ROBUST OPTIMIZATION APPROACH FOR LONG-TERM PROJECT PRICING

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ABSTRACT

ROBUST OPTIMIZATION APPROACH FOR LONG-TERM PROJECT PRICING

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In this study, we address the long-term project pricing problem for a company that operates in the defense industry. The pricing problem is a bid project pricing problem which includes various technical and financial uncertainties, such as estimations of workhour content of the project and exchange & inflation rates. We propose a Robust Optimization (RO) approach that can deal with the uncertainties during the project lifecycle through the identification of several discrete scenarios. The bid project's performance measures, other than the monetary measures, for R&D projects are identified and the problem is formulated as a multi-attribute utility project pricing problem. In our RO approach, the bid pricing problem is decomposed into two parts which are solved sequentially: the Penalty-Model, and the RO model. In the Penalty-Model, penalty costs for the possible violations in the company’s workforce level due to the bid project’s workhour requirements are determined. Then the RO model searches for the optimum bid price by considering the penalty cost from the Penalty-Model, the bid project’s performance measures, the probability of winning the bid for a given bid price and the deviations in the bid project’s cost.

Especially for the R&D type projects, the model tends to place lower bid prices in the expected value solutions in order to win the bid. Thus, due to the possible deviations in the project cost, R&D projects have a high probability of suffering from a financial loss in the expected value solutions. However, the robust solutions provide results which are more aware of the deviations in the bid project’s cost and thus eliminate the financial risks by making a tradeoff between the bid project’s benefits, probability of winning the bid and the financial loss risk. Results for the probability of winning in the robust solutions are observed to be lower than the expected value solutions, whereas expected value solutions have higher probabilities of suffering from a financial loss.

Keywords: Robust Optimization, Project Bid Pricing, Multi-Attribute Utility Model, Defense Industry

ÖZ

UZUN DÖNEMLİ PROJE FİYATLANDIRMASI İÇİN SAĞLAMCI OPTİMİZASYON MODELİ

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Bu çalışmada savunma sanayiindeki bir şirketin uzun dönemli proje fiyatlandırma problemini ele alıyoruz. Fiyatlandırma problemi, kur & enflasyon oranları ve proje işyükü gereksinimi tahminleri gibi çeşitli teknik ve finansal belirsizlikleri içeren proje teklif fiyatlandırması problemidir. Bu çalışmada, çeşitli senaryoların tanımlanması yolu ile, projenin ömrü boyunca karşılaşılabilecek belirsizliklerin üstesinden gelebilecek bir Sağlamcı Optimizasyon (SO) yaklaşımı öneriyoruz. Teklif projesi için Ar-Ge projelerine özgü olan parasal ölçüler dışındaki başarım ölçüleri tanımlanır ve proje fiyatlandırma problemi, çok-nitelikli yarar problemi olarak formüle edilir. SO yaklaşımımızda, teklif fiyatlandırma problemi ardışık olarak çözülen iki parçaya ayrıştırılır: Ceza-Modeli ve SO modeli. Ceza-Modeli'nde, teklif projesinin işyükü gereksinimine bağlı olarak, şirketin işgücü seviyesinde ortaya çıkabilecek olası aşımlar için ceza maliyetlerine karar verilir. Daha sonra SO modeli; Ceza-Modeli'nin çıktısı olan ceza maliyetini, teklif projesinin başarım ölçülerini, belli bir teklif fiyatı için teklifi kazanma olasılığını ve teklif projesinin maliyetindeki sapmaları dikkate alarak en iyi teklif fiyatını araştırır.

Model, özellikle Ar-Ge tipi projeler için, beklenen-değer çözümlerinde, teklifi kazanmak için daha düşük teklif fiyatları verme eğilimindedir. Bu nedenle AR-Ge projeleri, proje maliyetlerindeki olası sapmalara bağlı olarak, beklenen-değer çözümlerinde yüksek olasılıkla finansal kayıp yaşarlar. Ancak, sağlamcı sonuçlar, teklif projesinin maliyetindeki sapmaların daha çok farkında olan çözümler sağlar, ve bu nedenle finansal kayıp riski ile teklif projesinin yararları ve teklifi kazanma olasılığı arasında ödünleşme yaparak finansal riskleri ortadan kaldırırlar. Sağlamcı çözümlerdeki teklifi kazanma olasılığı sonuçlarının, beklenen-değer çözümlerindeki sonuçlardan daha düşük olduğu gözlemlenir; oysa ki beklenen-değer sonuçlarındaki finansal kayıp daha yüksek olasılıklıdır.

Anahtar kelimeler: Sağlamcı Optimizasyon, Proje Teklif Fiyatlandırması, Çok-Nitelikli Yarar Modeli, Savunma Sanayii

To My Family and Friends

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CHAPTER 1

INTRODUCTION

Defense projects, especially the R&D projects among them, are usually long-term projects including many environmental and company-related uncertainties. These uncertainties are usually called “financial risk” and “technical risk”, respectively.

The company under consideration in this study has been operating in the defense industry for more than 20 years. A project for the company is usually a scheduled program carried out either by the company know-how using its existing knowledge (production type project) or by starting with the R&D phases (R&D type project). In only a few cases, a project may be a service type job.

The company is able to estimate and then manage technical risk and unpredictable deviations during the project’s lifecycle through manageable (controllable) variables. On the other hand, the project’s financial management system and the bidding phases involve both controllable and uncontrollable (stochastic) variables concerning the financial risks. The exchange rate used in the bids and the inflation rate (increase in salaries or labor rates) are the examples for the stochastic variables.

The importance of the financial risk in the bidding process has increased, since fluctuations both in the exchange rate and inflation rate have extremely affected the projects' performances especially in the last 5 years. In spite of the fact that the technically evaluated and managed projects have found to be technically successful, financial losses have been observed in these projects. Moreover, the banks' financial predictions hint at an uncertain financial environment for the future years. Both the negative effects of fluctuations in the exchange and inflation rates on the previous projects' performances and the uncertain financial environment in the future have forced the financial risk evaluation of a project as a requirement in the bidding process.

In order to reflect the various decision making behaviors, several meetings have been held with the company personnel from different departments related to the bidding process. It is observed that priorities in the evaluation of the projects vary among the departments. Some company personnel like the finance managers are more inclined to be financially secure, expecting a rewarding profit from the project and hence a low financial risk; whereas some personnel like the project managers are more inclined to win the project due to its benefits to the company other than the profit, maximizing the probability of winning.

The aim of this study is to deal with the abovementioned uncertainties both in the project and its environment by employing the Robust Optimization approach. By the Robust Optimization (RO) approach, we intend to propose a decision support system that can provide the best bid price -that is robust- in the bidding process, considering some possible scenarios and current situation of the company. In order to eliminate the financial risk, the company may offer higher bid prices. Since financial risk aversion and hence conservative bid prices may cause the company to lose some of the bid projects, a robust solution is to be searched for which will consider the financial risks and make a tradeoff between the financial risk and the probability of winning.

The content of the study is structured in the following chapters as follows:

Chapter 2 contains the literature survey forming the theoretical background of the thesis. The literature on robust optimization, pricing concepts for the defense industry, project evaluation methods for R&D projects and utility theory as relevant to our study is reviewed.

In Chapter 3, the company's bidding process is explained.

In Chapter 4, the mathematical models developed for determining the bid price are presented. Forming the objective function along with the R&D project evaluation techniques and use of utility theory in its development is discussed in this chapter.

In Chapter 5, scenario generation procedure is identified and the financial and technical scenarios thus generated are presented.

Chapter 6 includes the computational studies and presents the main findings of the computational results. Sensitivity analyses through changing the probabilities of scenarios are discussed in this chapter.

In Chapter 7, general conclusions of the study and future research issues are presented.

CHAPTER 2

LITERATURE REVIEW

In order to deal with the problems in the bid pricing process for a long-term defense project; optimization methods handling uncertainty, pricing for defense industry, and utility theory need to be reviewed. In the first part of the chapter, robust optimization approach is presented along with a comparison with the other optimization methods. In the second part, pricing in defense industry and R&D project evaluation techniques are reviewed. In the last part of the chapter, utility theory is discussed as relevant to our study.

2.1. Optimization techniques handling uncertainty

Most of the mathematical models assume a deterministic environment. However, in real-life cases, data are often uncertain, noisy or incomplete; hence, the majority of problems in the domains of production planning, scheduling, transportation and finance require decisions to be made in uncertain environments. Some examples of uncertain data are returns of financial instruments, demand, exchange rate and inflation rate. These are most likely to be known with some probability distributions. The main difficulty in the optimization of such problems is to deal with a large-scale optimization problem in an uncertain environment. To make decisions under an uncertain environment, a lot of mathematical programming approaches have been developed. The most widely used ones are linear programming with sensitivity analyses, stochastic optimization and robust optimization (RO).

2.1.1. Linear Programming with Sensitivity Analyses

Most decisions, if not all, are made under uncertainty, so the model is an approximation of the real-life case. As a result, decision makers may have doubts about the quality of the optimal solution. The diet nutrition problem as a linear programming model with uncertain parameters was firstly addressed by Dantzig in 1955 [9]. Assuming mean values for the uncertain parameters is preferred to address the uncertainties. So linear programming is formulated by "best guessing" uncertain values [21]. However, the expected value solution in an uncertain environment may be far from the optimal solution when a scenario is realized with some uncertain parameters in the vicinity of its limits.

To measure the quality of the optimal solution, sensitivity analysis is mostly used in literature. Sensitivity analysis explores how changes in the problem parameters might lead to a change in the optimal solution [16]. To give some details, one way to handle these sub-optimal solutions is to perform sensitivity analyses for the uncertain parameters. If the solution is found to be too sensitive to the uncertain parameters, an alternative feasible solution should be searched for. However, single parameter sensitivity analysis disregards the parameter interactions. Moreover, finding a feasible, near optimal solution may be impossible by carrying out sensitivity analyses on the several uncertain parameters.

Sensitivity analysis is only a reactive approach to the model’s suggested solution developed based on the uncertain parameters’ expected values. Also sensitivity analyses turn out to be too complicated, when many of the parameters are uncertain.

2.1.2. Stochastic Optimization

Stochastic linear programming is a constructive approach that utilizes probability distributions to handle the uncertainty in the parameters and generally maximizes/minimizes the expected value of the objective function [21]. In stochastic optimization, the feasibility of a solution is expressed using chance constraints. Assuming the distributions of the input parameters are given, the stochastic problem is optimized [19].

