Integrated Methodology for Project Risk Management

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Abstract: This article presents a generic project risk management process that has been particularized for construction projects from the point of view of the owner and the consultant who may be assisting the owner. The process could also be adapted to the needs of other project participants, and many points referred to in the article can be directly applied to them. Any project risk management process must be tailored to the particular circumstances of the project and of the organization undertaking it. First, the article explains a complete or generic project risk management process to be undertaken by organizations with the highest level of risk management maturity in the largest and most complex construction projects. After that, factors influencing possible simplifications of the generic process are identified, and simplifications are proposed for some cases. Then the application to a real project is summarized. As a final validation, a Delphi analysis has been developed to assess the project risk management methodology explained here, and the results are presented.

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Introduction and Foundations

The idea that risk management should be an important and integral part of project management is currently well and widely recognized by the leading project management institutions (Simon et al. 1997; IPMA 1998; PMI 2000; AEIPRO 2001). The period since 1990 has seen a variety of writers proposing a range of risk management processes. Al-Bahar and Crandall (1990), the U.K. Ministry of Defense (MoD-PE-DPP 1991), del Caño (1992), Wideman (1992), BSI (1999), NASA (Rosenberg et al. 1999), the U.S. Department of Defense (DSMC 2000), and the U.S. Department of Transportation (DOT 2000) are among these suggesting the use of processes with four or five phases. For example, phases may include initiation, identification, analysis, response planning, and control. The processes may be applied in general, or for specific project sizes and types.

Probably the most noteworthy, comprehensive, and sound project risk management (PRM) processes today are PRAM (Simon et al. 1997; Chapman and Ward 1997b), RAMP (ICE et al. 1998), and PMBoK-2000 (Project 2000). PRAM has a special importance because it was the first highly comprehensive process developed by a large team, including both practitioners and academics. The RAMP process has characteristics similar to those of the PRAM process in scope, structure, and conception but has been conceived for the construction environment. Finally, the importance of the PMBoK-2000 process lies in its relevance as an ANSI and IEEE standard. PRAM and RAMP tend to reflect more a ‘‘British-European’’ way of performing PRM, whereas the PRM chapter of the PMBoK was prepared by a mix of contributors from North America (United States and Canada) and Europe (U.K. and Spain; one of the writers was part of that team). Nevertheless, PRM practice is not very different in North America and Europe.

The writers present PUMA (Project Uncertainty MAnagement), an integrated methodology based on a hierarchically structured, flexible, and generic PRM process, here particularized for construction projects from the point of view of the owner and the consultant who may be helping the owner. The PUMA methodology is completely embedded in the project planning function; it is essentially consistent with and expands, among others, PMBoK-2000, RAMP, and PRAM. The main components of the methodology are

1. A generic PRM process to be undertaken by companies or institutions with the highest level of risk management maturity in the largest and most complex projects;
2. A set of flexible guidelines provided to simplify the global process, taking into account a wide set of project circumstances, especially those related to the level of risk management maturity of the organization undertaking the project, the relative project size, and the project complexity; and
3. A set of recommendations for the use of existing risk analysis techniques, taking into account similar criteria.

In the PUMA methodology, the ideal would be to develop processes tailored to the individual needs of each organization and even each project (Chapman and Ward 1997a,b; Turner and Payne 1997). And the best way to define how a generic model can be simplified is through empirical methods. The generic process and its possible simplifications will serve to define a specific process according to the organization and project's circumstances. These simplifications may or may not be followed in each individual case after a previous analysis. In the beginning, studying and analyzing the complete PRM process is always recommended to determine the most appropriate simplifications to adopt. A detailed knowledge of the process, organization, and circumstances surrounding the type of projects undertaken will make possible to simplify the generic process without losing its effectiveness.

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Construction project complexity questionnaire **Project:** **Code:**			
Factor (short description)	**value**	**weight**	**v*w**
Environment: direct complexity			
Various socio-political conflicts potentially affecting the project, and interrelationship among those conflicts		3	
Diversity and interrelations (differentiation and interdependence) of current legislation and regulations		1	
Diversity of construction elements which imply environmental impact		1	
Diversity of possible environmental impacts (air, water, noise, solid waste, visual, social)		1	
...			
Environment: indirect complexity			
Intensity of socio-political conflicts potentially affecting the project and level of pressure and uncertainty they add to it		3	
Level of demand in legislation and regulations affecting the project (for instance, in nuclear power stations)		1	
Concern for environmental issues in social, political and managerial levels and level of pressure they exert on the project		3	
...			

Fig. 1. Questionnaire to estimate complexity of construction projects

Another basis for this methodology is a questionnaire developed by the writers to classify construction projects according to their size and complexity (de la Cruz 1998). This questionnaire considers two types of complexity: direct and indirect. Direct complexity includes differentiation and interdependence among a system's elements; this first type of complexity coincides with the general concept of complexity referred to by Baccarini (1996) and with what Williams (1997) calls structural complexity. According to this concept, a nuclear power plant is, technically speaking, more complex than an expressway or an office building, even when the project budgets are similar. Indirect complexity, on the other hand, relates to factors that, apart from differentiation and interdependence, tend to lead eventually to higher levels of interdependence among the elements of a system (Williams 1997). Uncertainty is one of the major sources of indirect complexity, and schedule compression, the criticality of meeting cost objectives, or excessive quality requirements are other factors that lead to it.

Using those concepts, the writers have analyzed the principal sources of direct and indirect complexity in construction projects. A simple questionnaire with 69 short questions (Fig. 1) has been elaborated to estimate a project's complexity, in qualitative terms, in seven project areas (project environment, facility to build, technology, project organization, project objectives, information, and cultural aspects). Answers are placed on a scale between zero and three (zero when the question is not applicable, and values from one to three for positive answers) to show how much importance each factor has for a particular project. At the same time, each question has a weighting or level of importance (also from one to three). The index of complexity refers to the quotient between the weighted average of the answers and the maximum value of complexity that can be obtained answering the questionnaire.

The two theoretical extremes of values for this index are 0 and 100%, even though it is not possible for a project to reach such extremes. In real terms, the extreme values fluctuate between 5 and 60%. Thus, as real-life examples, an apartment complex might have a complexity index of around 7%; the Channel Tunnel, about 50%. Within the framework of the questionnaire, typically low-complexity projects measured up to 15% on the complexity index; those seen as involving high complexity, at 30% or above; and midrange complexity projects, at intermediate values. Subjectivity comes into play with this classification of projects, but here the goal is only to establish recommendations within a flexible methodological framework.

Another of the linchpins of this methodology is based on the taxonomy with which Hillson (1997) establishes possible risk management maturity levels. The first of these is called "naïve": at this level, the organization is unaware of the need for risk management. The second level is called "novice": the organization is now beginning to experiment with risk management through a small number of individuals, but there is no generic, structured approach to manage risk. The third level is called "normalized": now risk management is included in normal business processes and consistently implemented on all or most projects. The organization uses an integrated set of techniques and tools, and generic risk management processes are applied in a formal way; the organizational culture includes an accepted policy for risk management. The fourth level is called "natural": at this level, the organization has a risk-aware culture with a proactive approach to risk management in all aspects of the business and with an emphasis on opportunity management. The organization is continuously updating its processes and constantly learning from experience. The experience of the writers is similar to that of Hillson (1997); they find that few organizations are currently at level 4; many organizations are either at levels 2 or 3, and a significant number remain at level 1. In the writers' experience, project-driven organizations can be at level 1, but many are at levels 2 and 3. Only project-driven organizations could be at level 4; in contrast, non-project-driven organizations are normally at level 1.

