# A Multicriteria Risk-based DSS for Bidding using Mixed Integer Programming.

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**Abstract.** This work presents a Decision Support System to provide help in complex bidding processes. Usually, this task involves a huge expense in the preparation of the proposal and an important mobilization of resources. Also, this phase of the project is characterised by a high level of uncertainty. In industrial practice, bids are usually evaluated on the basis of multiple criteria, the 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.

## 1 Introduction

In this last decade, risk assessment and mitigation have reached a relevant role in the literature. At the beginning, basically it was applied to natural disasters [1-3]. In recent years, its application has been extended to Project Management and financial policies fields, where risk mitigation is raising an increasing interest ([4-6]) due to the accomplishments that can be obtained, such as cost reductions, improvement in product's quality and a better understanding of the project.

Sometimes, the lack of interest in risk mitigation and therefore, the lack of investing in loss prevention measures, is based on several factors as 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 a project framework [7-10]. 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 ([11]).

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 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 non enough to undertake this process in a adequate way. Another drawback is the little automatization and database support used by the companies in this process. 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 to 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 [12-14] will be used. The objective of PRIMA project is the building of 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 [15] 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 in order to organize 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.

## 1 System description

Consider a request for proposal (RFP) from the customer. The objective is delivering a final proposal, P, satisfying the specifications of the customer. In industrial practice and during the bidding phase, the development of several alternative candidates to be the "final proposal", is a common procedure as consequence of the 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 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

[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/)

risks are going to be managed, have to be taken. The DSS also have to determine the best way to manage the risks of each one of the alternative proposals.

The structure to model risks of every candidate 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 are the consequences on the project if the risk becomes a fact and if no mitigation or preventive actions are taken. From the DSS point of view, we are going to be interested on impacts affecting the decision criteria. So, there are as many different types of initial impacts as involved criteria. Possible types of impacts or criteria can be the "estimated cost" or "delivery time".

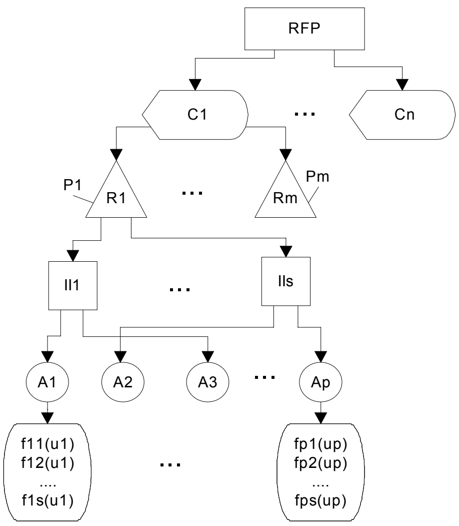


**Fig 1.** Risk structure of a RFP.

The 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 been considered in this paper. A mitigation action will reduce the initial impact of a risk.

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

Mitigation actions are described by functions $f_{ij}(u_i)$ where $u_i$ is the control variable (in this paper will be modelled by the cost of the mitigation action $i$). Also, $f_{ij}$ is the reduction of initial impact $j$ when action $i$ is applied.. Figure 2 is an example of these functions.

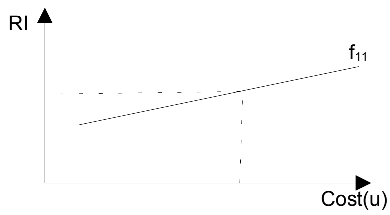


**Fig. 2.** Graphical representation of a mitigation action. .

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

$$f_{ij} = 0 \Rightarrow \text{action } i \text{ does not affect criterion } j \qquad (1)$$
$$f_{ij} \neq 0 \Rightarrow \text{action } i \text{ affects criterion } j$$

**Table 1.** action types.

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

*f* functions can be continuous or discrete and therefore, $u_i$ can be an integer or real variable. Examples of discrete mitigation actions are the contract of new workers (control variable is the number of new workers and *u* is the cost of the contracting) or the purchasing of new machinery. 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 modeling ([16-17]). 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 ([1-3]).

## 2 Proposed Decision Algorithm

### 2.1 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 Attribute Decision Making Model ([18-19] ).

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 have been selected, the next step is 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 each one of the candidates.

Multiple techniques can be used to rank alternatives [20]. Analytic Hierarchy Process (AHP) [21] 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. It is suitable for complex decisions that involve the comparison of decision elements, which are difficult to quantify. AHP requires values for identifying the relative importance between pairs of criteria. These values have to be introduced by the user. AHP is based on a matrix, where criteria are localized in the first row and column of it (see figure3). 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 2 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 of each one of them, that is, the weights. In this case, the bid manager can introduce directly these weights.