Stochastic programs are superior to sensitivity analysis, because stochastic programs reflect the time points the decisions are made and distinguish between what will be known and what will remain uncertain when the decisions are made. Usage of recourse variables with stochastic linear programming models provides the ability to adjust the model recommendations based on the realization of the uncertain data. However, it may be difficult to identify a complete description of the probability distributions of uncertain parameters, especially when there is no historical data. Stochastic programs may grow large, and become hard to solve. As they grow large and the identification of uncertain parameters’ probability distributions become harder, optimization models are solved by making “best-guessing” or “worst-case” assumptions for the uncertain parameters [22]. The best-guessing solution is similar to the solutions obtained using mean values in linear programs. The worst case solutions, on the other hand, produce conservative and expensive solutions.

2.1.3. Robust Optimization

If the solution of an optimization model is close to the optimal solution for all scenarios of the input data, it is ‘solution robust’. If the solution of an optimization model is almost feasible for all scenarios of the input data, then it is ‘model robust’ [21].

Bai et al. suggest an alternative pro-active approach, called Robust Optimization, which uses discrete scenarios to find a near-optimal solution that is not overly sensitive to any specific realization of the uncertainty [1]. Robust optimization is also described as finding a solution that is close to the optimal solution for any realization of the scenarios. However, the robust solution might not be optimal for any of the potential scenarios.

In this approach, the modeler or the industry expert or the decision maker provides possible realizations for the uncertain parameters (point estimates to uncertain parameters), called scenarios, to the model along with assigning the probability of occurrence of each scenario. Generation of scenarios and assigning probabilities to them is a difficult task; but problem size can be reduced by identifying the relationships among the uncertain parameters and eliminating the unrealistic cases [6]. After the model outcomes are obtained, sensitivity analysis for the probability of occurrences is required to verify if the solution is dependent on the assigned scenario probabilities.

In the robust optimization approach, infeasibilities in the control constraints are allowed by adding a new term in the objective function: the penalty cost for infeasibilities. In order to find better solutions, the control constraints are relaxed and violations of the constraints under some of the scenarios are penalized.

In robust optimization (RO), the robustness term with respect to optimality (close to optimal solutions) is defined as the solution robustness, whereas robustness with respect to feasibility (almost feasible solutions) is defined as the model robustness. More generally, RO approach is a scenario-based multi-objective goal programming model that generates a series of solutions that are progressively less sensitive to realizations of the model parameters from a scenario set.

Robust Optimization Model

There are two types of variables for robust optimization: design variables and control variables.

Design Variables (x): Noise-free decision variables which are not dependent on the uncertain parameters.

Control variables (y): Variables that are dependent on the uncertain parameters and the design variables.

RO model's objective function consists of two parts. The solution robustness part, $\sigma(x, y_1, .., y_n)$, is a higher moment of the distribution of the objective function value in the original LP model, which includes the tradeoff between the mean value and variance. The second part, the model robustness part, $\omega\,\rho(z_1, .., z_n)$, is a feasibility penalty function that handles the violations of the constraints. Tradeoff between solution robustness and model robustness is handled by the goal programming weight, ω [21]. $(z_1, .., z_n)$ is a feasibility error vector that measures the infeasibility of the control constraints under each scenario ($\forall s \in \Omega$). The formulation of the robust optimization model is as follows:

$$
\begin{aligned}
&\min \sigma(x, y_1, \ldots. y_n) + \omega\ \rho(z_1, \ldots z_n) \\
&s.t. \\
&Ax = b \\
&B_s x + C_s y_s + z_s = e_s \qquad \forall s \in \Omega \\
&x \in \Re_+ \\
&y_s \in \Re_+ \qquad \forall s \in \Omega \\
&z_s \in \Re_+ \qquad \forall s \in \Omega
\end{aligned}
$$

2.2. Pricing for the defense industry

In the defense market; governments, NATO or friendly armed forces usually order for new products that do not exist. These products are developed and produced generally in low quantities at very high unit costs, and they contain many technical uncertainties. Thus, the amount of risk involved in defense business is relatively higher than that in the comparable commercial business [15]. The uncertainties and high risk that suppliers experience to produce major weapon systems and also the existence of suppliers in the defense industry depend heavily on the willingness of the buyers to cover some portion of the investment required [15].

Contracting methods in the defense industry

Four types of contracting methods are carried out in the defense industry [3]. These contracting methods are described below:

Cost-Plus-Percentage-of-Cost Contracting (CPPC): Incurred costs of the company are met by the customer. Profit is a percentage of the total costs.

Cost-Plus-Fixed-Fee Contracting (CPFF): It is similar to *CPPC*, whereas profit is a fixed amount specified in the contract.

Firm-Fixed-Price Contracting (FFP): Contract is awarded by the sealed bids in a competitive manner. The excess cost is covered by the supplier.

Cost-Plus-Incentive-Fee Contracting (CPIF): Subject to lower and upper limits on the total cost, a fraction of excess cost or excess profit is beared by the supplier.

CPPC is free of competition and abuse; and excess profits may be gained through the falsified reporting of costs. Department of Defense (DOD) of U.S.A had published the Armed Services Procurement Regulations (ASPR) in 1947 to regulate the defense market [4]. DOD had constructed administrative limits on fees for all other types of negotiated contracts in ASPR. The Weighted Guidelines incorporated into ASPR provides a greater percentage range of fees as an incentive to reduce cost and increase efficiency and performance.

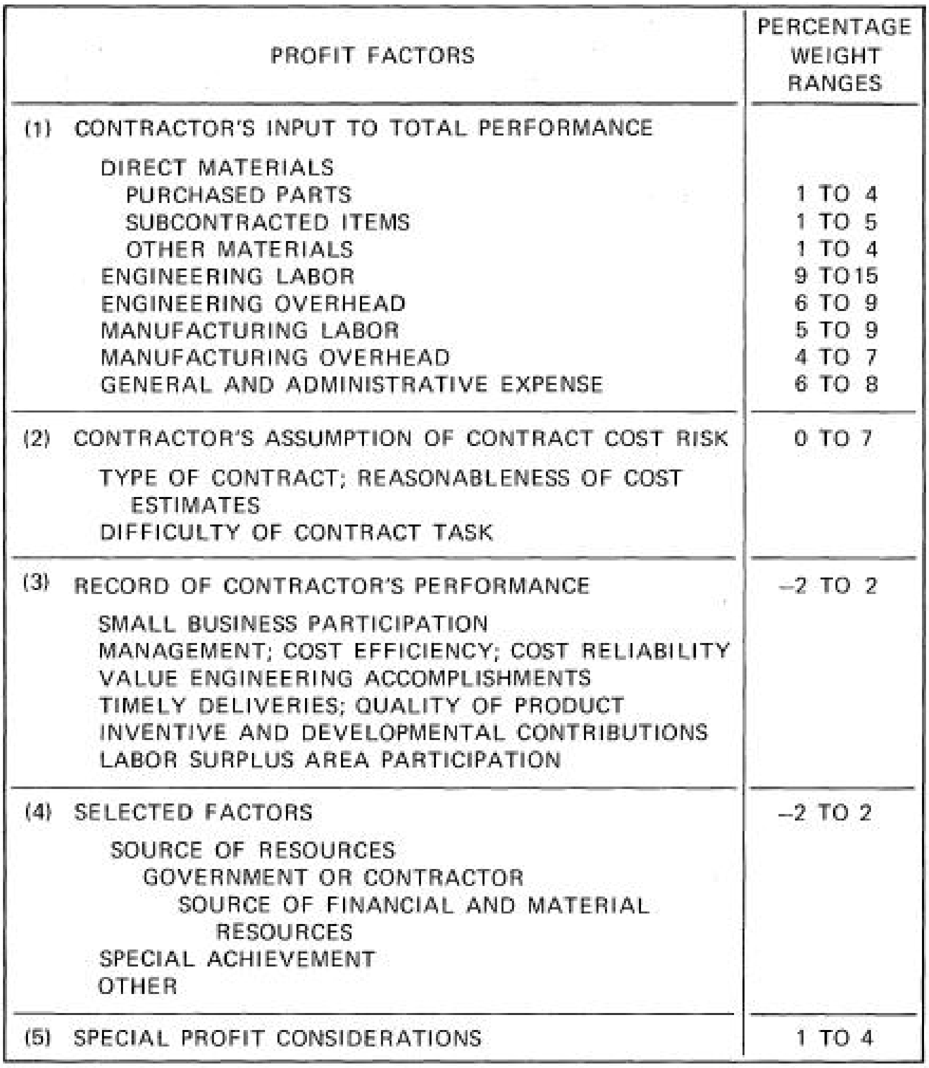
CPPC auditing and regulation is defined in ASPR. For determining the profit percentage on cost, Weighted Guidelines method and weighted importance of profit factors are used which are described in Table 1 [4].

Some methods for evaluating the weights of factors are as follows:

- Profit percentage for ‘direct material’ cost component is determined depending on whether its acquisition is simple or complex; if managerial and technical abilities are required to acquire the parts/components, a high weight is assigned for this cost component.
- Profit percentage for ‘Engineering labor’ cost component is the degree of specialized engineering and scientific talent of employee’s required to fulfill the contract. Also, profit percentage for ‘Manufacturing labor’ cost component depends

on the manufacturing skills and experience of employee's that is essential for the project [4].