Furthermore, the concept of risk taken into account to conceive the process explained here is as an uncertain event that, if it occurs, has a positive (opportunities) or negative (threats) effect on a project objective. The origin of risk is the uncertainty inherent to any project, and every risk is associated with (at least) a cause, a consequence (at least, if it occurs), and the probability or likelihood of the event occurring. There are known risks (known unknowns) that can be analyzed and managed, and other unknown risks (unknown unknowns) that can be addressed through a general contingency based on the project manager's experience. There may be "static" risks, which will maintain their characteristics during their period of existence, but many risks are "dynamic" and can change their probability and impact during the project life cycle. Moreover, there are risks with a single or normal uncertainty (weather phenomena), and other risks (Soros 1999) with other components of uncertainty caused by their interactive character (social, political, and economic phenomena). These are the reasons why PRM must be a continuous process

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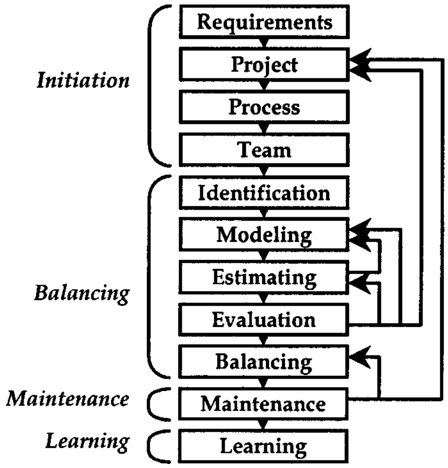

Fig. 2. Phases and stages flowchart

with feedback, from the beginning to the end of the project.

Otherwise, when developing the risk management process and methodology referred to here, the writers attempted to cull the best aspects of the models reflected in the literature about this topic. In particular, the process has taken into account, among others, aspects of the models proposed by the previously quoted writers, as well as those proposed by Lichtenberg (1981, 1983), Archibald and Lichtenberg (1992), Down et al. (1994), Grey (1995), or Reitan and Hauge (1997). The reader may also consult other interesting contributions to PRM by CCI (1989), Gibson et al. (1995), Bing and Tiong (1999), Bing et al. (1999), Kangari (1995), Javid and Seneviratne (2000), and Mak and Picken (2000). This work is also based on

- Analyzing practice in occidental organizations. More than 250 bibliographic references were consulted for this purpose; several interviews were also developed with professionals in the construction sector with experience in domestic and international construction projects (working as owners, engineers, consultants, and contractors); and
- The professional experience of the writers obtained through different positions in construction project management companies; in small, medium, and large construction and urban planning and development projects; and by post mortem analysis of projects in which the writers have been involved from 1986.

The aim of this article is to stimulate reflection on ways to develop the PRM tasks in different environments (projects, companies, and so on).

Generic Project Risk Management Process

As previously mentioned, the generic PRM process is conceived to be undertaken by organizations with the highest level of risk management maturity in the largest and most complex construction projects. This generic, or complete, process is structured in four levels. The first level includes four process phases. Two of these phases have a breakdown into several stages or subphases (second level); therefore, the process has a total of 11 stages. Fig. 2 is a flowchart showing the four process phases (first level) and their breakdown into several stages or subphases (second level). In this flowchart, only the main feedback has been included.

The process stages are divided into steps or activities (third level). In specific cases, an activity is divided into subactivities (fourth level). The first phase is called initiation (initiating the PRM process) and consists of four stages: requirements, project, process, and team. The second phase of the process is called balancing (balancing the risk environment). As the name implies, it is about providing equilibrium to the risk environment of the project (Down et al. 1994), in the sense of balancing opportunities with threats; it consists of five stages: identification, modeling, estimating, evaluation, and balancing. The third phase is called maintenance and is about keeping the risk environment balanced. Finally, the fourth phase is called learning, that is, the closure subprocess to learn from the present project experience. The stages of the process can overlap and can also interact with the project management activities. The process definition also includes flowcharts to provide a complete picture of the feedback and interrelation between the different activities at the third level and between subactivities at the fourth level. The methodology also includes more detailed guidance than is expressed in this paper, due to the limitations on the paper's length.

Requirements Stage

The requirements stage kick-starts the risk management process between the staff with the greatest levels of responsibility for it and the most senior among the clients for whom the work is to be carried out. Needs and constraints are established, and a simple opportunity analysis of the process is done. Normally this stage will be developed in a rapid and sometimes informal way: that is, resolved in a few hours. The first step is to obtain the minimum of information about the main features of the project from the client of the process. At this point, this step will be taken without great contrasts, so that the coherence between these features and the project objectives is analyzed in only a cursory fashion.

It is desirable to have the minimum information related to the general environment; stakeholders or interested parties; their motives (profit, benefit); conceptual design; project plan; project breakdown structure; available human and material resources; milestones schedule and estimated deadlines and costs; prioritization of project objectives; and other data about the program that concern the present project (link with program management). The next step is to obtain basic information from the process client about their risk management needs. Now is the moment to interview the client about all stakeholders and interested parties in the process; the profit or benefit they hope to gain (savings, increased profitability) and other motivations in the process; the desired process scope; time scale available (at least for the initial and balancing phases); the assigned budget for the process; and, finally, prioritization of the process objectives.

Following the collection of this information, a contrastive study is made. If the process goes forward, a small team will be named to follow through with the rest of the initiation phase, including the appointment of the risk process manager. The main goal of this stage is to avoid wasting time in the following stages of this phase, in case of a mismatch between the needs of the process clients and their own restrictions or those emerging from the project itself. This stage may be left out in many cases, but it will be useful for an outside consultant to estimate his or her prospects of winning the contract, or at least to determine how much effort should be made in order to win it. For similar reasons, it will also be handy for the internal staff responsible for risk management.

Project Stage

The project stage entails a detailed study of the project and a definition of how the project's success will be measured. The first

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step is a familiarization with the project and an analysis of it as far as risk management is concerned. This consists, first, of gathering and summarizing any existing information about the project. The type of data needed is not different from that of the requirements stage, but adds information related to underlying assumptions and parameters considered key to the project (for example, revenue, operation costs, time to market, and so on). However, the work is now done by the risk management team to make a contrastive study in their capacity as project management ''guardians'' or ''watchdogs.'' The team's goal now is to suggest possible changes in the project and to produce formal documentation for this stage. If necessary, additional information will be sought. In tandem, a search and analysis of historical information about similar internal and external projects will be done. The second step is to contrast the project objectives, comparing all the information collected up to this point to decide if everything goes forward or if the project requires serious reconsideration. Finally, the way in which project success will be monitored, and even measured, must be established (de Wit 1988; Gray 1995).

Process Stage

The process stage includes an analysis of the feasibility of the risk management process and its planning. There are various clear differences between this and the requirements stage. First of all, it is the risk management team who now prepares the information needed. Another difference is that process planning will now be carried out in a similar way when a project is planned; this stage cannot be dropped. The first step in this stage is to analyze the feasibility of the process. This entails

- Reconsideration of the information about stakeholders and interested parties and the advantages (profit, benefit) they hope to gain from the process;
- Gathering and summarizing information about stakeholders' risk tolerances, the organization's risk management policies, and existing PRM procedures;
- Analysis of the internal and external risk (Chapman and Ward 1997b) inherent to the project (program management, corporate management) to determine which risks can be handled within the project's framework and which should be dealt with by outsiders;
- The definition of the different process objectives (methodological scope and techniques employed and necessary resources and deadlines for the rest of the process, its cost, and objectives prioritization); and
- At this point, a cost/benefit analysis for the process can be developed, and it should be decided if major rethinking is needed, if the process is to be abandoned, or if it goes forward.

