Copyright © IFAC Control Applications of Optimisation.
Visegrád, Hungary, 2003

ELSEVIER
IFAC
PUBLICATIONS
www.elsevier.com/locate/ifac

A MULTICRITERIA RISK-BASED DSS FOR BIDDING USING INTEGER PROGRAMMING.

Ascensión Zafra-Cabeza , Miguel A. Ridao, Eduardo F. Camacho

Departamento de Ingeniería de Sistemas y Automática, Universidad de Sevilla.
Camino de los Descubrimientos s/n.
41092, Seville, SPAIN
Tel. +34 954487360 Fax +34 954487340
{asun, ridao, eduardo}@cartuja.us.es

Abstract: This work presents a Decision Support System to provide help in bidding processes. This phase of the project is characterised by a high level of uncertainty and it involves a huge expense in the preparation of the proposal and important mobilization of resources. In industrial practice, bids are usually evaluated on the basis of multiple criteria; this algorithm evaluates candidates according to different criteria configurations. A risk-based approach has been incorporated in the procedure in order to minimise an objective function that involves the mitigation actions of risks. Mitigation actions can own a discrete or continuous nature. *Copyright © 2003 IFAC*

Keywords: Risk, Integer programming, Knowledge Engineering, Decision Support Systems, Business Engineering.

1. INTRODUCTION

In the recent past, risk assessment and risk mitigation have reached a relevant role in the literature. At the beginning, these techniques were applied to natural disasters (Schuster et al., 1986; Caulkin et al., 1996; Litan et al., 1992). In the last years, the application has been extended to Project Management and financial policy fields, where risk mitigation is raising an increasing interest (Jaafari, 2001;Doherty, 1997;Kleindorfer, 1999). It has been shown that accomplishments such as cost reductions, improvement in product's quality and a better understanding of the project can be obtained by using these techniques.

The lack of interest in risk mitigation and therefore, the lack of investing in loss prevention measures, is motivated by several factors: the underestimation of risk probability, long term horizons to retrieve investments, aversion to extra costs or in public disasters situations, expectation of disaster assistance.

The need to manage risks is inherent during the whole project life cycle. Poorly written specifications can result in wrong functionality and cause delays during implementation and testing. Some risks can be caused by market payoffs, project budgets, product performance, market requirements or project schedules.

Theoretic appraisals have been developed as attempt to carry out formalization of models and algorithms to manage risks in the project framework (Grabowski et al., 2000; Chapman and Ward, 2000; Crouhy et al., 2000). Hence, risk management can be summarized as the identification, ranking and priorization of risks, resolution of those deemed significant, and monitoring risks through their applicable life (Hyatt and Rosenberg, 1997).

The early phase of the project is characterized by a high level of uncertainty. When a request for proposal (RFP) is received by the bid manager, the first task is taking a quick decision about the interest of the bid, and in an affirmative case, a proposal will be developed. The bid manager has to realize, in absence of detailed information, an assessment about the possible risks that could appear during the progress of the project. Usually, the response time is very scarce and not enough to undertake this process in an adequate way. Another drawback is the little automatization and database support used by companies in this task. Bidding process for a project involves a huge expense in the preparations of the proposal and an important mobilization of resources.

The objective of this paper is to design a Decision Support System (DSS) for bidding processes, to aid the decision-maker in the choice of the best proposal that will be delivered to the customer. Bidding process methodology developed in PRIMA[1] project (Alquier et al., 2000; Zafra-Cabeza et al., 2001; Zafra-Cabeza et al., 2002a; Zafra-Cabeza et al., 2002b) will be used. The objective of PRIMA project was the building of a method and a software tool allowing storing, organizing and reusing of all the necessary information to build competitive bids, proposing a risk-based business approach.

The present work aims to define an optimization method to mitigate risks according to a proposed risk structure. The use of real and integer variables to model the risk mitigation actions leads to the use of mixed integer programming to solve this problem. Also, a multi-objective approach has been adopted for proposal assessment. According to selected objectives to evaluate proposals, different solutions will be obtained.