Table 1- ASPR weight ranges for profit factors



PROFIT FACTORS	PERCENTAGE WEIGHT RANGES
(1) CONTRACTOR'S INPUT TO TOTAL PERFORMANCE	
DIRECT MATERIALS	
PURCHASED PARTS	1 TO 4
SUBCONTRACTED ITEMS	1 TO 5
OTHER MATERIALS	1 TO 4
ENGINEERING LABOR	9 TO 15
ENGINEERING OVERHEAD	6 TO 9
MANUFACTURING LABOR	5 TO 9
MANUFACTURING OVERHEAD	4 TO 7
GENERAL AND ADMINISTRATIVE EXPENSE	6 TO 8
(2) CONTRACTOR'S ASSUMPTION OF CONTRACT COST RISK	0 TO 7
TYPE OF CONTRACT; REASONABLENESS OF COST ESTIMATES	
DIFFICULTY OF CONTRACT TASK	
(3) RECORD OF CONTRACTOR'S PERFORMANCE	−2 TO 2
SMALL BUSINESS PARTICIPATION	
MANAGEMENT; COST EFFICIENCY; COST RELIABILITY	
VALUE ENGINEERING ACCOMPLISHMENTS	
TIMELY DELIVERIES; QUALITY OF PRODUCT	
INVENTIVE AND DEVELOPMENTAL CONTRIBUTIONS	
LABOR SURPLUS AREA PARTICIPATION	
(4) SELECTED FACTORS	−2 TO 2
SOURCE OF RESOURCES	
GOVERNMENT OR CONTRACTOR	
SOURCE OF FINANCIAL AND MATERIAL RESOURCES	
SPECIAL ACHIEVEMENT	
OTHER	
(5) SPECIAL PROFIT CONSIDERATIONS	1 TO 4

Overhead allocation concern in the defense industry

When contracting a long-term project, companies want to guarantee to cover some portion of the overhead costs in the project's lifecycle[26]. This overhead allocation concept is defined by Fox [11]: "Profit is not a defense contractor's only concern when bidding on or conducting a development or production program. Defense contracts are sought to cover payroll and overhead costs, and to provide company personnel with the opportunity to develop technical and managerial skills useful in future commercial and defense business."

Contribution over direct cost (COD) concept

Projects having the same winning prices and total costs can be differentiated based on the term COD that Kortanek et al. [17] suggests. Kortanek et al. defines COD as profit contribution over a period of time. It is an analytical tool which can be used to evaluate the net profit received per unit time. As an example, a firm will be more eager to succeed in a project bid P1, which has a winning bid price of 1000, total cost of 900 and direct labor cost of 100, over a project bid P2, which has the same winning bid price and total cost, but higher direct labor cost of 500. P1 has a COD value of 10 (=1000/100), whereas P2 has a COD value of 2 (=1000/500). It means that P2 uses more of the company's resources rather than the supplied resources for the same profit level. As a result, P1 is more preferable than P2.

2.3. Project evaluation techniques for the R&D projects

In order to evaluate and compare projects, there are several methods used in project selection. The most common methods used in project evaluation and selection are scoring models, profitability models and multi-attribute utility models. These models address the project selection problem as a constrained model which try to optimize the allocation of resources as manpower, funds, equipment, and facilities among different projects [5].

Scoring Models

In scoring models, for each project, project overall score is computed from the ratings of the determined decision factors. The basic flow used in scoring models is defined by Burton and Nishry [5] in the flow diagram below:

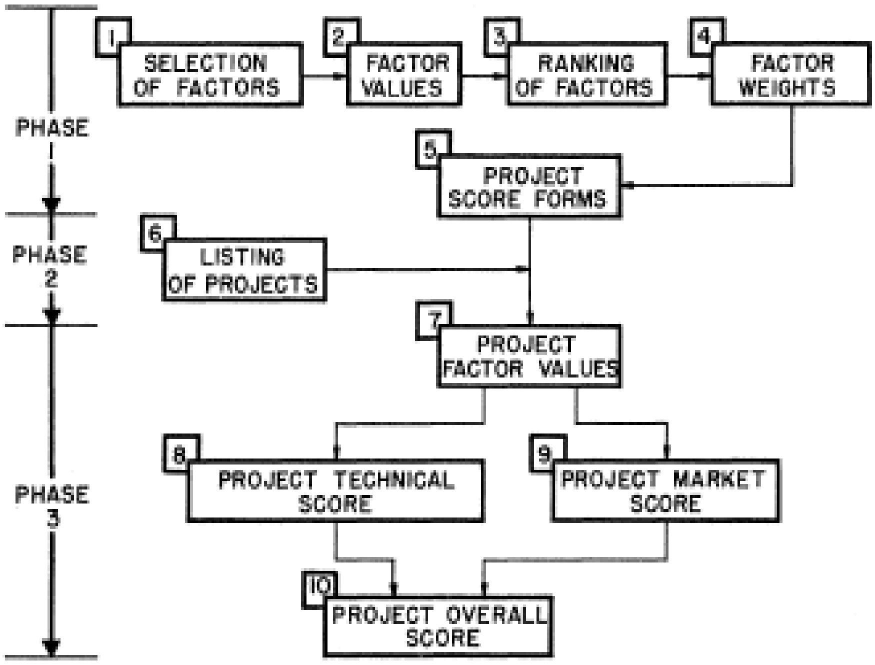


Figure 1- Flow diagram for the scoring models

There are three phases in the method which are described below:

The first phase is the preparation phase which is not to be repeated for every project or every review of the same project. Project score forms are prepared in this phase. Phase 1 contains five steps: step 1 as the selection of factors, step 2 as the factor values, step 3 as the ranking of factors, step 4 as the factor weights and step 5 as the project score forms. At step 1, personnel who are planned to be involved in the project select the relevant factors. At step 2, each factor is accompanied by statements that correspond to scales (values over the range 1–least favorable to 5–most favorable). At step 3, factors are ranked by the relevant personnel and at step 4, factor weights are determined. At step 5, project score forms are prepared as the list of factors with their respective weights and scale values constitute the project score form.

Phase 2 contains step 6 as listing of projects. At this step, the projects among which one or more will be selected are gathered to form the project list.

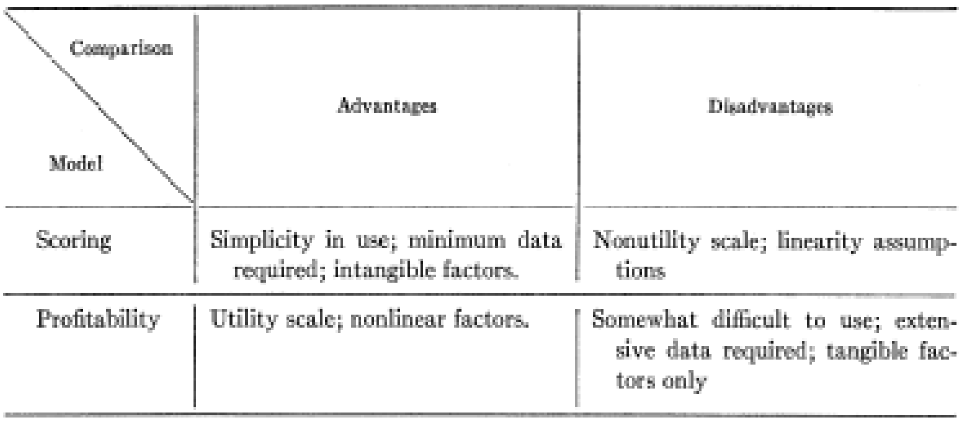
Phase 3 contains step 7 as project factor values, step 8 as project technical score, step 9 as project market score and step 10 as project overall score. At this phase, all projects in the project list are evaluated for each factor and then the overall score of each project is computed by using the weighted sum of scores.

Profitability Models

The scoring model is a linear model in which project scores form the basis for project selection. Because of ranking of projects using an ordinal scale, it is not possible to measure directly 'how much' one project is better than the others. When the objective function of the scoring model is constructed, nonlinear terms are likely to appear. In addition, the evaluation of projects about the profitability or risk is not computed in usual business terms and the discrimination among projects as good and bad is not possible. However, a simple and useful checklist of all relevant factors including some important intangible factors is reflected in the scoring model.

In the profitability model, nonlinear factors are included by using interactions among variables. To measure the profitability of each project, a well-defined performance measure with a cardinal scale defined by the present value of future profits is used, so comparison among projects can be done with respect to profitability. However, there are some disadvantages of the model: it requires extensive data; all input variables must be measurable; and the values of variables must be point estimates. The comparison of scoring and profitability models is shown in Table 2 [5].

Table 2- Comparison of scoring and profitability models



Comparison / Model	Advantages	Disadvantages
Scoring	Simplicity in use; minimum data required; intangible factors.	Nonutility scale; linearity assumptions
Profitability	Utility scale; nonlinear factors.	Somewhat difficult to use; extensive data required; tangible factors only

Multi-attribute utility models

In multiple-attribute utility models, each performance measure of the project is converted into a scalar performance measure using multiple attribute utility (MAU) theory. The decision maker's risk preference is included in the performance conversion function.

Factors that arise to be more common in R&D project evaluation and selection models are the followings:

- Probability of success as a risk factor ([2], [5], [14], [18], [20], [25], [27])
- Allocation of resources, such as cost, manpower and facility ([2], [17], [20])
- Project income or payback period as project's direct benefit ([20], [27])
- Market share impact and government funding as the non-monetary benefits [17].

2.4. Utility Theory

Utility theory is concerned with people's choices, decisions and preferences. Interpretations of utility theory are classified into two categories: prediction and prescription. In the predictive approach, a theory is studied to predict the actual choice behaviors. Psychologists are primarily interested in prediction. Management science, statistics and economists are mainly interested in the prescriptive approach which formulates how a person ought to make a decision [10]. Since utility theory is a wide area, only the terms that will be required and included in this thesis will be mentioned below.

As it is explained before, measuring utility is not a simple process that is totally dependent on the decision maker's choice. One popular and simple way to quantify utility is to apply a utility function which will scale the utility between 0 and 1, assigning 0 to the least preferred and 1 to the most preferred [24].

Expected Utility

In uncertain environments, utility of a decision maker will also be uncertain. The expected utility of a factor, A, for two outcomes (I_1 and I_2) is simply formulated by Friedman and Savage [13], where *p* is the probability of occurrence of an outcome.

$$U(A) = pU(I_1) + (1 - p)U(I_2)$$

Multi-attribute utility theory

In multi-attribute utility (MAU) theory, utility of multiple-attribute outcomes or consequences is expressed as a function of the weighted utilities of each attribute taken singly [28]. In MAU theory, several forms of MAU functions are present as additive, multiplicative and multi-linear. The general form of MAU is shown in Figure 2 as defined by Butler et al. [7], where X_i is the realization for performance measure i; $u_i(X_i)$ is a single attribute utility function over measure i; w_i is the weight for measure i and w_{ijm} are the scaling constants that represent the impact of the interaction among attributes i, j and m on preferences.

$$
\begin{aligned}
u(\mathbf{X}) = {} & \sum_{i=1}^{n} w_i u_i(X_i) + \sum_{i=1}^{n} \sum_{j>i} w_{ij} u_i(X_i) u_j(X_j) \\
& + \sum_{i=1}^{n} \sum_{j>i} \sum_{m>j>i} w_{ijm} u_i(X_i) u_j(X_j) u_m(X_m) \\
& + \cdots + w_{123\ldots n} u_1(X_1) u_2(X_2) \ldots u_n(X_n),
\end{aligned}
$$

Figure 2- General form of MAU

Additive Form:

When additive independence condition of MAU theory is satisfied, which means that attributes are independent of each other, the additive form of MAU can be used. Additive independence holds only when preference for one measure is independent of the level of the other measure [7]. Because of its computational simplicity, the additive form is more generally used:

the MAU utility function: $\sum_j w_j u(X_j)$, and $\sum_j w_j = 1$.