The second step is to establish and document the process planning. Above all, one must look at the effects of

- Defining process tasks and how they relate to project tasks;
- Defining roles and responsibilities;
- Defining acceptable risk thresholds;
- Defining in detail the process scope (techniques, tools, and so on) to decide on the prerequisites in this field (such as software acquisition or updating). Scope includes not only techniques and tools, but also criteria and other data necessary to use those techniques and tools. It also involves the manner of categorizing risks and the definition of acceptable risk thresholds or scoring methods, among other aspects;
- Estimating costs and defining the work schedule for the process, dovetailing it with the project schedule; and
- Obtaining the formal results of the process (risk register and other documents) and deciding which people and organizations must be informed of those results and the way they will be communicated.

Team Stage

In the team stage, the definitive team will be formed to deal with the remaining phases of the process. First, it is necessary to identify the key players in the process: not only those who are active on the risk management team, but also anyone else who can offer information for this process (designers, users, maintenance personnel, and so on). Moreover, roles and responsibilities must be identified. The next step includes communicating the results of the PRM initiation phase and, in tandem, identifying outside resource needs, selecting and setting up the team, contracting external resources, and designating roles and responsibilities. Finally, one should identify and resolve the training and integration needs of the established team. This last step may coincide with the first stages of the next phase.

Identification Stage

This stage includes the identification not only of risks (opportunities and threats), but also of potential responses to enhance and take advantage of opportunities and to fight against threats. There are several reasons to include response identification from this point on. Quantitative risk models will be developed in certain cases of large and complex projects carried out by organizations with an adequate degree of maturity. A correct quantitative risk analysis model needs to include both risks and responses. Since it is necessary to compare the various alternative responses to a risk, responses must be included in the model. Quantifying the results using different responses will provide useful information for choosing among the alternatives. Another reason to include response identification at this point is that a specific response to a risk can bring secondary risks that would not exist in other cases. For example, a turnkey contract at a fixed price will reduce the risk of cost overruns for the owner, but quality risks may arise.

First, at this stage the team must establish the project activities to be considered in the risk management process. It is recommended that, in the case of large-scale projects, there be between 30 and 50 activities (5 to 10 and 10 to 30, in case of small- and medium-scale projects, respectively). At the same time, the response identification environment must be defined, including existing risk allocation policies, identification of interested parties that could allocate the risk, and possible contract types to use. The next step is to identify and classify risks (opportunities and threats) and responses. It is necessary to identify primary risks (opportunities and threats), their causes, characteristics, consequences, triggers (warning signs), and possible owners (allocation). At the very least, one must classify these as key risks (with an important positive or negative impact on project outcomes) and other types of risk (those affecting secondary objectives or whose impact on project outcomes cannot be considered as important). For other, more thorough ways to classify risk, the reader can consult Wideman (1992), Reitan and Hauge (1997), or de la Cruz (1998), among others.

It is also essential to identify and classify primary responses. Furthermore, an identification is needed of secondary risks and their causes, characteristics, and consequences, as well as the responses to these risks. The risk team can use a combination of different risk and response identification techniques (Simon et al. 1997; de la Cruz 1998; PMI 2000). Among these are project

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documents review (prompt lists or documents); information gathering techniques (such as brainstorming, Delphi, interviewing, and SWOT—strengths, weaknesses, opportunities, and threats); checklists; assumptions analysis (stability of assumptions and effect of wrong assumptions); and diagramming techniques (flowcharts, fishbone diagrams, and influence diagrams, to identify the interrelations between activities, risks, consequences, and responses). It will also be useful to review the six basic questions proposed by Chapman and Ward (1997b), the project life cycle, and published information, as well as to visit the site. The project plan (including estimates, plus resource and procurement plans), the work breakdown structure, and the organizational breakdown structure are prompt lists that can be employed to promote meditation and, along with it, risk identification. By also reviewing the prioritization and trade-off criteria of the project objectives (including the uncertainty in defining them), the design, or the schedule logic, one can facilitate risk identification.

The assumptions made during the project feasibility study and in the project plan are other factors that require analysis in the risk identification stage, which is the moment to revise the position that the current project holds within the program it forms a part of. It is also time to contrast the project objectives with those of the program. Doing so will help identify risks as well. Once the identification work has been completed, one can move on to the third step, going over the contrastive analysis of previous results with parties outside the risk management team. This step will be very useful to identify unexpected or hidden risks. The reader must take into account that specific stakeholders' circumstances can be unmentionable, and hence be the cause of risks that are identifiable but initially hidden. This task is normally carried out by means of interviews, Delphi technique, panel sessions, or brainstorming. After that, an analysis of the reliability of the information used and generated in the identification will be performed. In the final step, after a preliminary prioritization of risks and responses (using simple qualitative techniques), a record of the work that has been carried out up to this point will be created. This information will make up the risk register, a document to be used and updated in subsequent phases.

Modeling Stage

The modeling stage has to do with an in-depth analysis of risks and responses that involves developing a model to serve as a basis for the evaluation stage. The first step is to formulate the problem, so that the purpose of this stage and its possible restrictions are clarified. Then an analysis is done to decide which risks are to be included and which excluded in the model, which model or models are to be developed, and which risks will be included with each. This is followed by model definition; these models may be as simple as a table that summarizes activities, risks, responses, and main interrelations, or complex enough to be on par with sophisticated dynamic models (system dynamics, process simulation) to include project activities, risks, responses, their consequences, and their relations.

If necessary, this is when one should define any special technique required for a specific risk analysis (particular techniques not applicable to all kind of projects, such as specific weather models for off-shore projects, as opposed to techniques such as Monte Carlo simulation, applicable in many cases). As for projects where there is already sufficient information, standard models may be used. Model structuring may entail a clarification of how the following interrelate: project activities (distinguishing flexible and nonflexible interrelations); activities and primary risks; primary risks and responses; primary responses and secondary risks; secondary risks and responses; risks and their consequences; and responses and their consequences. Moreover, one needs to determine risk-risk and response-response relations. To finish, it is necessary to integrate the relations to build the model. Once a satisfactory definition of the model has been reached, the next step is to go over a contrastive study of the model with parties outside the risk management team (interviews, Delphi technique, panel sessions, brainstorming).

Estimating Stage

In the estimating stage, one attempts to calculate the degree of uncertainty associated with risks. Frequently only a qualitative evaluation will be carried out. After deciding on the type of assessment (qualitative or quantitative), and as for quantitative evaluations, the second step involves carrying out an initial estimate of the probability and (positive or negative) impact of different scenarios for each risk. Typically, there will be three scenarios: a pessimistic one of maximum nominal impact foreseeable in the case of threats (or minimum nominal impact in the case of opportunities); its optimistic counterpart, turning this picture on its head; and an intermediate scenario—the most probable of the three. In the case of qualitative evaluation, a similar process can be carried out, but there will be an estimate of the probability level (high, medium, or low) for each risk in different scenarios. Although this is a qualitative evaluation, the impact should always be quantified (given a minimum and maximum) to establish contingency allowances.