### 2.2 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, $\psi$, and the vector of weights $\beta$. Both of them have the same length, *s,* being a result of the previous step.

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

| | 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.

$$J = \sum_{k=1}^{s} \beta_k * \Psi_k \qquad (2)$$

$$0 < \beta_k \leq 1 \quad and \quad 1 = \sum_{k=1}^{l} \beta_k$$

$\beta_k$ is the weight of $k^{th}$ criterion (obtained from AHP). $\Psi_k$ is the expression that describes the value of the candidate, according to $k^{th}$ criteria. Notice that criteria can be variables of very different nature, i.e. cost and delivery time. To use them in the same expression, a normalization procedure is needed. Again, $s$ is the number of criteria.

In the proposed algorithm, cost criteria takes critical importance because mitigation actions are going to be considered in term of an additional cost to the Project. Cost criteria is going to be considered always in the objective function as the first one ($\Psi_1$).

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

$$\Psi_k = Fv_k + \sum_{j=1}^{m} GE_k(P_j, II_j, RI_j) + \begin{Bmatrix} 0 \; if & if \; k > 1 \\ \sum^{p} u_i & if \; k = 1 \end{Bmatrix} \qquad (3)$$

where $Fv_k$ is the 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 gives the total global exposure. Then, $\Sigma u_i$ is the sum of costs of the mitigation actions $A_i$ and obviously only is considered in the first criteria (cost).

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

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

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. Also, $f_{ik.}$ 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 variables $u$

$$g(u) \leq 0 \qquad \textbf{(5)}$$

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 $II_1$"

$$(f_{11} + f_{21} \leq II1) \qquad \textbf{(6)}$$

The proposed optimization problem is a mixed-integer programming problem. There are no generic solving algorithm 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.

Now, if $n$ different alternative proposals exists, the problem can be stated as the resolution of a mixed-integer programming for each one of them and select the one with the best $J$ value.

$$J = \begin{bmatrix} J1 & J2 & \dots & Jn \end{bmatrix} \qquad \textbf{(7)}$$

with $n$, the number of candidates

## 3 Example

Figure 4 depicts the example that has been taken to illustrate the proposed algorithm. Only one proposal $C_1$ is going to be considered, and also only one risk, $R_i$, 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 . $Fv$ (value of criteria if no risk are considered) and initial impacts are presented in table 2. Mitigation actions and its parameters and functions are described in Table 3.

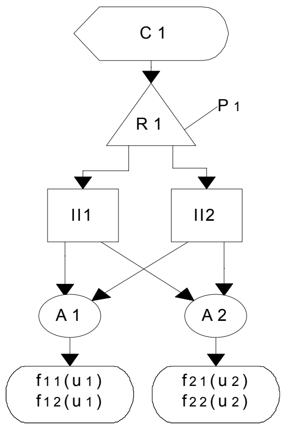


**Fig 4.** Illustrative example. Risk structure for the candidates.

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

| Criteria | Fixed Values (*Fv*) | Initial Impacts (*II*) |
|---|---|---|
| *Product Cost* | 45000 | 10000 |
| *Product Delivery Time* | 90 | 33 |

**Table 3.** Expressions of mitigation actions

| Action | Description | Variable | Type of Criteria | |
|---|---|---|---|---|
| | | | PC | PDT |
| $A_1$ | Contract Insurance | Real | $f_{11}= 10u_1$ | $f_{12}= 0$ |
| $A_2$ | Auxiliary System purchasing | Boolean | $f_{21}=5000u_2$ | $f_{22}=-5u_2$ |

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

The expression of the objective function for *C1,* according expressions (2-5) is

$$
\begin{aligned}
J &= \beta_1 * \Psi_1 + \beta_2 * \Psi_2 \\
\Psi_1 &= Fv_1 + P_1 (II_1 - f_{11}(u_1) - f_{21}(u_2)) + u_1 + Cm * u_2 \\
\Psi_2 &= Fv_2 + P_1 (II_2 - f_{12}(u_1) - f_{22}(u_2))
\end{aligned}
\quad \textbf{(8)}
$$

*subject to*

$$
\begin{aligned}
& f_{11}(u_1) + f_{21}(u_2) \le II_1 \\
& u_1 \ge 0
\end{aligned}
$$

### 3.1 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 4, as a function of the probability of the risk occurrence and the criteria weight.