Multiplicative Form:

If mutual independence holds among the attributes, the multiplicative form is appropriate that is shown in Figure 3 as defined by Butler et al. [7]. *w* is the impact of interactions which is the same for all criteria.

$$
\begin{aligned}
u(\mathbf{X}) = {} & \sum_{i=1}^{n} w_i u_i(X_i) + \sum_{i=1}^{n} \sum_{j>i} w w_i w_j u_i(X_i) u_j(X_j) \\
& + \sum_{i=1}^{n} \sum_{j>i} \sum_{m>j>i} w^2 w_i w_i w_m u_i(X_i) u_j(X_j) \\
& \times u_m(X_m) + \cdots + w^{n-1} \prod_{i=1}^{n} w_i u_i(X_1),
\end{aligned}
$$

Figure 3- Multiplicative form of the MAU

CHAPTER 3

PROBLEM DESCRIPTION

As a result of prevailing customer requests and intensive business development/marketing operations, opportunities for new projects arise in the company under consideration. The pre bid process for the defense industry is shown in Figure 4 below.

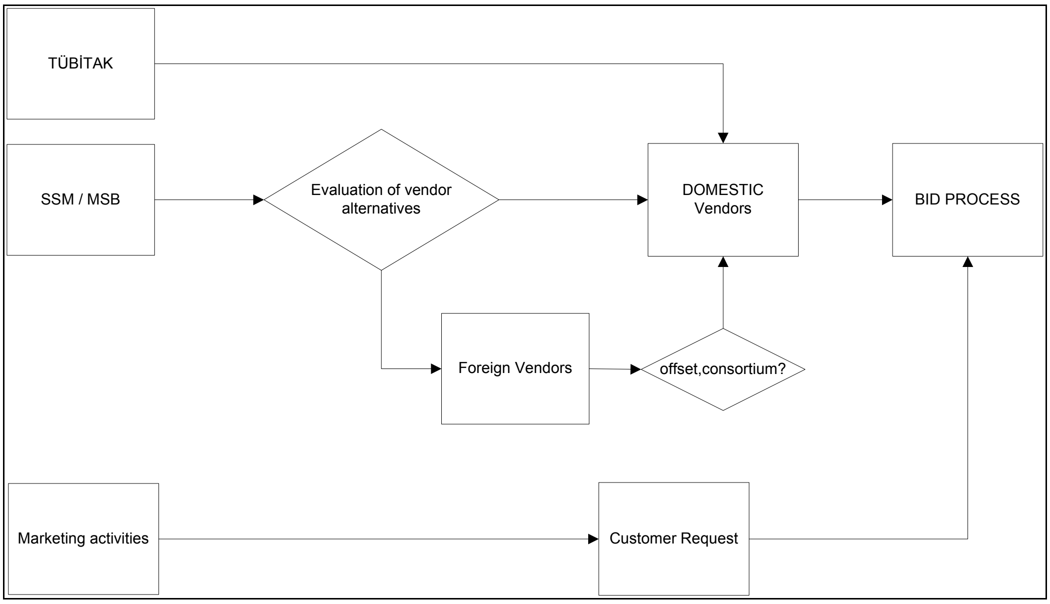


Figure 4- Pre bid process for the defense industry

Project lifecycles are medium to long term, that is, between 2 and 10 years. If a project is found to comply with the company's strategic plan, the option is accepted and the bid preparation process begins.

3.1. Project Characteristics

Firstly, we define the project characteristics that we use to analyze the problem environment.

Project Code: Unique number that identifies the project

Project Type: Types of projects carried out in the company are described below.

- *Production project*: Projects that include products in the existing product portfolio.
- *Research and development (R&D) project*: Projects by which the company gains competitive and strategic advantage in order to support future product developments. These project costs are met mostly by the company's foundations and government promotion.
- *Service project:* Turn-key factories, test supports and laboratory tests made for military agencies and several different customers.
- *Mixed project (R&D and production project):* Project that has both design and production phases. These are usually long-term projects (5-10 years). Design phase includes non-recurring activities and costs, while production phase includes

recurring costs. The aim is to produce the pre-designed final products.

Project Phases:

Design phase: (Non-recurring) If the company has no existing know-how and capability about the project requirements, R&D activities are carried out first. Most of the costs related to this phase are non-recurring costs.

Production phase: (Recurring) According to a known bill of materials, production and quality control activities are carried out to build the semi-finished and final products. Activities and costs are of recurring type in this phase.

Project Currency: The currency determined by the customer in the contract. Customers make all payments and advances in this currency. Generally, currencies used are Turkish Lira (TRY), US Dollars (USD), Euro (EUR) and Sterling (GBP).

Project Cost elements:

- Labor Cost
  - Technician
  - Engineer
- Material Cost
- Subcontracting Cost
- Investment Cost
- Training Cost
- Travel Cost

- Freight, Insurance Cost
- Warranty Period Cost

Work Breakdown Structure (WBS): Discrete work elements are identified.

Project Workplan: According to the WBS, work elements are detailed and scheduled. Cost centers and personnel that will be responsible from the workplan are assigned.

Project Financial Plan: Tasks in the project workplan that have financial characteristics are selected in order to generate the project's financial plan.

Quantity to be produced: The quantity to be produced is determined by the contract. During the lifecycle of the project, customer may change the contract quantity. Possible percentage of deviation in the contract quantity is usually specified at the contract, e.g ± %5.

Vendors: Vendors are selected for the critical materials and some services, like technology transfer, consultancy and specific work package realization.

Project Payment Plan: Payments are made in contract currency. Usually 30% of the bid price is given in advance. The other payments are progressive payments.

3.2. The Bid Preparation Process

In the bid preparation process, activities include the followings: business development and marketing, market research, customer meetings/presentations, defining customer specifications, job and activity analysis, past data analysis, conceptual design, conceptual and graphical modeling, bid cost preparation (budgeting), pricing and determining the final bid.

In order to identify the responsible of these activities, the bid preparation group is established.

Bid Preparation Group

The bid preparation group is crucial for a detailed and realistic proposal document. Members of this group are required to be experienced and aware of the company’s capabilities. The bid preparation group consists of the members defined below:

Project Manager: Coordinator of the project

Bid Responsible: Pricing and other bid preparation processes responsible

Technical Responsible: R&D department responsible, design related issues (conceptual design, technical design, system design)

Functional Department Responsible: Production related issues (capability, labor hour)

Financial Responsible: Main functions include labor rate calculation, exchange rate and inflation rate predictions, and raw material escalation.

Responsibilities

Business Development and Marketing Department (Bid Responsible)

- Sign NDA (Non-disclosure agreement) with the shareholders
- Assign the Bid Preparation Group
- Prepare a plan for Bid Preparation
- Price the bid according to data provided by the finance department responsible and the project responsible (such as labor hours, material and fixed asset expenditures)

Projects Department (Project Responsible)

- Prepare project work breakdown structure (WBS), financial structure and project schedule with the functional departments and project technical responsible
- Collect bid costs and prepare bid budget

R&D Department (Technical Responsible)

- Prepare the project technical approach and the implementation plan
- Prepare a test and assessment plan
- Prepare the job definitions

Finance Department (Financial Responsible)

- Prepare the unit labor cost projection for each of the cost centers working in the project
- Prepare the assumptions for the projected exchange rates
- Conduct the necessary relations with the banks
- Prepare the financial cost of the bid (cost of the letter of guarantee, financial costs due to cash flows)

- Prepare letter of applications for the government promotions
- Conduct market research for the costs of the fixed asset items in the proposal document

Bid Costs Collecting

After the WBS is established and responsibilities of work packages are determined, the bid cost collection process starts. Cost elements are static and all departments can select any type of cost element for realizing their responsibility. Cost elements used in both phases of project (design phase and production phase) are presented in Figure 5.

Cost Elements

In this section cost elements of the bid are detailed. The cost elements defined are used for both design phase and production phase.

Labor Cost

All technical and non-technical departments related directly to the project (production, quality, project management and R&D departments) budget the labor hours for the project in technician and engineer details.

Investment Cost

The investment costs include the project related assets such as building construction, machine, tool, license, software and other investment requirements of the responsible cost centers.