It must be emphasized here that the main objectives of quantitative analysis are to provide project participants with an opportunity for reflection and to make any uncertainty in the project as patent as possible to those participants. A quantitative analysis should never be idolized. It should be done seriously and rigorously; otherwise, it is preferable to avoid it altogether (garbage in—garbage out). It should also be used with prudence, mainly as a communication tool.

The third step involves fine-tuning the estimates of the risks that are considered opportune. In each process of fine-tuning, what may take place is simply an elicitation of the initial estimates, a better definition of a probability distribution, a change in the type of probability distribution, or a combination of all of these. If subjective data have been mixed with objective historical data, one should decide if it is necessary to multiply the subjective estimates by a coefficient so that they can be assimilated with the objective estimates (Chapman and Ward 1997b).

This is when one should also decide if it is necessary to carry out a successive breakdown to reduce the estimates' uncertainty of critical risks with unacceptable variance (typical deviation in the case of quantitative analysis, or any excessive distance between maximum and minimum impact in the qualitative analysis). This reduction will be achieved by applying Lichtenberg's successive principle (Lichtenberg 1981, 1983; Archibald and Lichtenberg 1992), breaking down the risk event and estimating the impact (and probability, in case of quantitative analysis) of the several components of that event. This breakdown will continue until acceptable remaining levels of uncertainty are achieved. The next step is to estimate the external costs of covering the various insurable risks, comparing them with the expected value of taking this risk on internally. The final step is to update the risk register with the prioritization of risks here performed.

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Evaluation Stage

The evaluation stage entails introducing the estimates from the previous stage into the models defined in the modeling stage to evaluate the project's risk. First, the data about the risks are introduced into the models (with and without risk responses, in different scenarios, including various combinations of responses) to carry out partial and global calculations, graphic outputs, possible model restructuring, and a diagnosis that includes a sensitivity analysis. This diagnosis establishes the necessity of restructuring the model, modifying the project plan, or fine-tuning the previous estimates. Second, the triggers are identified in a definitive manner. Third, the risk thresholds are defined, and a final evaluation will be undertaken establishing opportunities to take advantage of or to ignore, as well as threats to respond to and to accept, and the overall risk ranking of the project (to allow for comparison and facilitate decisions between projects). The evaluation stage is essentially quantitative; it can be reduced to a minimum in the case of certain projects and organizations. This dispenses with the first step of carrying out a quantitative analysis for every model. Nevertheless, the rest of the stage process still holds, although in a simplified form.

Balancing Stage

In the balancing stage, one finally puts into effect the first measures toward reaching a balance between opportunities and threats. This stage embraces the project's global planning (which, in turn, includes the selection of definitive risk responses) and the planning of the following phase of risk management, and above all entails getting started with all the necessary immediate action. Project planning will be developed at two or three levels (Chapman and Ward 1997b), depending on the project duration. There will always be global planning, which spans the project's life cycle with a minimum level of detail (first level). Beyond this, more detailed planning (at a second level) will be carried out for more reduced timelines. This planning will take place at different stages of the project in a dynamic concept; these timelines may or may not coincide with each phase of the project. Finally, planning with the maximum detail (at a third level) will be done at different stages of the project to flesh out the work undertaken at the second level. Along with providing other advantages, this "successive" work prevents the kind of project plan that is unrealistic, avoiding wasted effort and time, along with excessive spending, surprises, confusion, disagreements, and a lack of motivation.

One party's risk can be another party's opportunity. The first step in the balancing stage is about defining the final project's policies for risk allocation. In the following step, one identifies the risks that will be allocated to each organization and person (external or internal to the owner) to establish who has the responsibility for managing them and who will withstand the impact should this occur. In the third step, one should plan for contracting in terms of contract types (traditional, turnkey, construction management, and so on), the definition of contract clauses, and finally, deadlines and contractual milestones. The fourth step, on the one hand, is to confirm all of the above with the participants, making any necessary changes; on the other hand, one must check if all that has been accomplished until now is coherent and legally correct. The fifth step is to gather, summarize, verify, and document the project's global plan. Moreover, the risk register will be updated to include the work that has been carried out up to this point, including the lessons learned. In both cases, the compiled documents will be distributed. The sixth step is to define the timelines for any other project planning (second and third levels). The seventh step is to carry out project planning at the second level and the first detailed project planning. The eighth step is to establish fallback or contingency plans to minimize the impact of risks if the planned responses fail when the risk event occurs, including contingency allowances (time, cost). Then the following phase of this risk management process must be planned for, defining the format, frequency, and contents of the risk reports and their integration into the global project reports. After communicating the results of this stage, the final step is to carry out any immediate action established in the project plan, including that which is related to risk opportunities (enhance, take advantage of, ignore) and threats (avoid, transfer, mitigate, accept).

Maintenance Stage

As the name indicates, the maintenance stage or phase is about maintaining the equilibrium of the project's risk environment. In this phase there is an activity of general monitoring, which includes the project (as well as its objectives and assumptions) and the program. At the same time, risk monitoring will be carried out. This will deal with the evolution of risk factors, triggers, responses (their implementation and effectiveness), and other aspects of the risk environment, along with releasing contingencies as required, detecting trends in the PRM process, and updating the risk register. Another task is to carry out periodical and exceptional or special checks (including the updating of the risk register). This includes reviewing risks, responses, risk models, and risk evaluation. Risks identified at the beginning may disappear, with new ones cropping up. Furthermore, periodical or exceptional risk reports will be produced; these are to be integrated into the project reports.

Along with all that has been mentioned, one should, at certain intervals, develop, document, and implement the successive, detailed planning of the project at the second and third levels. Should a crisis arise, it will be necessary to take certain steps to reestablish the balance of the risk environment (crisis management). In the first place, one must confirm the presence of the corresponding triggers, whether or not these have been anticipated. Then the crisis team must be built, the crisis must be analyzed, and the corrective measures previously planned for (contingency planning) must be selected and applied. If possible, preventive actions will be taken to avoid similar crises in other areas of the project or even in other projects (domino effect). Thereafter, one should establish and put in place workarounds, which are urgent responses that have not been planned for (Wideman 1992). Finally, the risk register is updated. From the experience gained in the various iterations of this stage, one may reach the conclusion that it is necessary to go back to one of the previous stages. This may lead to, among other things, a modification of the project plan. The cycle of normal activities within this stage will be periodically repeated until the project enters its closing process.

Learning Stage

The learning stage or phase entails reflecting on what one has experienced during the project; it is about learning from this experience to improve on future activity and increase the body of corporate knowledge. First, the scope of this phase must be defined and planned for. Then there is the final collection of any remaining data related to risk management for this project, adding any finishing touches to the risk register. The next step is to pro-

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		Relative size	Small	Medium	Large
Maturity	High level	High complexity	Zone M3	Zone M4	Zone M5
		Medium complexity	Zone M2	Zone M3	Zone M4
		Low complexity	Zone M1	Zone M2	Zone M3
	Low level	High complexity	Zone m3	Zone m4	Zone m5
		Medium complexity	Zone m2	Zone m3	Zone m4
		Low complexity	Zone m1	Zone m2	Zone m3

Fig. 3. Classification of projects by complexity, relative size, and organization risk maturity level

cess and make a final analysis of the data, including project objectives achievement and a comparison between expected and actual risks. After that, the team will reflect on the results of this analysis and assess the PRM process developed, and the corporate data bases will be updated accordingly. The last task is to produce a final risk management report; this will be incorporated into the project's final report. This phase must be performed not only in the case of the project ending as planned, but also in that of premature project termination (abortion).