The paper is organized as follows: section 2 presents the problem definition and the proposed risk data structure that organizes the information. The optimization problem is described in section 3. A practical example will be shown in section 4 to illustrate the obtained results. Some concluding remarks are made in section 5.

2. PROBLEM DESCRIPTION

The objective of the bidding process is to deliver a final proposal satisfying the requirements of the customer specified in their request for proposal (RFP). In industrial practice and during the bidding phase, the development of several candidates to be the "final proposal", is a common procedure as consequence of the possible and different technical solutions to carry on the execution of the project. The DSS must help in the decision of the best candidate according to a set of selected criteria.

As it was mentioned before, a risk-based approach is used in this paper. After the risks affecting the project have been identified and assessed, the decision about how these risks are going to be managed, has to be taken. Therefore, the DSS has to determine the best way to manage the risks of each one of the possible proposals.

The structure that models risks of every candidate used in here has be taken from the PRIMA project and it is described in figure 1. Thus, a RFP can own some proposal candidates (C_i) and in turn, each candidate has associated some risks (R_i), as a result of the risk assessment. The risk is characterized by a probability of occurrence (P_i) and some initial impacts (II_i). Initial impacts produce consequences on the project if risks become facts and if no mitigation or preventive actions are taken.

From the DSS point of view, only impacts affecting the decision criteria have been considered. Consequently, there is so many different types of initial impacts as criteria involved. Possible types of impacts or criteria can be the "*estimated cost*" or "*delivery time*".

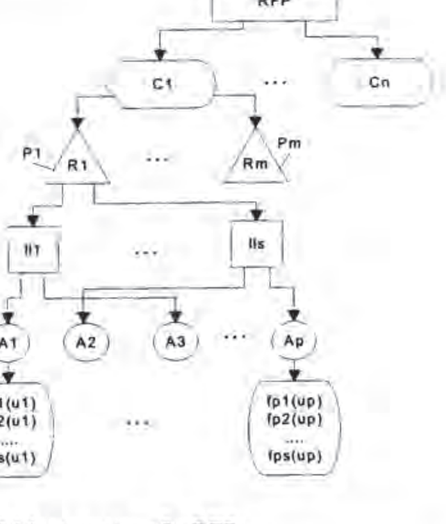


Fig. 1. Risk structure of a RFP.

Risks can be controlled by executing corrective actions. Four types of actions can be considered as is shown in table 1. Preventive actions are not treated in this paper. A mitigation action will reduce the initial impact of a risk.

---

[1] PRIMA (IST-1999-10193) is a research and technological development project partially supported by the Information Society Technologies (IST) Programme of the European Union's Fifth Framework programme. (http://www.esi2.us.es/prima/)

Table 1. Action types.

Type of actions	Description
Mitigate	Modify the impact of a source of risk
Prevent	Change the probability of occurrence .
Avoid	Plan to avoid specified sources of risk
Accept	Accept risk exposure, but do nothing about it.

In the proposed model, several mitigation actions (*Ai*) can reduce the same initial impact and one action can mitigate more than one initial impact (*II*). The assumption of dependency between risks, initial impacts and mitigation action is allowed.

Mitigation actions are described by functions *f* and *g*. f_{ij} (u_i) determines the reduction of initial impact *j* when action *Ai* is applied. u_i is the manipulated variable. . Figure 2 is an example of these functions where *IR* is the impact reduction..

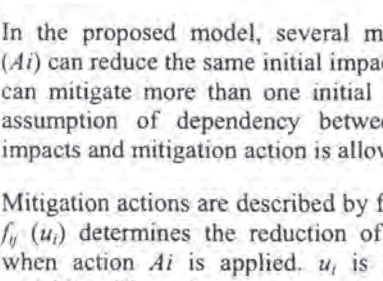


Fig. 2. Graphical representation of a mitigation action.