**Table 4.** 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] |
| | $\Psi_1$=54000 | $\Psi_1$=45700 | $\Psi_1$=46000 |
| | $\Psi_2$=112,7 | $\Psi_2$=124,7 | $\Psi_2$=119,7 |
| $P_1 = 0.1$ | | [0 1] | [0 1] |
| | $\Psi_1$=46000 | $\Psi_1$=45700 | $\Psi_1$=45700 |
| | $\Psi_2$=93,8 | $\Psi_2$=93,8 | $\Psi_2$=93,8 |
| $P_1 = 0.01$ | | [0 0] | [0 0] |
| | $\Psi_1$=45100 | $\Psi_1$=45100 | $\Psi_1$=45100 |
| | $\Psi_2$=90,33 | $\Psi_2$=90,33 | $\Psi_2$=90,33 |

Three experimental modules have been undertaken taking into account several risk probabilities. In the case of $P_1$=0.01, the values of $\Psi_1$ and $\Psi_2$ are unchanged due to any mitigation action is realised. If the probability is increased until 0,9 and $\beta_2$ holds low, the action 2 is selected, in spite of the negative impact in the criterion cost. If $\beta_2$ 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 $\beta$, the auxiliary system purchasing ($A_2$) results more interesting, as consequence of being its cost (*Cm*) lower that the insurance contract ($A_1$).

## Conclusions

This paper describes an algorithm to help managers to take decisions in the bidding process of a project. The problem has been stated as a mixed integer optimization problem based on a multicriteria approach, where the best proposal and the set of actions to mitigate risks are obtained. A simple example shows the logical decisions of the algorithm.

## References

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

2 P. Caulkins, ,R.Feulner, A.Barefoot, L. Beasley ,L. Burns, J. Clark.”Aquatic Dialogue Group: Pesticide Risk Assessment and Mitigation” Society of Environmental Toxicology & Chemistry (1996)
3 R. Litan, F. Khringold, K. Clark, J. Khadhkar. “Physical damage and Human Loss: The Economic Impact of Earthquake Mitigation Mesures”.New York: Insurance Information Institute Press.(1992)
4 A. Jaafari. “Management of risks, uncertainties and opportunities on projects: time for a fundamental shift”. International Journal of Project Management, 19,89-101.(2001)
5 N. Doherty. “Financial innovation for financing and hedging catastrophe risk”. Proceedings of the Fifth Alexander Howden Conference on Disaster Insurance, Goal Coast.(1997)
6 P. Kleindorfer, H. Kunreuther, “Challenges facing the insurance industry in mnaging catastrophic risks”. The financing of Catastrophe Risk. University of Chicago Press. (199)
7 M. Grabowski , J. Merrick, J. Harrald, T. Mazzuchi and J. Van Dorp.,’Risk Modeling in Distributed, Large-Scale Systems’. *IEEE Transactions on Systems, Man, and Cybernetics*, **30**, 651-660, (2000).
8 C. Chapman and S. Ward, *Project Risk Management . Processes, Techniques and Insights*. John Wiley &Sons, (2000).
9 Michel Crouhy, Robert Mark and Dan Galai. “Risk Management”. McGraw Hill(2000)
10 R. Max Wideman, Rodney J. Dawson. “Project and Program Risk Management : A Guide to Managing Project Risks and Opportunities”. Project Management Inst Pubns; ISBN: 1880410060; (1998)
11 Hyatt, L., Rosenberg, L..”Sofware metrics program for risk assessment”. Acta Astronautica 40,N0 2-8,223-233(1997)
12 A.M. Alquier, E. Cagno, F. Caron and M.A. Ridao, ‘Analysis of external and internal risks in project early phase.’ PMI Research Conference, (2000)
13 A. Zafra-Cabeza, M.A. Ridao and E.F. Camacho,’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,(2001)
14 A. Zafra-Cabeza, M.A. Ridao and E.F. Camacho,’A Decision Support System for Bidding process’, Proc. 15th IFAC World Congress on Automatic Control, (to appear),(2002)
15 M. Morari and A. Bemporad. “Control of systems integrating logic, dynamics, and constraints”. *Automatica* **35,** 407-427 (1999).
16 P. Kleindorfeer and H. Kunreuther.”The complementary roles of mItigation and Insurance in managing catastrophic risks”.Risk Analysis, 19, 4.(1999)
17 H. Kunreuther.”Incentives for mitigation investments and more effective risk management :the need for public-private partnerships”.Journal of Hazardous Materials, 86,171-185.(2001)
18 J. Malczewski.”GIS and Multicriteria Decision Analysis”.John Wiley and sons.(1999)
19 Seydel, J, Olson, D.L. Olson, ‘Multicriteria Support for Construction Bidding’, *Mathematical and Computer Modelling* **34**, 677-702, (2001).
20 O. Larichev. Ranking multicriteria alternatives_ The method ZAPROS III. *European Journal of Operational Research* **131**, 550-558, (2001)
21 T. Saaty and J.M. Alexande. *Conflict resolution: the Analytic Hierarchy Process*. Praeger,(1989).