Simplification of the Generic Process

Various factors come into play when contemplating the simplification of the generic process. One is role (owner, engineer, contractor, and so on), although here the process has been particularized for the owner's role. Three other main aspects include the maturity of the organization, the relative size of the project, and its complexity. Fig. 3 offers a classification of projects according to their complexity, relative size, and degree of maturity in terms of risk management of the company carrying out the project. For Fig. 3, two levels of risk maturity are used. The low maturity level includes levels 1 and 2 ("naïve" and "novice") from Hillson's (1997) model. The high maturity level includes levels 3 and 4 ("normalized" and "natural") from Hillson's model. Projects are then categorized by complexity and relative size. Factors related to complexity have been referred to above. Regarding relative project size, the criterion is to compare project budget and company capitalization, as proposed by Turner and Payne (1997). For example, we can say that the project is small, medium, or large when the project budget is on the order of 1/100, 1/10, or 1/1 of the company capitalization. Of course, Fig. 3 includes shaded zones as a remainder that the limits between maturity, complexity, and size levels are fuzzy. A table including general guidelines for the simplification of the generic process has been developed (Fig. 4). [In Fig. 4, the NPV is the net present value: some NPV issues will be discussed later in the paper.]

Analysis Techniques

Risk analysis techniques must be chosen according to the project, its determining factors, and the type of analysis to carry out (prof-

Zones	Zones characteristics	Guidelines
m1 & m2	Low risk maturity level and low complexity or small relative size	1. Risk management only applied to trouble-free, well-managed projects. It's useful to contract outside consultants (carefully selected), or to take on staff from companies with a higher level of risk maturity. Internal staff training needed. It's recommendable to produce draft procedures with templates while performing PRM. The RM team will normally be the project team. Risk register: very simple including risk, qualitative probability assessment, and quantitative impact assessment.
		2. Only 4 phases and 7 stages: Project, Process, Identification, Estimating, Balancing, Maintenance and Learning.
		3. Project Stage: absence of internal information of historical value; search other sources to locate such information. Possible problems in defining the factors that measure project success. Outside experts: inestimable help; completing the entire process with internal resources is feasible, but these phases will remain far from perfect.
		4. Process Stage: no feasibility analysis of the process (the decision is previous to the process); only analyzing the process environment and planning the process.
		5. Identification Stage: one may skip identifying secondary risks and responses; not advisable for important projects.
		6. Estimating Stage: only qualitative analysis except for NPV (sensitivity analysis). No risk model, except for NPV and the risk register already mentioned.
		7. Balancing and Maintenance Stages: similar to the complete process, but only with 1 or 2 project planning levels.
		8. Almost inevitable: formal procedures for certain automation that will reduce the cost of the process; while facilitating the task, it also serves as a catalyst for the process, and for increasing of the organization's risk maturity level. These formal procedures should make use of checklists for the majority of risk management activities.
...	...	...
M4 & M5	High risk maturity level and high complexity or large relative size	1. To allow the generic process to develop completely and rigorously. Possibility of utilizing special mathematical techniques. These are projects suitable for including a dimension of research and development in risk analysis

Fig. 4. Simplification of the generic process: general guidelines regarding Fig. 3

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itability, time, cost, and so on). Any rigid recommendation in this field would once again be absurd. The main qualitative risk analysis techniques (Simon et al. 1997; de la Cruz 1998; del Caño and de la Cruz 1998; PMI 2000; among others) currently used are

- Checklists;
- Assumptions analysis (already referred to);
- Data precision ranking, to examine the extent to which a risk is understood, the data available about it, and the reliability of the data in order to evaluate the degree to which the data about risks are useful;
- Probability and impact description, to describe those parameters in qualitative terms (very high, high, moderate, and so on);
- Probability-impact risk rating tables, which assign risk ratings (very low, low, moderate, and so on) to risks based on combining probability and impact qualitative scales;
- Cause-and-effect diagrams, also called Ishikawa or fishbone diagrams, to illustrate the interrelations between risks and their causes, including the domino effect;
- Flowcharts and influence diagrams, as pure graphs reflecting the interrelations between activities, risks, and responses; and
- Event and fault trees, which are typically used in risk analysis of engineering systems (nuclear power and petrochemical plants, and so on) and which can also be used in project management.

The main quantitative techniques (Simon et al. 1997; de la Cruz 1998; del Caño and de la Cruz 1998; PMI 2000; among others) in current use are

- Sensitivity analysis, to discover the criticality of various project parameters;
- Expected value tables, to compare expected values for different risk responses;
- Triple estimates and probabilistic sums applied to cost estimating (for example);
- Monte Carlo, Latin hypercube simulation, to obtain the cumulative likelihood distributions of the project's objectives (net present value, cost, time) using probabilistic estimation of the input parameters;
- Decision trees to aid decision making when there are choices with uncertain outcomes;
- Probabilistic influence diagrams combining influence diagrams with probability and Monte Carlo theory to simulate aspects of project risk;
- Multicriteria decision-making support methods (MDMSMs) for making choices among alternatives with conflicting demands. Analytic hierarchy process (AHP), for example, is a type of MDMSM that can be used for multicriteria selection among different risk responses, mixing qualitative and quantitative criteria;
- Process simulation, using a variety of techniques to simulate specific project processes;
- System dynamics, combining influence diagrams with a more complex mathematical framework to dynamically simulate specific aspects of project parameters with feedback loops and the ability to simulate the selection among different alternative actions; and
- Fuzzy logic, with potential applications to scheduling, cost control, and multicriteria selection among several alternatives.

In addition to these, other support techniques such as brainstorming, Delphi, and interviewing can be used in risk analysis, estimations, and estimation refinement.

The best way to begin from zero would be to use the most basic qualitative techniques and to later gradually increase the complexity of the techniques until one has achieved the best cost-profit ratio for each type of firm and project. Fig. 5 is similar to Fig. 3, but now the third classification criterion is absolute rather than relative size; here the criterion is to compare the project budget with the typical budgets for small, medium, and large construction projects. For example, we can say that the project is small, medium, or large when the project budget is less than US$25·10^6, between US$25·10^6 and, US$100·10^6, or greater than US$100·10^6. Fig. 6 is an example that sheds light on the analysis techniques to be used according to an organization's maturity, as well as the complexity and size of the project. Defined in the figure is the logical range of possible analysis techniques for each of the zones found on Figs. 3 and 5, alongside other, more specific considerations. For more detail in relation to the techniques included in Fig. 6, the reader can consult Simon et al. (1997), de la Cruz (1998), del Caño and de la Cruz (1998), and PMI (2000), among others.

		Absolute size	**Small**	**Medium**	**Large**
Maturity	*High level*	*High complexity*	Zone MC	Zone MD	Zone ME
		Medium complexity	Zone MB	Zone MC	Zone MD
		Low complexity	Zone MA	Zone MB	Zone MC
	Low level	*High complexity*	Zone mC	Zone mD	Zone mE
		Medium complexity	Zone mB	Zone mC	Zone mD
		Low complexity	Zone mA	Zone mB	Zone mC

Fig. 5. Classification of projects by complexity, absolute size, and organization risk maturity level

Some specific tools performing a sensitivity analysis, Monte Carlo, and probabilistic influence diagrams do not take into account the possible correlation between risk aspects, while others do. The latter entail more complex risk models, and consequently more knowledge and experience are needed for that purpose. The greater the maturity of the organization and the project's magnitude, the more such a correlation should be taken into account. On the other hand, all techniques based on the concept of expected value (product of probability and impact) must be used carefully, without forgetting the double dimensionality of risk (Williams 1996): risks can be ranked not only by their expected value, but also independently by their probability and its impact. Finally, sophisticated quantitative techniques (process simulation, system dynamics, fuzzy logic) will only be used in a small number of cases of high-level risk maturity organizations undertaking "megaprojects," particularly when the organization wants to add a component of research and development.