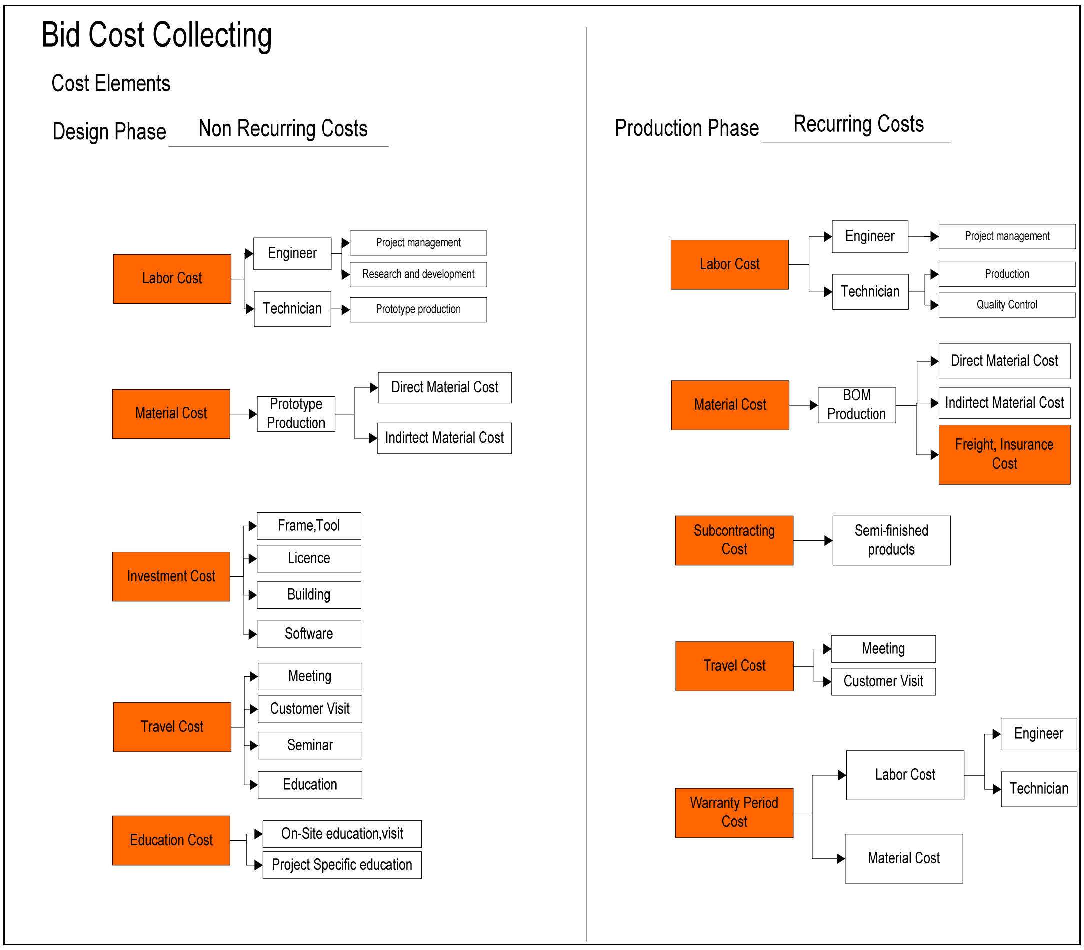


Figure 5- Bid cost collecting

Material Cost

Quantity and type of material used in R&D, design, test activities for the non-recurring phase of the project are determined by all related departments. For the recurring phase, requirements are determined from the pre-designed similar bill of material. For the prediction of material costs, purchasing department selects vendors and conducts price analysis.

Subcontracting Cost

Semi-finished products may be subcontracted if it is more cost effective. Material supplies of subcontractors are made by the company itself.

Education Cost

Knowledge requirement for specific project issues that are not in the cost center’s knowledge are met with external sources such as seminars or specific technical courses.

Travel Cost

Travel costs for education and seminar purposes and vendor-customer visits are also determined and budgeted.

Freight, Insurance Cost

In addition to material and investment costs, freight and insurance costs for material and asset procurements.

Warranty Period Cost

After the completion of the project; labor and material costs for the warranty period are predicted and specified in the contract.

Cost Characteristics

Design Phase Costs

Costs in the design phase period are non-recurring costs. After the completion of cost collection, project management responsible schedule the cash outflows.

Production Phase Costs

Activities and costs are of recurring type in the production phase. The main input of the process is the quantity of the end product agreed on the contract (finished goods to be delivered to the customer for series production and the number of prototypes to be tested for the R&D projects). After the collection of labor hour requirements of the project from the departments, the labor cost outflow is determined based on the production schedule. Material costs and other costs are scheduled by the project management responsible. The details of the process of determining the recurring costs and scheduling costs are given in Figure 6.

Bid Price Determination

After the collection of recurring and non-recurring costs, bid responsible prices the bid in coordination with the financial department responsible.

Pricing Activities

Scheduling the Costs

After the completion of cost collection, project management responsible schedules the non-recurring costs cash-flow according to both the workplan and the financial plan. Production schedule determines the recurring costs cash flow of the project.

Exchange Rate Predictions

Finance Department Responsible conducts meetings with some or several banks and financial institutions and prepares an exchange rate prediction table over the project lifetime.

Unit Labor cost

Unit labor cost is calculated by the finance department based on the previous year's costs. Labor cost consists of direct labor cost, indirect labor cost, non-project overhead cost, non-project depreciation and general administration cost. Labor cost elements are detailed in Figure 7 below.

Labor Cost Determination

After each cost center estimates the labor hours annually, the estimated labor hour is multiplied with the unit labor cost of that cost center. Afterwards, labor cost is determined annually in TRY (i.e., the company's accounting currency code).

Cost Conversion

All costs that are collected, calculated and scheduled are then converted into contract currency by the current exchange rate.

Escalation

Labor rate escalation factor:

Labor cost is changed on a yearly basis, based on the inflation estimations. By taking into account the currency effect and inflation predictions, yearly escalation factor is calculated by the finance department. Inflation estimation is made based on the market insight and the last five years' realizations.

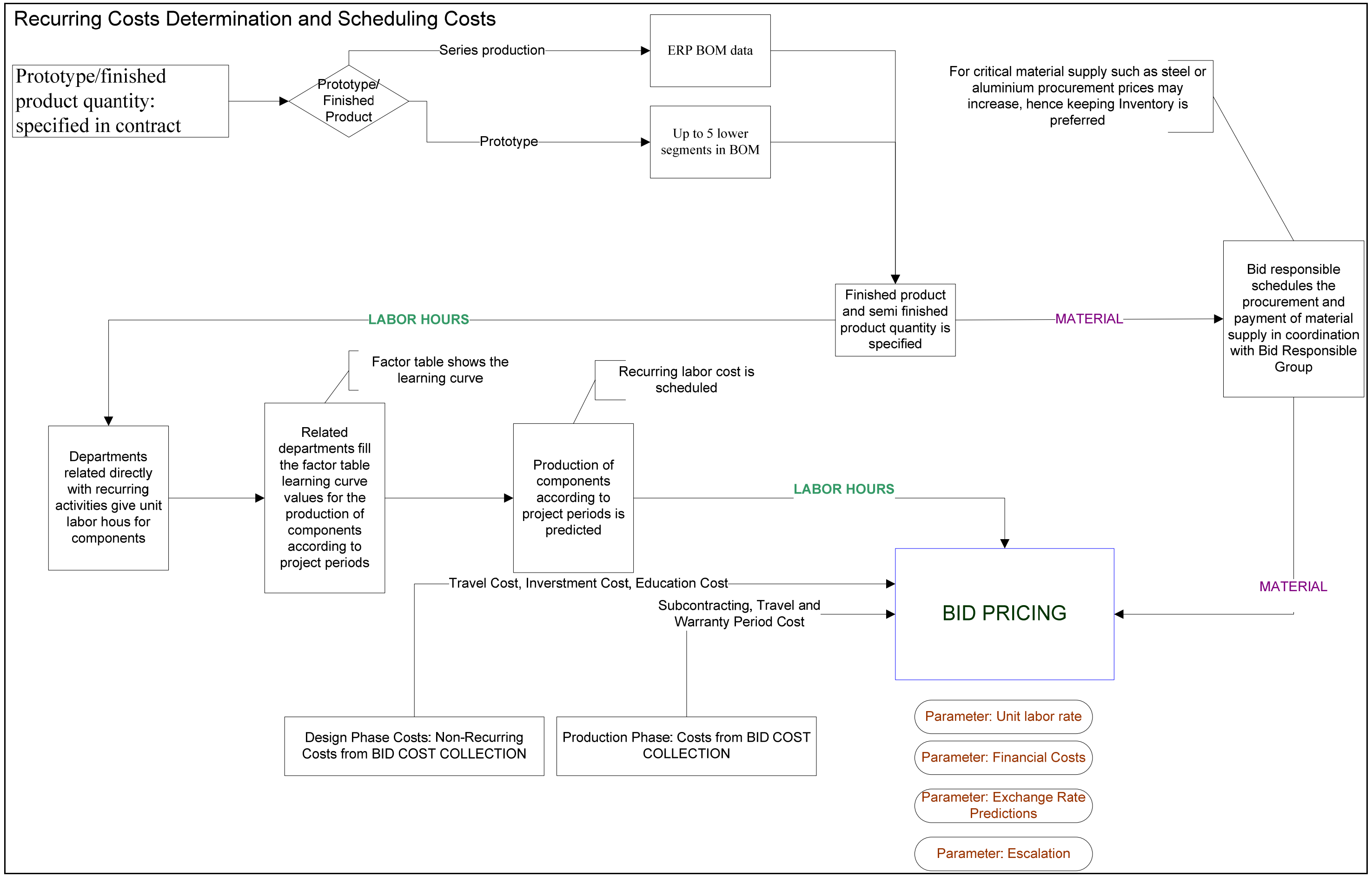


Figure 6- Determination of the recurring costs and scheduling costs

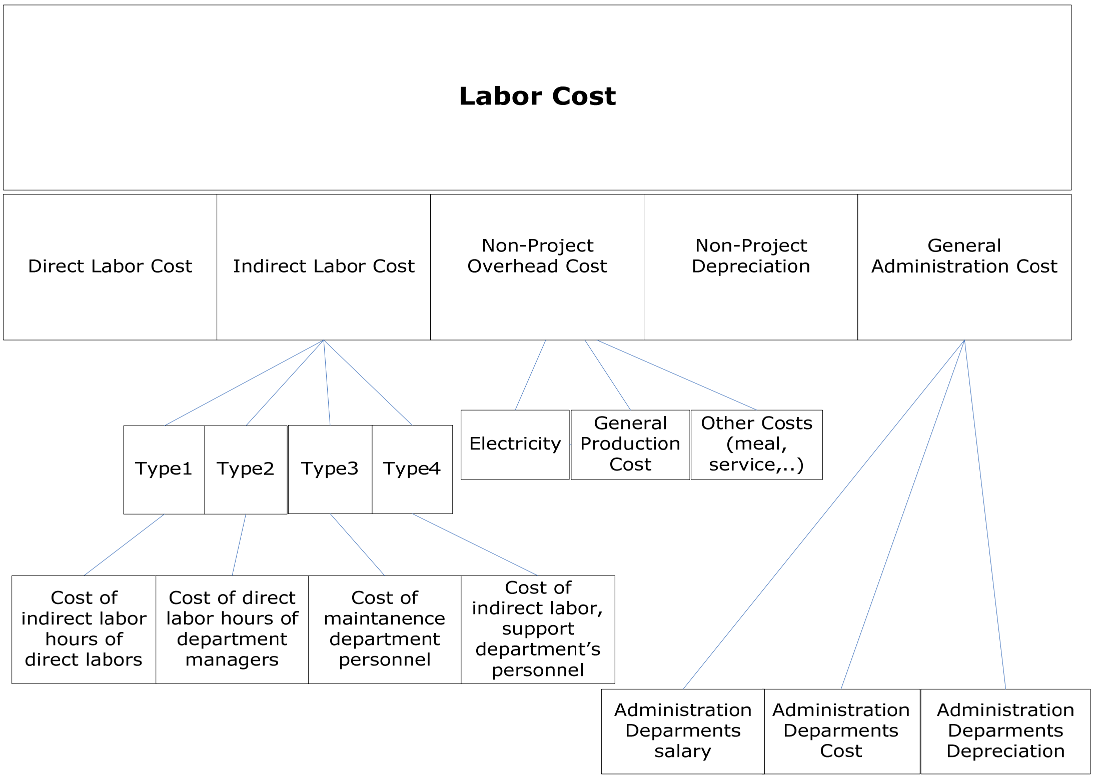


Figure 7- Labor cost elements

For example: Exchange rate of USD is 1.392 TRY on the last day of December 2003, and 1.5207 TRY on the last day of December 2008. Consumer price indices are 104.12 and 160.44, respectively, in years 2003 and 2008. In order to predict the escalation factor for the forthcoming 5 years, the inflation and currency rates of the last 5 years are used. In this example, 5-year inflation rate (54%) and currency rate increase (9%) result in yearly average of 8.2% for the escalation factor (Table 3).

