within *Project Management*. Nevertheless, to allow analysis using an ordinal scale or a cardinal scale, it is necessary to expand again the matrix of Figure 7a, using the third levels of the WBS and RBS. With a cardinal scale approach, a 7×17 matrix is produced (Figure 7b), which attributes a value to each risk based on its impact and occurrence. Our analysis stops at the third level of WBS and RBS: with the third matrix of dimension 38×36, which constitutes the base of the pyramid. For brevity, we have stopped the development of the pyramid levels in the example; of course, the analysis could go more in detail right down to individual risk statements.

Going up the pyramid, it is possible to quantify risk for every area of the project, summing the numerical values of the single risks at the lowest level of the pyramid. Repeating this procedure to the highest matrix, we could calculate a total value of 568, which represents the total degree of risk arising from RBS source *Program constraints* that could affect the WBS area of *Project Management*. Repeating this calculation a further 14 times (there are 15 cells in the first matrix RBM), the evaluation of risks in the whole project can be completed, both for individual project areas and for all areas together. In this way, top management has all the information required to decide the right actions to respond to future risks, focusing resources on the most vulnerable areas of the project.

Conclusions

Two of the main areas of complexity in projects arise from the work to be done and the risks that could affect achievement of objectives. Hierarchical frameworks have been developed to provide structure in these two areas: the WBS for project tasks and activities, and the RBS for sources of risk. Both WBS and RBS are powerful tools for understanding and managing the scope and risk of the project, respectively.

There is, however, a further level at which these two tools can be used to assist the project manager in addressing project complexity as it affects both scope and risk. Combining WBS and RBS to form the RBM allows identified risks to be linked with affected areas of the project. This paper has shown how to generate a base-level RBM from the lowest level of the WBS (Work Packages, WPs) and the lowest level of the RBS (individual risks), revealing the most significant risks and those WPs in the project most exposed to risk.

Further development of the RBM concept allows different levels of WBS and RBS to be linked, producing a pyramid of hierarchical RBMs, each at a higher level of detail. At the top level, the RBM relates key sources of risk to the major deliverables and tasks of the project, allowing senior management to make strateb

Da WBS (da Project Management)			Da RBS (Program constraints)						
			Resources			Contract		Program interfaces	
			Staff	Budget	Facilities	Type of contract	Restrictions	Customer	Subcontractors
	Planning	Develop Project Charter			I =3, p=2: R=6	I =6, p=5: R=30	I =7, p=7: R=49	I =7, p=5: R=35	-
		Define Scope	I =8, p=6: R=48	I =7, p=4: R=28					I =4, p=4: R=16
		Develop Resource Plan	I =7, p=5: R=35				I =4, p=3: R=12		
		Develop Communication Plan	I =5, p=3: R=15				I =3, p=2: R=6		
		Develop Risk Plan	I =7, p=5: R=35						
		Develop Change Control Plan							
		Develop Quality Plan					I =4, p=3: R=12		
		Develop Purchase Plan		I =8, p=4: R=32					
		Develop Cost Plan							
		Develop Organization Plan							
		Develop Project Schedule							
	Meetings	Conduct Kickoff Meeting	I =7, p=5: R=35			I =3, p=2: R=6			
		Weekly Status Meeting							
		Monthly Tactical Meeting							
		Project Closing Meeting						I =3, p=2: R=6	
	Administration	Standards	I =8, p=6: R=48					I =7, p=5: R=35	I =4, p=4: R=16
		Program Office					I =5, p=3: R=15	I =8, p=6: R=48	

a

Da WBS (da Project Management)		Da RBS (Program constraints)		
		Resources	Contract	Program Interfaces
	Planning	R=199	R=109	R=51
	Meetings	R=35	R=6	R=6
	Administration	R=48	R=15	R=99 22

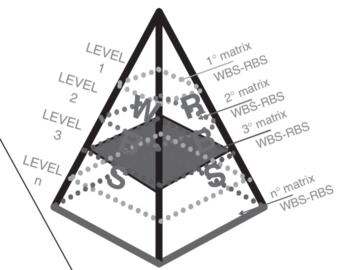

Figure 7 Second (a) and third (b) matrix RBM.

gic decisions. Analysis can also be performed up and across the pyramid, providing useful information on patterns of risk exposure. Finally the pyramid provides a consistent framework for project risk reporting at all levels in the project.

The RBM is a significant development of the tools available to assist the project manager in addressing project risk, providing unique insights into the effect of risk on different aspects of the project.

About the Authors

Dr David Hillson is an international risk management consultant and Director of Risk Doctor & Partners. Dr Hillson holds the PMP® certification from the Project Management Institute (PMI®), and is a Fellow of both the UK Association for Project Management (FAPM) and the UK Institute of Risk Management (FIRM). He is an award-winning conference speaker and author on risk management, and received the 2002 PMI Distinguished Contribution Awardfor his work in developing the discipline. He is responsible for several significant innovations in risk management, which have been widely adopted.

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Carlo Rafele received his MSc in Mechanical Engineering in 1984 from the Politecnico of Turin. Since then he has acquired considerable practical work experience in many industries, working as project manager in engineering and construction companies. He later joined the Department of Production Systems and Business Economics at the Politecnico of Turin as an Assistant Professor, and now teaches Project Management and Industrial Plants as Associate Professor. He has published several articles on project management and logistics.

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