Notice that a mitigation action will affect some decision criteria. Therefore, given the action *i*, there are *s* functions f_{ij} , for j=1 to *s*, being *s* the number of criteria.

$$\begin{aligned} f_{ij}(u_i) &= 0 \Rightarrow \text{mitigation action } i \text{ does not affect criterion } j \\ f_{ij}(u_i) &\neq 0 \Rightarrow \text{mitigation action } i \text{ affects criterion }_{\text{j}} \end{aligned} \qquad (1)$$

The cost of mitigation actions is denoted by functions g. Thus, every mitigation action, A_i, owns a g_i function that describes its cost, also as a functions of u_i.

u_i can be an integer or real variable. Therefore, examples of discrete mitigation actions are the contract of new workers or the purchasing of new machinery. In the first case, the control variable, (u_l), is the number of new workers and $f_{1l}(u_l)$, is the impact reduction that is reached with the contracting.

An insurance is an example of continuous mitigation action, perhaps, the most common practice to mitigate risks. In fact, insurance companies have an increasing interest in improving risk estimates to encourage mitigation through scientific modelling (Kleindorfeer and Kunreuther, 1999; Kunreuther, 2001). There is considerable scientific work undertaken in the areas of natural, technological and environmental hazards to provide estimates of the probabilities and consequences of events of different magnitudes (Schuster et al., 1986; Caulkin et al, 1996; Litan et al., 1992).

3. PROPOSED DECISION ALGORITHM

3.1 Multicriteria Approach

In industrial practice, bids are usually evaluated on the basis of multiple criteria considering the main aspects for the bid manager.

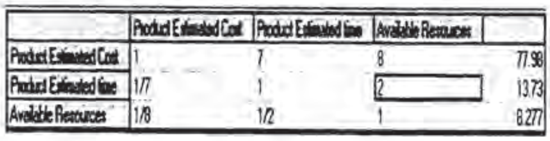
A global performance indicator for the bid competitive value is calculated using competitive factors as parametric variables. The calculation depends on the number of parameters, the type of ranking or the knowledge structure complexity. This problem may be effectively approached by a Multi Criteria Decision Making Model (Malczewski, 1999; Seydel and Olson, 2001).

In order to start the assessment of the different candidates, it is necessary to define the set of criteria that will take place in the evaluation. When the criteria had been selected, the next step will be the calculation of weights for each criterion. The weight represents the importance of the criterion and hence, the contribution of the criterion in the whole value of the candidates. These criteria and weights constitute an objective function used to evaluate and optimize every candidate.

Multiple techniques can be used to rank alternatives (Larichev, 2001). Analytic Hierarchy Process (AHP) (Saaty and Alexande, 1989) is one of the most popular methods for decision making with multiple criteria. It formulates the decision problem in a hierarchical structure and prioritizes both the evaluation criteria and the competing alternatives by pairwise comparison. AHP is suitable for complex decisions that involve the comparison of decision elements, which are difficult to quantify. The identification of the relative importance between pairs of criteria by the user is required by this method.

AHP is based on a matrix, where criteria are localized in both rows and columns (see figure 3). The user has to fulfil the table, where each item of the rows should be compared with each item of the columns. The user determines whether the criteria associated with the row is more important than the one representing the column and if therefore, how much more important. In this paper, it has been adopted the scaling method defined by Saaty, where values between 1 and 9 are allowed. The value '1' represents the equality of criteria and the value '9' represents the maximum value that the criterion localized in the row can reach versus the criterion localized in the column. Hence, if the column is more important than the row, inverse of the above values is used. The diagonal of the table where each entry is compared to itself will be all ones. The values of the table below the diagonal will be the inverse of the value above the diagonal. Figure 3 shows an example of AHP matrix. AHP method calculates the weights for each criterion. They are represented in the last column of the matrix.

In the proposed decision algorithm, weights are calculated using AHP method. Nevertheless, sometimes, the customer describes in the RFP how the decision is going to be taken, that is the criteria and the importance (weights) of each one of them. In this case, the bid manager can introduce directly these weights.



	Product Estimated Cost	Product Estimated time	Available Resources	
Product Estimated Cost	1	7	8	77.98
Product Estimated time	1/7	1	2	13.73
Available Resources	1/8	1/2	1	8.277

Fig. 3. Weights calculation through AHP

3.2 Mitigation action decision algorithm

The objective is to decide, for each one of the candidates, the mitigation actions that are going to be taken, in order to minimize the objective function to evaluate candidates, as mentioned in the above paragraph.