Table 3- Escalation factor estimation

	December 2003	**December 2008**
TRY / USD	1.3923	1.5207
Consumer Price Index	104.12	160.44
Index in USD	74.78$	105.50$
5 Years Escalation (03-08)	41%	
Average Yearly Escalation	8.2%	

Raw materials price escalation factor

There is a strong probability that the cost of raw materials will rise and fall (commonly rise) periodically, to some extent, during the project. Therefore, price escalation should be determined systematically to cope with the sudden price changes of international raw materials under a fixed price contract. According to Bureau of Labor Statistics web site, price indices for the raw materials are as follows (Table 4).

Table 4- Escalation factor of raw materials

(1984=100)	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**5-Year Avg.**
Primary materials price index	117.9	124	158.6	163.9	183.6	190.4	
Price Index Rate		5.2%	27.9%	3.4%	12%	3.7%	10.4%

Generation of Cash Flow

After costs collection, scheduling, calculations and escalation are completed, cash flow is generated according to the payment plan specified in the contract. Payment plan is usually based on 30%-advance payment and the progressive payments. Workplan schedule determines the periods of progressive payments.

Financial Costs

According to the cash flow; financial cost or financial profits of the project are estimated by the financial department. Generally a sufficient financial cost is budgeted taking into account the unexpected conditions that may be encountered.

Technical Risk Determination

The company states the risk levels as follows:
5%: Minimum risk;
10%: Medium level risk;
15%: High level risk.

According to the project characteristics, one of the risk levels is selected. Risk level is held at the minimum for a production project, that is, 5%; whereas for R&D projects, depending on the technical requirements of the project, 10% or 15% risk levels may be selected.

Markup

Markup is specified in the contract. Price bargaining may change the markup for the project. It is also affected by non-monetary values such as know-how, technology transfer, etc.

Contract Cost

Contract cost is fixed as 5% of all costs.

Bid Price

Having defined all the steps of bid pricing activities in the previous sections, schematic representation of the bid pricing process is shown in Figure 8 below.

3.3. The Scope of the Problem

After the completion of the bid preparation process, main concern of the decision maker is about the extent to which the bid covers the risk. There are two types of risks.

Technical Risk

Technical risk of a project is defined as: completing the project with more work-hours, materials, investment amounts and other expenses than those budgeted. Technical risk is tried to be eliminated by the contract "Technical Risk" markup which is determined by the company's abilities and experience to meet the project requirements. Thus, technical risk depends on the ability and success of project responsible and the company.

Financial Risk

Financial risk includes the cost estimation errors, such as exchange rate differences and erroneous inflation predictions. This results in violation of the project's budget. Due to the financial risk, project cost

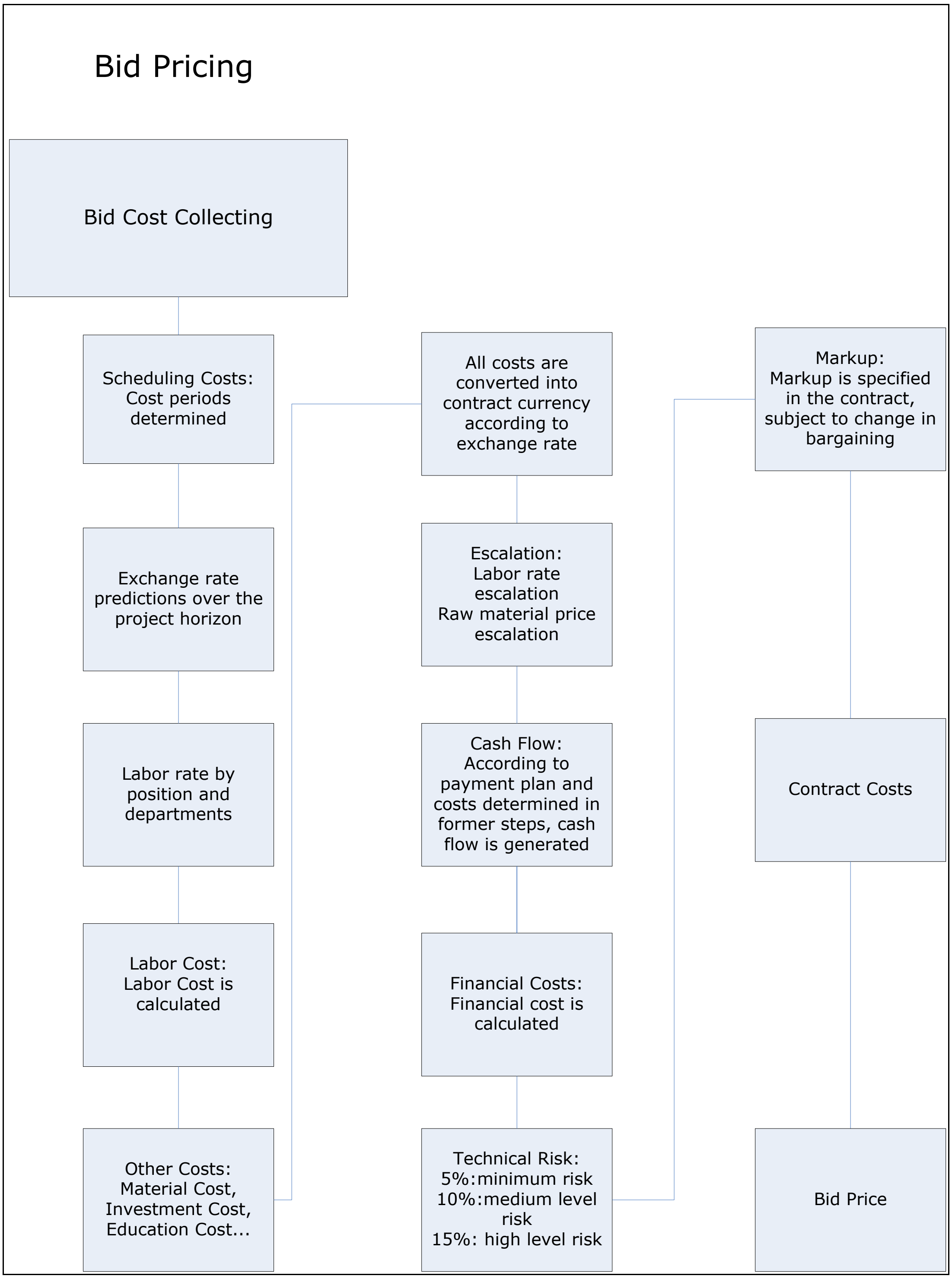


Figure 8- Bid pricing activities

may turn out to be higher than the contracted bid, therefore, expected profit may reduce, or more important than that, sometimes loss may result. Financial parameters that affect the project budget are formed by the market players and the global and local economic environments. Thus, the bid process should have an adaptable characteristic to handle all possible scenarios and stay on the safe side.

In this thesis, we deal with the financial risk management in project pricing via the robust optimization approach. According to the bid preparation process, the financial risk elements are the uncertainties in the exchange rate and inflation rate. Technical risk due to labor hours is also added in order to include the R&D projects' technical uncertainty at least to some extent. We aim at developing a Robust Optimization model so as to minimize the effect of risk on the project profitability. Validation of the developed model will be based on the generation and testing of different scenarios and also output analysis.

According to the financial and economical situations, robust optimization (RO) techniques are utilized based on several selected scenarios: some predicted scenarios and one pessimistic scenario. The RO model is intended to serve as a decision support tool for the top managers of the company, considering the total utility gain of the project and company profitability. Different economic and financial conditions' effects on the model's output are addressed in this thesis. Model runs will analyze the sensitivities around; probability of scenario occurrences, *p(s),* and probability of win with the bid price bp, pow*(bp).* Possible inaccurate estimations of these probabilities will be simulated with several runs to test the solution.

Since contribution over direct cost (COD), overhead allocation and opportunity cost of resource allocation notions are conflicting, the model is based on the expected total utility gain of a bid project. The possibility of losing the bid is not penalized by a cost term in the objective function; however the model is stabilized by the multiplication of the expected utility gain and the probability of win.

CHAPTER 4

A MIXED INTEGER ROBUST OPTIMIZATION FORMULATION FOR THE BID PRICING PROBLEM

In this chapter, a robust optimization formulation is to be constructed to obtain the optimum bid for a single project by considering the decision makers attitudes towards the upcoming bid projects. Firstly, to simplify the problem, some reasonable and acceptable assumptions are to be made related to the company's environmental characteristics.

4.1. Assumptions

In section 2.2, contracting methods in defense industry are described. Among these alternatives, in conformity with the competitive environment the company has, the Firm-Fixed-Price contracting method is more appropriate than the others.

Capacity considerations

- Company assets (such as machine, bench or building) are assumed to be sufficient. The additional required investment is included in the bid costs. Non-project related capacity increase of support and management personnel is assumed to be covered by non-project related overhead rates. Also a requirement in administrative personnel increase is covered by the general administrative rate in the labor cost.
- The land registered to the company is large enough for new production areas or building departments for the newly employed personnel.