Other Aspects That Influence the Risk Management Process and Techniques to be Used

Figs. 3 to 6 are related to specific recommendations on possible simplifications of the generic process and on the use of analysis techniques that can be established in internal corporate procedures. For instance, Fig. 6 can have variations depending on the organization (type, size, corporate culture, and so on) and the type of projects (construction, information technology, and so on), and even in the field of construction projects, the subtype of projects (process plants, office buildings, and so on) developed by the organization. It has already been mentioned that the organiza-

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	Main risk analysis techniques	Zones																			
		mA	*mB*	*mC*	*mD*	*mE*	*MA*	*MB*	*MC*	*MD*	*ME*	*m1*	*m2*	*m3*	*m4*	*m5*	*M1*	*M2*	*M3*	*M4*	*M5*
qualitative techniques	**Probability and impact description**	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Assumptions analysis	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Check lists	⊗	⊗	⊗	⊗	⊗	●	●	●	●	●	⊗	⊗	⊗	⊗	⊗	●	●	●	●	●
	Probability-impact tables	❍	❍	●	●	●	❍	●	●	●	●	❍	❍	●	●	●	❍	●	●	●	●
	Data precision ranking	❍	❍	❍	❍	❍	❍	❍	❍	●	●	❍	❍	❍	●	●	❍	❍	●	●	●
	Flowcharts			❍	❍	❍		❍	❍	❍	❍			❍	❍	❍		❍	❍	❍	❍
	Influence diagrams			❍	❍	❍		❍	❍	❍	❍			❍	❍	❍		❍	❍	❍	❍
	Cause-and-effect diagrams				❍	❍			❍	❍	❍				❍	❍			❍	❍	❍
	Event and fault trees				⊗	⊗				❍	❍				⊗	⊗				❍	❍
quantitative techniques	**Sensitivity analysis**	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
	Probabilistic sums		❍	❍	❍	❍	❍	❍	●	●	●			❍	❍	❍		❍	❍	●	●
	Monte Carlo and LHC simulation			⊗	⊗	⊗	❍	❍	●	●	●				⊗	⊗			❍	●	●
	Probabilistic influence diagrams			⊗	⊗	⊗	❍	❍	●	●	●				⊗	⊗			❍	●	●
	Expected value tables			❍	❍	❍	❍	❍	❍	❍	❍				❍	❍			❍	❍	❍
	Decision trees				⊗	⊗				❍	❍					⊗				❍	❍
	Event and fault trees				⊗	⊗				❍	❍					⊗				❍	❍
	Multicriteria DMSM (AHP, etc.)				⊗	⊗				❍	❍					⊗				❍	❍
	Fuzzy logic										⊗										⊗
	Processes simulation										⊗										⊗
	Systems dynamics										⊗										⊗

Legend: ● normal / most frequent use ❍ possible use for specific purpose / in specific circumstances
⊗ possible use preferably / necessarily with external help

Fig. 6. Sample recommendations about use of risk analysis techniques regarding Figs. 3 and 5

tion's maturity and the project's size and complexity are not the only factors that influence how the process may be simplified. Other factors include

- In cases where a certain level of maturity is given, whether or not one is dealing with the first applications of risk management to a specific kind of project;
- In cases where a certain degree of maturity is involved, whether or not the organization is, for the first time, in the transition from applying the process in small and well-managed projects to its application in more problematic and larger ones;
- The motivation and attitudes of personnel involved in the implementation of the risk management process;
- Whether or not the risk management process is applied from the project's inception;
- The way in which risk management is carried out in the program that includes the present project;
- The available (internal, external) resources and time;
- The type of contracting system (design/bid/build, design/build, construction management, and so on); and
- The prioritization of objectives.

Moreover, we can also find the case of non-project-driven organizations that will always undertake their projects with external resources, so that they are left with only key decision making. In these cases, the external consultants can develop a risk management process independently of the risk maturity level of the organization. Many of the aspects summarized in this section also influence the analysis techniques that will be used.

The PRM Process and the Construction Project: Application and Necessary Resources

Some writers [Ward and Chapman (1995), among others] have studied the development of a PRM process along the various generic project stages. From the point of view of the owner and the PRM process, the life cycle of a low-complexity construction project involving design/bid/build contracting has 10 stages: feasibility; funding (obtaining funds); planning; engineering allocation (contracting the engineering services); design; construction allocation (contracting contractors); construction; transfer (commissioning and handover); review (audit at the end of delivery); and support (supporting the operation in a specific period subsequent to the apparent construction completion). However, it is important to note that all the project management work must take into account the subsequent operation and close-down stages of the product (constructed facility), including the disposal of the facility. Some of the project and product stages overlap (for instance, construction and transfer, or support and operation), or may do so (as in fast-track projects). On the other hand, problems can result in a return from a stage to a previous one.

The project life cycle (PLC) can be simpler for the owner in case of design/build contracting. However, it can be more complex in owner-builder projects of high technical complexity, when it is necessary to perform part of the procurement task to develop the detailed engineering; in this situation, the PLC will have 12 stages: feasibility, funding, planning, engineering allocation, basic design, purchasing, detailed design, construction allocation, construction, transfer, review, and support. Furthermore, specific stages may be of varying importance and complexity, depending on the type and characteristics of the project and owner's organization. For instance, the funding stage may be almost nonexistent in the case of internal funding, or very important and complex in a large build-operate-transfer (BOT) project, from the point of view of the licensee; in the same way, in some projects the design will be developed by the client (without the need to contract engineering services), while in other circumstances, several engineering companies will be contracted.

Rarely is only one person directly managing all these project and product stages; in many instances, three people are directly

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responsible for some of the project stages: the development manager launches the project, leading the feasibility and funding stages and even the planning stage; the project manager is responsible for asset construction, leading the stages from planning to support; and a third manager is in charge of the (product) operation and close-down stages. In specific cases a different person may be in charge of the disposal of the facility. Occasionally, the project manager might lead all project stages.

The uncertainty and risk levels will be high in the early project stages, and the project objectives and performance criteria vague. These objectives will be progressively clarified and refined from the feasibility to the design stages. Meanwhile, the uncertainty and risk levels will gradually decrease in the course of the project: that is, the earlier the project stage, the higher the importance of the PRM process. At least the first two PRM phases (initiation and balancing) will be developed before the end of the planning stage. In complex projects, a complete first run of those two PRM phases will take place in the feasibility stage, and a second run during the planning stage. The PRM maintain phase will be worked out during the project stages from engineering allocation to transfer, and the PRM learning phase will be developed during the review stage. With the new facility in operation, a different risk management process should be started. In specific cases of important environmental danger during the facility's disposal, the close-down stage can be viewed as a complete project in itself; therefore, a specific PRM process will be developed. The PRM function has special importance in the case of fast-track projects (Ward and Chapman 1995), except when the design of elements first constructed is not dependent on that of subsequent elements.