Let consider a vector of selected criteria, ψ, and the vector of weights β. Both of them have the same length, s.

Given a candidate, the objective function used in this work is the following:

$$\begin{aligned} J &= \sum_{k=1}^{s} \beta_k * \Psi_k \\ 0 < \beta_k \leq 1 \quad & and \quad 1 = \sum_{k=1}^{l} \beta_k \end{aligned} \tag{2}$$

where:

β_k is the weight of k^{th} criterion (obtained from AHP).
Ψ_k is the expression that describes the value of the candidate, according to k^{th} criterion.
s is the number of criteria.

Notice that criteria can be variables of very different nature, i.e. "*cost*" or "*delivery time*". To use them in the same expression, a normalization procedure is needed.

In the proposed algorithm, "*cost*" criterion takes critical importance because mitigation actions are going to be considered in term of an additional cost to the Project. "*Cost*" criterion is going to be considered always in the objective function as the first one (Ψ_1).

Denote $\boldsymbol{u}$ as a vector of dimension p, where p is the number of mitigation actions, then:

$$\Psi_k = Fv_k + \sum_{j=1}^{m} GE_k(P_j, II_j, RI_j) + \begin{cases} 0 & if\ k > 1 \\ \sum\limits_{i=1}^{p} g_i(u_i) & if\ k = 1 \end{cases} \tag{3}$$

where Fv_k is the fixed value of the k^{th} criterion for the candidate, if risks are not taken into account. If a risk occurs, this value will be increased by the corresponding impact of the risk. But as a risk will occurs or not with a given probability, the mean value of the impact will be used. This value is named "*Global Exposure*" and it is computed by multiplying the risk probability and its impact.

As mentioned before, the initial impact of a risk (*II*) can be reduced (*RI*) with mitigation actions. These values are obtained in the algorithm with *f* functions described in section 2. The sum of the exposure of each one of the *m* risks (it is assumed that the candidate is linked to *m* risks) gives the total global exposure. Then, Σg_i is the sum of costs of the mitigation actions A_i and obviously, only is considered in the first criterion ("*cost*").

The global exposure for risk *j* and criteria *k* ,
$GE_k(P_j, II_j, RI_j)$, can be expressed as:

$$GE_k(P_j, II_j, RI_j) = P_j(II_{kj} - \sum_{i=1}^{p} f_{ik}(u_i)) \tag{4}$$

Equation 4 depends on the risk occurrence probability, P_j, the initial impact of risk *j* related to k^{th} criterion and their impact reduction (*RI*) achieved with the mitigation actions. f_{ik} is the impact reduction of k^{th} criterion when action *i* is executed. The total impact reduction is computed by adding the results of all the adopted mitigation actions.

This optimization problems allows constraints in the control variable, u:

$$h(u) \leq 0 \tag{5}$$

where g are general functions where the user can introduce information about the morphology of the risks structure as well as requirements of the functions f, into the optimisation problem. Thereby, and in accordance with example of figure 1, a typical constraint could be: "*the sum of the impact reductions of action A_1 and A_3 can not be higher than the initial impact II_1*"

$$(f_{11} + f_{31} \le II_1) \qquad (6)$$

The proposed optimization problem is a mixed-integer programming problem. There are no generic solving algorithms for this problem and only exists for linear or quadratic functions and linear constraints. In this paper, linear functions and constraints are going to be considered.

If there are n different alternative proposals, the problem can be stated as the resolution of a mixed-integer programming for each one of them. The best candidatate will be the one that possesses smaller value of J.

$$J = \begin{bmatrix} J_1 & J_2 & \dots & J_n \end{bmatrix} \qquad (7)$$

4. EXAMPLE

Figure 4 depicts the example that has been chosen to illustrate the proposed algorithm.

Only one proposal C_1 is going to be considered, and also only one risk, R_1, which states the possibility that the implemented system has adverse environmental troubles beyond its permitted limits and increased liabilities. This risk provokes two different impacts, and their values if no mitigation actions are taken, are II_1 and II_2, affecting to criteria "*Product cost*" (PC) and "*Delivery Time Product*" (DTP) respectively. Fixed Values (F_v) (value of criteria if no risk are considered) and initial impacts are presented in table 2. Mitigation actions, its parameters and functions are described in table 3 and table 4.