According to the above assumptions, capacity considerations are based only on labor utilization.

- Yearly overtime hours can be at most 10% of the workforce hours.

Labor grouping

- Labor is divided into two categories; engineering labor and manufacturing labor as in Burns [4]. Engineering labor has two sub-categories: project-management engineer and R&D engineer. Manufacturing labor is diversified as production engineer and production technician. Since there is no need for diversification of quality department personnel and production department personnel in terms of labor rate and project phase, quality department personnel is included in the sub-categories of production engineer and production technician.

- In bid cost collection activity, labor rate is calculated elaborately for each department. As labor is grouped into 4 sub-categories, labor rates in the model are taken as the arithmetic means of the related departmental labor rates calculated by the financial department.

Cash Flow Assumptions

- Money conversion, borrowing or lending activities are held at the beginning of the years.
- Either borrowing or lending is allowed. After the money is borrowed or lent, financial gain or loss is assumed at the beginning of next period.
- Once money is converted into TRY, conversion to the project currency is not available.
- Since the payment plan of the project is determined as rewarding, financial cost of the project does not affect the decision maker’s choice. Financial cost of the project is taken as a cost parameter and financial cost defined in the bid will be a budget constraint on the model-calculated financial cost.
- Escalation factor for raw materials is not shown in the model, however, raw material cost values are the escalated values.

4.2. Model Formulations

The formulation of the bid pricing problem is decomposed as two models. First model, the Penalty-Model, addresses the labor issues. Penalty-Model determines hiring, firing levels and overtime levels. The objective is to have a decision set that has the minimal penalty, in other words when infeasibility in labor capacity constraints is inevitable, the model should find a decision set which has the least negative affects. In the model robustness part of the Robust Optimization model, as we will see later, penalty cost of workforce decisions is multiplied with the binary decision variable which causes a non-linearity. Workforce decisions such as hiring, firing and overtime levels are assumed not to change the cost of the project. These decisions bring penalty costs.

Hence, there is no direct relationship between the BIDPRICE decision and workforce decisions. So these decisions can be separately made without giving rise to suboptimality. Therefore, we can safely calculate the penalty cost in the Penalty Model and avoid non-linearity in the Robust Optimization Model. Then penalty cost turns out to be a parameter for the Robust Optimization Model. Below, the penalty cost term of the Penalty-Model is shown in the Robust Optimization Model.

$$-\underbrace{gpw}_{\text{Goal programming parameter}}\left(\sum_{bp}\underbrace{x(bp)}_{\text{Binary decision variable:selected Bid Price}}\; pow(bp)\; \underbrace{penalty)}_{\text{Penalty cost, includes decision variables}}\right)$$

Figure 9- Model robustness part of the Robust Optimization model

Secondly, the Robust Optimization Model determines the rate of return for the bid project that takes into account the decision maker's preference by utilizing several utility functions related to the project characteristics and decision maker's attitudes. Only the penalty term of the Penalty-Model is included in the Robust Optimization Model, as a parameter, whereas hiring, firing and overtime decision variables' values help the decision maker foresee the company's workforce requirement level.

Both models use the same sets and parameters. Nevertheless, in order to provide integrity of these models, common sets and parameters sections are mentioned both in the Penalty-Model and Robust Optimization Model with small differences.

4.2.1. The Penalty-Model

The Penalty-Model takes into account the changes in the workforce level. Changes in the company's workforce are penalized in order to have a smooth workforce level.

Sets

s	Set of scenarios 1,…n_s
t	Set of annual time periods 1,…n_t
i	Set of labor types 1,…n_i

Parameters

The parameters can be categorized as: the scenario related, labor cost related, capacity related, and penalty parameters.

Scenario related parameters

Scenario probabilities

Uncertain financial parameters are the inflation rate and the exchange rates for the horizon. Also there are technical uncertainties in preparing a bid related to the realization of the project with the pre-determined budgeted work-hour, material, investment and other expenses. Technical uncertainty stems from the work-hour requirements. Scenario probabilities are assumed to be the product of probability of financial uncertainty and probability of technical uncertainty. We use the following notation:

p(*s*)	Probability of scenario s occurrence
infl(s,t)	Inflation rate estimation in year t with scenario s
exch(*s*,*t*)	Exchange rate estimation in year t with scenario s
cuminfl(s,t)	Compounded inflation rate estimation from year 1 to t with scenario s
techrisk(s)	Technical risk in labor-hour estimation in scenario s

Labor Cost related parameters

Labor Rate

Labor rate is calculated by finance department according to previous year’s data. Labor rate consists of direct labor cost, indirect labor cost, non-project overhead-depreciation and general & administrative costs. In this Penalty-Model, only direct labor rate is used.

$d(i)$	Direct hourly labor rate of labor type i

Capacity related parameters

wh	Work-hours per year per worker (assumed to be 2000 hours)
$per(i,t)$	Projected number of personnel of labor type i in year t
$bw(i,t)$	Budgeted work-hour of labor type i in year t by the pre-contracted projects
$pw(i,t)$	Required work-hour of labor type i in year t by the bid project

Penalty Parameters

Penalty rates:

$prhire$	penalty rate for the newly hired personnel
$prfire(i)$	penalty rate for the fired labor of type i
$prextra$	penalty rate for the overtime of personnel per hour
$prsurp$	penalty rate for the surplus due to the newly hired personnel

Four types of decisions are penalized; hiring, firing, overtime and surplus due to the newly hires.

Hire

A newly hired personnel works effectively after a 3-month working period. So, $prhire$ is set to 0.25 in order to calculate the penalty cost of hiring for the company.

Fire

Severance pay for fired personnel is one salary for one year. It is assumed that fire cost is $d(i)wh$; more than one month salary for an employee including the indemnity required to pay and severance payment. Penalty of firing of personnel is set to high purposefully, since it is not preferred by the managers.

Overtime

Overtime wages are 1.5 times the normal wages. So $prextra$ is set to constant coefficient, 0.5.

Surplus

Instead of working overtime, the decision may be to hire personnel. Surplus of work-hour due to these newly hired personnel is penalized by constant coefficient $prsurp$ as 0.5.

Decision Variables

As previously defined, there exists a technical risk for projects denoted with a constant coefficient $techrisk(s)$. Work-hour estimations of departments may not be realistic, since R&D projects include many uncertainties. Hiring & firing decisions are made at the beginning of the years, whereas decisions to make extra-hour can be made upon realizing the technical uncertainty. Due to this fact, overtime and dependent surplus variables include the scenario index, s.

Capacity related variables

Integer Variables

h(i,t)	Number of hired labor of type i in year t
f(i,t)	Number of fired labor of type i in year t
chire(i,t)	Cumulative hires of labor type i up to year t
cfire(i,t)	Cumulative fires of labor type i up to year t

Continuous Variables

eh(s,i,t)	Overtime worked by labor type i in year t for scenario s
surp(s,i,t)	Surplus of work-hour of labor type i in year t for scenario s
wf (i,t)	Workforce of labor type i in year t
dplus(s,i,t)	Surplus due to the newly hired labor of type i in year t for scenario s

Indirect Variables

These variables are the calculated variables and used in the equations in order to have simplicity in the model.

Expen	Expected penalty
pen(s)	Total penalty cost in scenario s
penhire(s)	Penalty cost of hires in scenario s
penfire(s)	Penalty cost of fires in scenario s

penextra(s)	Penalty cost of overtime in scenario s
pensurp(s)	Penalty cost of surplus in scenario s

Capacity Constraints

Personnel, working directly for the projects are divided into four categories: project management engineer, R&D engineer, production engineer and production technician. Project management engineer takes place in all phases of the project. However, R&D engineer works intensively in the R&D phase and production labor takes place mainly in the production phase. Labor grouping is important in order to build labor cost in a yearly manner.

The company has a projected personnel level for each type of labor, $per(i,t)$. In addition, the bid project may require new personnel hires, $h(i,t)$. Projected personnel level may change due to yearly hires. Cumulative effect of yearly hires of personnel is calculated by (1). Also idle workforce may be fired in some periods and cumulative effect of yearly fires is calculated by (2).

$$chire(i,t) = \sum_{j=1}^{t} h(i,j) \qquad \forall i,t \qquad (1)$$

$$cfire(i,t) = \sum_{j=1}^{t} f(i,j) \qquad \forall i,t \qquad (2)$$

So the workforce for each labor type i in year t is $wf(i,t)$, and calculated in (3).

$$wf(i,t) = (per(i,t) + chire(i,t) - cfire(i,t))\,wh \qquad \forall i,t \tag{3}$$

For each labor type, the company allows for overtime up to 10% in a year:

$$eh(s,i,t) \le 0.1\,wf(i,t) \qquad \forall i,t,s \tag{4}$$

Equation (5) below is the main capacity constraint. For each labor type and each year, yearly budgeted direct workhour for pre-contracted projects, $bw(i,t)$, plus the bid project's yearly required direct workhour $pw(i,t)$, should be covered by the workforce $wf(i,t)$ and overtime worked, $eh(s,i,t)$. Excessive workhour is a surplus for the company $surp(s,i,t)$.

$$bw(i,t) + pw(i,t)\,techrisk(s) = wf(i,t) + eh(s,i,t) - surp(s,i,t) \qquad \forall i,t,s \tag{5}$$

Penalty Costs

Penalty cost of the newly hired personnel corresponds to the 3-month learning period. Multiplier $prhire$ is used as 0.25 in the model. Penalty cost of hire is calculated by multiplying ineffective hours, $wh * prhire$, by direct cost of labor, $d(i)$. Penalty cost for hire is converted into project currency code:

$$penhire(s) = \sum_t \left(\sum_i h(i,t)\, d(i)\, wh\, prhire \right) cuminfl(s,t) / exch(s,t) \; \forall s \tag{6}$$

As it is explained before, penalty for firing a personnel is calculated by (7), then penalty cost is calculated by (8).

$$prfire(i) = d(i)\, wh \qquad \forall i \quad (7)$$

$$penfire(s) = \sum_t \left(\sum_i f(i,t) prfire(i) \right) cuminfl(s,t)/exch(s,t) \qquad \forall s \quad (8)$$

Wages for overtime are 50% higher than the normal wages. Multiplier $prextra$ is used as 0.5 in the model. Penalty cost for overtime are calculated and converted into project currency code in equations (9).

$$penextra(s) = \sum_t \left(\sum_i eh(s,i,t)\, d(i)\, prextra \right) cuminfl(s,t) \,/\, exch(s,t)$$

$$\forall s \quad (9)$$

In order to find surplus penalty, extra workforce required for the bid project for each scenario, labor type and year is calculated in (10).

$$\begin{gathered} reqwf(s,i,t) = 0 \rightarrow (per(i,t)\, wh) - bw(i,t) - (pw(i,t)\, techrisk(s)) \geq 0 \;; \\ reqwf(s,i,t) = (per(i,t)\, wh) - bw(i,t) - (pw(i,t)\, techrisk(s)) \rightarrow \\ (per(i,t)\, wh) - bw(i,t) - (pw(i,t)\, techrisk(s)) \leq 0 \end{gathered}$$

$$\forall s,i,t \quad (10)$$

The condition to initialize $reqwf(s,i,t)$ is evoked when current workforce is less than the budgeted pre-contracted work-hour plus the uncertain project work-hour. This parameter is always less than or equal to 0.