In the feasibility stage the PRM process will be wide in scope, predictive in nature, and concerned with the project's profit (or benefit, in the case of public infrastructures). Technical feasibility issues, such as the industrial process potential performance or safety and environmental risks caused by design fault, will also be considered. It cannot be expected that every relevant risk across all the PLC stages will be fully assessed at this point. The purpose of risk management at this moment is to evaluate the project conception and help define the project's concept and objectives. The main risk model to build and use now (PRM modeling stage) will be the one related to the net present value (NPV) or internal rate of return of the project. In this sense, various project configurations (size, technology) or even different projects (alternatives) to achieve the same objectives can be studied now. Several submodels of the NPV model can also be built now, such as the ones related to the future facility's location, capital and operation costs, and market research.

The purpose of the funding stage is to contrast the results of the previous stage, making improvements on and reusing the NPV model and analyzing the risks associated with each finance alternative. At the planning stage, the PRM process will focus on the evaluation of the project plan. The risk models that can be built or improved upon and used are those related to time and capital cost. As for the allocation stages (for engineering or construction, as well as at the purchasing stage), the purpose is to evaluate the agreements ready to be signed, analyzing the time, cost, and quality risks associated with the contracting of each possible company. The data related to these risks can be fed into the time, cost, and NPV models already being used. At the design stage, the main purpose is to evaluate the design (particularly its quality) and to contrast the time and cost estimations. Specific quality models can be built for use during the construction stage, and other models can also be constructed to analyze safety and environmental risks caused by design fault. On the other hand, the normal reduction of uncertainty associated with this stage will lead to an improvement in the reliability of the results of the already existing time, cost, and NPV models.

In cases where several engineering companies are working in parallel, risk management must also be concerned with coordination issues. The principal areas of concern related to the PRM process at the construction stage will be quality and, depending on the contracting system, coordination and health and safety issues. The previously developed risk models related to time, cost, quality, and NPV can be improved, if possible, and used again periodically and in the case of important events implying threats or opportunities. The main purpose of the transfer stage will be to assure that the actual performance of the new facility is as expected, or at least good enough to support the operation stage, achieving an adequate profitability without health, safety, and environmental danger. Obviously, the risk models that can be used again, if necessary, are the ones related to all these issues. In the review and support stages, the PRM process is meant to ensure that all important lessons are learned and documented; additionally, the purpose of the support stage is to detect new problems.

Another question is the team and time necessary to perform the PRM function and its associated cost. In relation to the team, there will be no specific risk team for small projects and low-maturity organizations; the project team will perform this function. For large projects, it is recommended that a risk process manager be appointed to plan, implement, and supervise the PRM process; this person can be helped by one or more risk analysts. In specific cases the risk team can include someone responsible for collecting and documenting data. Obviously, a wide range of other project participants will help in the PRM process (designers, contractors, users, maintainers, insurance companies, and so on). To be effective, the risk process manager must have a deep understanding of the project processes and wide experience in other similar projects; imagination, creativity, and good communication skills are also needed. This person should be independent of the project team, to ensure its objectivity, and can be exclusively dedicated to risk management, or a member of another project team (for instance, another project manager). In many cases the process risk manager is an internal staff member working part time in different (or all) projects undertaken by its organization. This allows performing effective PRM, even in small projects, at a low cost. The risk analyst will be responsible for building risk models; at least, he or she must have experience in time and cost estimation and control and be always dedicated to the project part-time.

How much time is needed to perform the PRM process is dependent on several factors, such as PRM scope, clients, available data, and human resources, among others. A PRM process can take from a few hours to several months (Chapman and Ward 1997b). To be useful in small, low-complexity projects where the analysis will only be qualitative, the two first phases of PUMA (initiation and balancing) will take a minimum of 2 to 5 days. Depending on the factors referred to above, a complete and detailed PRM process can take from 15 days to 3 months (overlapping the project planning).

Finally, the cost of the PRM process can range from that of a person working part-time for 2 to 5 days, to a maximum of 5 to 10% of the project management costs. Taking into account that the project management can account for between 5 and 10% of the capital costs, the cost of PRM will range from a few hundred dollars to 0.5 to 1% of the capital costs, depending on the factors already referred to.

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Application to a Real Project

An application to a real project (simplification of the generic process, selection of analysis techniques, and development of the first two PUMA phases) has been developed in collaboration with the owner, and the main issues are explained here. It is a medium complexity project (complexity index = 23) is examined to build a plant for liquefied petroleum gas (LPG) regasification, near Ferrol, Galicia (an autonomous region in the northwest of Spain). Currently the gas utility sector has a liberalized market (private sector) in Spain, and Galicia has no plant of this type. Therefore, the regional authority aspires to decrease the energy dependence on other regions. The scope of the project includes a new pier and unloading facilities for ships carrying up to 135,000 m^3 of LPG; two 150,000 m^3 storage tanks; a regasification facility with a minimum nominal vaporization performance of $250 \cdot 10^3$ kg/h; regulation, measurement, testing, and other auxiliary plant facilities; and two gas pipelines from the plant to the main consumption points and to links with the national mains. The project started in 1999, and its estimated deadline is in the last quarter of 2004. The estimated project cost is US\$ $295 \cdot 10^6$ (contingencies included), so it is a large project in absolute terms. The initial promoter has been a small, private-sector petrochemical company belonging to the second industrial group of Galicia; it sees the project as a business in itself and also as a step prior to building a new petrochemical plant at the same location, thus obtaining gas at a low price. The capitalization of this company is on the order of 1/10 of the project budget, so the project includes a search for partners and the subsequent founding of a new company. The shareholders are

- The initial promoter, which contributes a share of 18%, also provides a strategic and suitable location and enjoys a cordial relationship with the regional authority;
- Two Spanish multinational public utility companies (21% each), which want to convert several coal-fueled power stations located in Galicia into combined-cycle fueled systems (with gas as the main fuel), and for whom this project is an opportunity for obtaining gas at a low price;
- The regional authority (10%), which wants to oversee the project;
- An Algerian company, which will sell the gas (10%); and
- Two bank companies (10% each), which will provide the necessary loans to the new company.

The shareholders will provide 30% of the project budget (20% of the capital will be investment grants for locating the plant in a depressed area, and the remaining 50% will be loans). Therefore, the project can also be considered larger, in relative terms. The project's estimated base internal rate of return (IRR) is on the order of 30%, taking into account the real price of gas. Nevertheless, the real IRR will be lower because the first three shareholders will consume gas at a low price. Taking into account the project's technology and other circumstances, the owner has opted for a design/build contract at a fixed price. Following Berkeley's model (Ibbs 2000), the estimated project management maturity levels are 4 (integrated) for the utility companies; 2 (planned) for the initial promoter; and 3 (managed) for the regasification company. Following Hillson's model, the corresponding estimated risk management maturity levels are, respectively, between 2 and 3; 1; and 2. Hence, the project is in zone m4 of Fig. 3 and in zone mD of Fig. 5. The general guidelines for process simplification in zone m4 can be applied to the project. These guidelines are similar to those of zones m1 and m2 (Fig. 4), except for the following factors:

- The project size allows for the existence of a specific PRM team;
- Primary and secondary risks must be identified;
- Three planning levels should be used;
- In the case of an internal PRM team, only the use of qualitative analysis techniques can be recommended, with the same PRM process as in zones m1 and m2 (adding the team stage if there is a specific PRM team); and
- Simpler or intermediate-level quantitative analysis techniques could be used with the help of outside experts, adding the modeling and evaluation stages (simplified, because the risk models will be simple). In this situation, the risk register will include the corresponding quantitative data, and the consultant should perform the requirements stage.