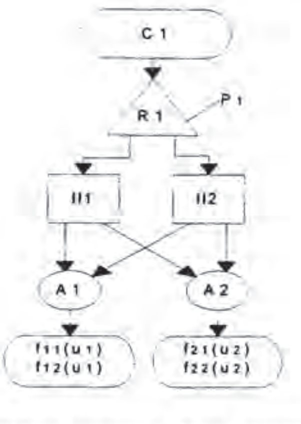


Fig 4. Illustrative example. Risk structure for the candidates.

Table 2. Expressions of fixed values and initial impacts of criteria.

Criteria	**Fixed Values (F_v)**	**Initial Impacts (*II*)**
Product Cost	45000	(II_1):10000
Product Delivery Time	90	(II_2): 33

Table 3. Mitigation actions description.

Action	**Description**	**Type**
A_1	Contract Insurance	Real
A_2	Auxiliary System purchasing	Boolean

Table 4. Expressions of mitigation actions.

Action	**Impact Reduction**		**Cost**
	PC	**PDT**	
A_1	$f_{11}= 10u_1$	$f_{12}= 0$	$g_1= u_1$
A_2	$f_{21}=5000u_2$	$f_{22}=-5u_2$	$g_2=200\ u_2$

Notice that the minus character in mitigation actions functions (-) means the negative contribution to the specified criterion.

The expression of the objective function for C_1, according expressions (2-5) is

$$\begin{aligned} J &= \beta_1 * \Psi_1 + \beta_2 * \Psi_2 \\ \Psi_1 &= Fv_1 + P_1 (II_1 - f_{11}(u_1) - f_{21}(u_2)) \\ &\quad + g_1(u_1) + g_2(u_2) \\ \Psi_2 &= Fv_2 + P_1 (II_2 - f_{12}(u_1) - f_{22}(u_2)) \\ &\textit{subject to} \\ & f_{11}(u_1) + f_{21}(u_2) \le II_1 \\ & u_1 \ge 0 \end{aligned} \qquad (8)$$

4.1 Results

To solve the above mixed integer programming problem a commercial tool has been used, the Numeric Algorithm Group and, particularly, nag_ip_bb (h02bbc). This function solves "zero-one", "general", "mixed" or "all" integer linear and quadratic programming problems using a branch and bound method. The experiments and results are shown in table 5, as a function of the probability of the risk occurrence and the criteria weight.

Three experimental modules have been undertaken taking into account several risk probabilities. In the case of P_1=0.01, the values of Ψ_1 and Ψ_2 are unchanged due to any mitigation action is realised. If the probability is increased until 0,9 and β_2 holds low, the action 2 is selected, in spite of the negative impact in the criterion cost. If β_2 is increased, the algorithm obtains that only the insurance contract is the best option. In the case of P_1=0.1, and independently of β, the auxiliary system purchasing (A_2) results more interesting, as consequence of being its cost lower that the insurance contract (A_1).

Table 5. Experiments and outcomes.

Risk Probabilities	**Without mitigation actions**	**Weights**	
		$\beta_1>\beta_2$	$\beta_1<\beta_2$
P_1 =0.9		[500 1]	[1000 0]
	Ψ_1=54000	Ψ_1=45700	Ψ_1=46000
	Ψ_2=112,7	Ψ_2=124,7	Ψ_2=119,7
P_1 =0.1		[0 1]	[0 1]
	Ψ_1=46000	Ψ_1=45700	Ψ_1=45700
	Ψ_2=93,8	Ψ_2=93,8	Ψ_2=93,8
P_1 =0.01		[0 0]	[0 0]
	Ψ_1=45100	Ψ_1=45100	Ψ_1=45100
	Ψ_2=90,33	Ψ_2=90,33	Ψ_2=90,33

CONCLUSIONS

This paper describes an algorithm to help managers to take decisions in the bidding process of a project. It has been shown that the problem can be stated as a mixed integer optimization problem as consequence of the different types of involved variables (real, integer or boolean). A multicriteria approach has been introduced. It allows that the assessment of several candidates is based on some criteria like "*cost*" or "*delivery time*". Hence, the best proposal and the set of actions to mitigate risks are obtained. A simple example shows how the algorithm takes the decisions (mitigation actions to undertake).

REFERENCES

Alquier A.M., E. Cagno, F. Caron and M.A. Ridao,. (2001). In: *The Frontiers of project Management Research.* Chap. 21, pp. 349-363. Project Management Institute.

Caulkins P., R. Feulner, A. Barefoot, L. Beasley ,L. Burns, J. Clark. (1996). "Aquatic Dialogue Group: Pesticide Risk Assessment and Mitigation". *Society of Environmental Toxicology & Chemistry.*

Chapman C. and S. Ward. (2000) "*Project Risk Management : Processes, Techniques and Insights*". John Wiley & Sons.

Crouhy M., Robert Mark and Dan Galai.(2000) "*Risk Management*". McGraw Hill.

Doherty N. (1997). "Financial innovation for financing and hedging catastrophe risk". Proc. of the Fifth Alexander Howden Conference on Disaster Insurance, Goal Coast.

Grabowski M , J. Merrick, J. Harrald, T. Mazzuchi and J. Van Dorp. (2000). "Risk Modeling in Distributed, Large-Scale Systems". *IEEE Transactions on Systems, Man, and Cybernetics*, **30**, 651-660.

Hyatt, L. and Rosenberg, L. (1997). "Sofware metrics program for risk assessment". Acta Astronautica 40,N0 2-8,223-233.

Jaafari A. (2001) "Management of risks, uncertainties and opportunities on projects: time for a fundamental shift". *International Journal of Project Management*, **19**,89-101.

Kleindorfeer P. and H. Kunreuther. (1999). "The complementary roles of mltigation and Insurance in managing catastrophic risks". *Risk Analysis*, **19**, 4.

Kleindorfer P. and H. Kunreuther. (1999). "Challenges facing the insurance industry in managing catastrophic risks". The financing of Catastrophe Risk. University of Chicago Press.

Kunreuther H. (2001). "Incentives for mitigation investments and more effective risk management :the need for public-private partnerships". *Journal of Hazardous Materials*, **86**,171-185.

Larichev O. (2001). "Ranking multicriteria alternatives_ The method ZAPROS III". *European Journal of Operational Research* **131**, 550-558.

Litan R., F. Khringold, K. Clark, J. Khadhkar. (1992). "Physical damage and Human Loss: The Economic Impact of Earthquake Mitigation Mesures". New York: Insurance Information Institute Press.

Malczewski J. (1999). "*GIS and Multicriteria Decision Analysis*". John Wiley and Sons.

Max R., Wideman, Rodney J. Dawson. (1998). "Project and Program Risk Management : A Guide to Managing Project Risks and Opportunities". Project Management Inst Pubns; ISBN: 1880410060.

Saaty T. and J.M. Alexande. (1989). "*Conflict resolution: the Analytic Hierarchy Process*". Praeger.

Schuster, R. (1986). "Landslide Dams: Processes, Risk and Mitigation". American Society of Civil Engineer.

Seydel J. and Olson D.L. (2001) 'Multicriteria Support for Construction Bidding', *Mathematical and Computer Modelling* **34**, 677-702.

Zafra-Cabeza A., M.A. Ridao and E.F. Camacho. (2001) "Sistema de Ayuda a la decisión en el proceso de elaboración de ofertas usando técnicas multicriterio'. Proc. IX CAEPIA-TTIA, Vol. I, pp. 479-488.

Zafra-Cabeza A., M.A. Ridao and E.F. Camacho. (2002). "A Decision Support System for Bidding process", Proc. 15th IFAC World Congress on Automatic Control.

Zafra-Cabeza A., M.A. Ridao and E.F. Camacho. (2002). "Risk Mitigation in the bidding process using mixed programming". Proc. IEEE International Conference on Systems, Man and Cybernetics.