Fig. 6 shows various analysis techniques applicable to this project. In any case, one must take into account the chosen contracting system and the fact that this is the first formal PRM process for the team. Moreover (a priori for the owners), the prioritization of objectives is time (the corresponding projects to convert the power stations overlap), followed by quality-safety and cost. For these reasons, the more suitable techniques to be used by the owner are assumptions analysis, probability and impact description, probability-impact tables, and sensitivity analysis (for the NPV feasibility study, using correlation). In the event of special problems affecting NPV, time, or cost, triple estimates and probabilistic sums could be used to build models for these objectives. Instead of probabilistic sums, Monte Carlo simulation or probabilistic influence diagrams could be used, applying correlation and even "if" functions, but with the help of outside experts.

Delphi Analysis

A Delphi analysis has been developed as a final validation. Eight different meetings have been held with a total of 20 professionals with experience in industrial plants, offices, shopping malls, residential buildings, public works (BOT turnpike roads, harbors, railroad infrastructures), and urban planning projects up to US\$ $2 \cdot 10^9$; 16 of them have international experience. The [min, max, average] age of the interviewees is [25,61,41] years old. The [min, max, average] years' experience are [2,35,15]. The university education of those persons is varied (BS in naval architecture, BS and MS in industrial engineering, BS and MS in civil engineering, MBA, and PhD in business administration). The positions of the interviewees in the course of their professional careers are also very varied (ranging from project engineer to chief executive officer, including project managers and operations managers; see appendix for further details). The total number of different companies joined by those people in the course of their professional life is 19 (ranging from small domestic companies to large national and multinational companies such as Alcoa, Bovis, British Railways, Dragados, or Fluor Daniel; see appendix for further information). Respectively, [4,15] of those companies are in the [public, private] sector; and [11,8] are [national, multinational] companies. The companies' activity is varied (owners: factories, industrial plants, public bodies, property developers, BOT licensees; engineering and consultancy; general and specialty contractors). The [min, max] project management maturity level (Berkeley model) for those companies is [2 (planned), 5 (sustained)], and the [min, max] risk management maturity level (Hillson's model) is [1,4].

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Each interview lasted a minimum of 2 to 3 h. After a complete explanation (of the methodology and its relation to project management, the complete PRM process, and its relation to the project life cycle, the simplified process for zone m1, the simplification criteria, and the necessary team, time, and cost), the interviewees assessed the methodology with a number from 0 to 100%, also taking into account its potential effectiveness and adaptive nature. Furthermore, the interviewees explained the reasons for their assessment (pros and cons). The [min, max, average] assessment is [65, 80, 74%], the variance is 0.35, and the standard deviation is 0.59. The main pros stated by the interviewees are

- ''Very comprehensive, well structured, systematic, logical and clear methodology with extensive guidance for its application.'' ''Specifically, the simplified process for zone m1 is very easy to understand and use.''
- ''It's easy to modify the methodology to apply it to the role of the turnkey/design/build contractor.''
- ''The uncertainty of the owner's objectives will decrease.'' ''The feedback loops will avoid rework.'' ''Establishing action alternatives will avoid losses when crises arise.'' ''Risk will be avoided or reduced; at least, risk will be anticipated and assessed, so fighting against risk will be easy.''

And the main cons are

- ''To be completely effective, it needs a specific PRM corporate culture. If someone wants to apply it but the company doesn't support the initiative, the individual's motivation will finally disappear and, sooner or later, PRM will be abandoned.'' ''Even in companies with a certain project management maturity, a cultural change is needed towards risk management (for instance, the project manager could not be comfortable with a risk process manager who is not below him or her on the project).''
- ''From the point of view of the consultant, and taking into account the current project management and PRM maturity levels existing in Spain, the PRM consultancy service is not easy to sell. In small and even medium projects the main (and almost only) criterion to contract project management services is price. Frequently, only a slight differentiation from the other competitors will be achieved, at the most. In that kind of project, the service will only be bought if the owner has had good experience with it in the past, or if a tangible cost saving is proposed. Otherwise, the owner will not take it into account. The PRM service can be more easily sold in the case of large projects, and so much the better if the client is an Anglo-Saxon (U.K. United States, Australia, and so on) or Scandinavian multinational company. More or less similar problems can be found in other European countries like Italy, France, Portugal, or Germany, but not so in the aforementioned Anglo-Saxon and Scandinavian countries.''
- ''In the case of using sophisticated quantitative techniques [in a small number of cases of high-level risk maturity organizations undertaking ''megaprojects,'' and only when the organization wants to add a component of research and development], the PRM process can be excessively complex and expensive.''

Other comments stated by the interviewees were

- ''[Depending on the contracting system] beyond a more or less active participation in the PRM process developed by the owner, the ideal situation would be a PRM process developed by the different essential project participants.''
- ''The applicability increases with the project size, organization size, and risk management maturity.''
- ''The owner will normally want an efficient process based on experience.''

Thus, due to the specific characteristics of the Spanish market, the assessment could be higher in other countries.

Summary, Conclusions, and Further Research

This article has presented PUMA (Project Uncertainty MAnagement), a hierarchically structured, flexible, and generic project risk management (PRM) process that has been particularized for construction projects, from the point of view of the owner and the consultant who may be helping the owner. The process can also be adapted to the needs of the contractor or other project participants. Moreover, many aspects referred to in the article can be applied to other participants. First, the article has defined a complete or generic PRM process to be undertaken by companies or institutions with the highest level of risk management maturity in the largest and most complex construction projects. After that, the aspects influencing the possible simplifications to the generic process have been identified, and simplifications have been proposed for some cases. Any PRM process must be tailored to the particular circumstances of the project and the organization undertaking it. To do so, it is necessary to take into account the organization's risk maturity and the project complexity and size, among other factors. Similar criteria must be taken into account in relation to the risk analysis techniques used in the process. The aim of this article is not to persuade readers that a particular, rigid approach to PRM should be adopted, but to present a flexible methodology to be adapted to the project and organization circumstances and to stimulate reflection on the ways to develop the different PRM tasks in different environments (projects, companies, and so on).

PRM processes have been studied in depth over recent years, and there is currently an important and sound body of knowledge in this field. Further research and development must be undertaken in the areas (del Caño and de la Cruz 1998) of PRM processes (specific processes from the point of view of other participants, internationally accepted standards); techniques and tools (integration, templates, combination of techniques, development of integrated software applications, advanced techniques such as fuzzy logic, process simulation and systems dynamics, knowledge bases); organizational aspects; contracting aspects (strategies to avoid contractual rivalry); attitudes to risk; and education and training.

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Appendix: Delphi Analysis, Other Data

Positions of Interviewees in Course of Their Professional Career

Project assessor, project engineer, scheduling and cost control engineer, assistant project manager, project manager, operations as-

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sistant manager, operations manager, engineering services manager, technical services manager, plant maintenance manager, plant safety manager, divisional manager, managing director, general manager, and chief executive officer (CEO).

Companies Joined by Interviewees in Course of Their Professional Life

Ábaco Ingeniería y Sistemas, Alcoa Europe, Astano, Bovis, British Railways, CH2M Hill, Consultores 2, Dragados, Ferrovial, Fluor Daniel, Forestal del Atlántico, Heredia Consultores, Instituto Nacional de Industria (INI), Madritel (Grupo Auna), Priser, Regasificadora del Noroeste (Reganosa), Tile Stone, Urbamusa, and Z3 Gestión de Proyectos y Obras.

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