Then, surplus due to newly hired personnel *dplus(s,i,t)* is calculated by (11).

$$\left(chire(i,t)\text{-}cfire(i,t)\right) wh + reqwf(s,i,t) = dplus(s,i,t)\text{-}eh(s,i,t) \qquad \forall s \quad (11)$$

Finally, penalty cost of surplus can be calculated and converted into project currency code in equation (12).

$$pensurp(s) = \sum_t \left(\sum_i dplus(s,i,t) prsurp\ d(i) \right) cuminfl(s,t)/exch(s,t) \qquad \forall s \quad (12)$$

Total penalty cost for each scenario is the sum of all penalty cost elements as given by equation (13):

$$pen(s) = penhire(s) + penfire(s) + penextra(s) + pensurp(s) \qquad \forall s \quad (13)$$

Expected penalty cost is then calculated by (14).

$$Expen = \sum_s pen(s)p(s) \qquad (14)$$

Bounds on Variables

$h(i,t)$ and $f(i,t)$ are integer $\qquad \forall i,t \qquad (15)$

All capacity related variables are positive(16)-(21).

$chire(i,t) \geq 0 \qquad \forall i,t \qquad (16)$

$cfire(i,t) \geq 0 \qquad \forall i,t \qquad (17)$

$wf(i,t) \geq 0 \qquad \forall s,i,t \qquad (18)$

$surp(s,i,t) \geq 0 \qquad \forall s,i,t \qquad (19)$

$eh(s,i,t) \geq 0 \qquad \forall s,i,t \qquad (20)$

$dplus(s,i,t) \geq 0 \qquad \forall s,i,t \qquad (21)$

Objective Function

Objective function of the Penalty-Model is the minimization of the expected penalty cost:

$$\min \quad Expen \qquad (22)$$

Then the Penalty-Model is formulated as follows:

$$\min \quad Expen$$

s.t

$$chire(i,t) = \sum_{1}^{t} h(i,t) \qquad \forall i,t \qquad (1)$$

$$cfire(i,t) = \sum_{1}^{t} f(i,t) \qquad \forall i,t \qquad (2)$$

$$wf(i,t) = (per(i,t) + chire(i,t) - cfire(i,t))\, wh \qquad \forall i,t \qquad (3)$$

$$eh(s,i,t) \leq 0.1\, wf(i,t) \qquad \forall i,t \qquad (4)$$

$$bw(i,t) + pw(i,t)\, techrisk(s) = wf(i,t) + eh(s,i,t) - surp(s,i,t) \qquad \forall i,t \quad (5)$$

$$penhire(s) = \sum_{t}\left(\sum_{i} h(i,t)\; d(i)\; wh\; prhire\right) cuminfl(s,t) / exch(s,t) \; \forall s \quad (6)$$

$$prfire(i) = d(i)\, wh \qquad \forall i \quad (7)$$

$$penfire(s) = \sum_{t}\left(\sum_{i} f(i,t) prfire(i)\right) cuminfl(s,t)/exch(s,t) \qquad \forall s \quad (8)$$

$$penextra(s) = \sum_{t}\left(\sum_{i} eh(s,i,t)\; d(i)\; prextra\right) cuminfl(s,t) / exch(s,t)$$

$$\forall s \quad (9)$$

$$reqwf(s,i,t) = 0 \rightarrow \; (per(i,t)\; wh) - bw(i,t) - (pw(i,t)\; techrisk(s)) \geq 0 \; ;$$
$$reqwf(s,i,t) = (per(i,t)\; wh) - bw(i,t) - (pw(i,t)\; techrisk(s)) \; \rightarrow$$
$$(per(i,t)\; wh) - bw(i,t) - (pw(i,t)\; techrisk(s)) \leq 0$$
$$\forall s,i,t \quad (10)$$

$$\left(chire(i,t)\text{-}cfire(i,t)\right) wh + reqwf(s,i,t) = dplus(s,i,t)\text{-}eh(s,i,t) \quad \forall s \quad (11)$$

$$pensurp(s) = \sum_t \left(\sum_i dplus(s,i,t) prsurp\ d(i) \right) cuminfl(s,t)/exch(s,t) \quad \forall s \quad (12)$$

$$pen(s) = penhire(s) + penfire(s) + penextra(s) + pensurp(s) \quad \forall s \quad (13)$$

$$Expen = \sum_s pen(s)p(s) \quad (14)$$

$h(i,t)$ and $f(i,t)$ are integer $\quad \forall i,t \quad$ (15)

All capacity related variables are positive(16)-(21).

$$chire(i,t) \geq 0 \quad \forall i,t \quad (16)$$

$$cfire(i,t) \geq 0 \quad \forall i,t \quad (17)$$

$$wf(i,t) \geq 0 \quad \forall s,i,t \quad (18)$$

$$surp(s,i,t) \geq 0 \quad \forall s,i,t \quad (19)$$

$$eh(s,i,t) \geq 0 \quad \forall s,i,t \quad (20)$$

$$dplus(s,i,t) \geq 0 \quad \forall s,i,t \quad (21)$$

The influence diagram of the Penalty-Model is shown in Figure 10.

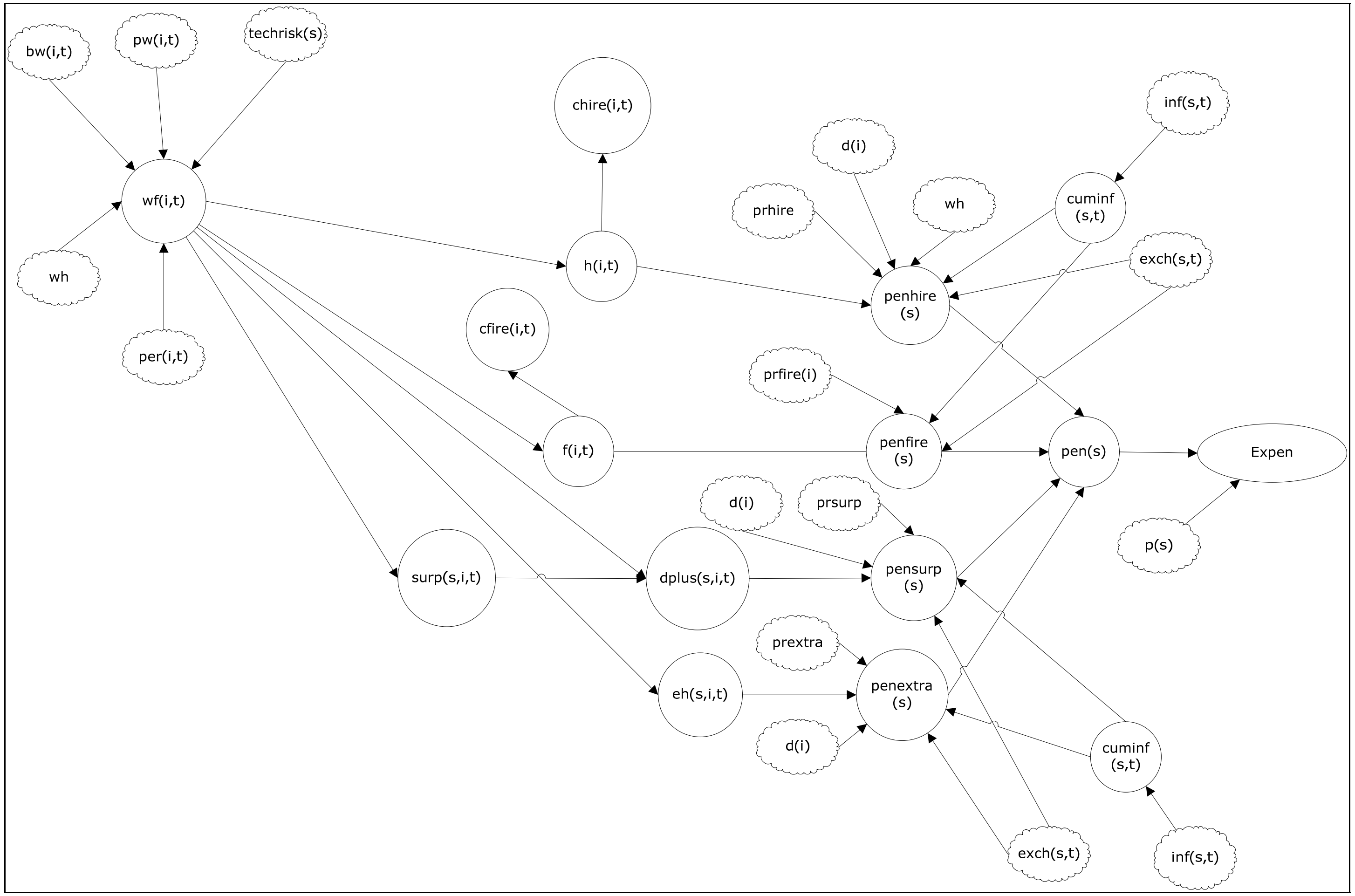


Figure 10- Influence diagram of the Penalty-Model

4.2.2. The Robust Optimization (RO) Model

Sets

s	Set of scenarios $1,\dots n_s$
t	Set of annual time periods $1,\dots n_t$
i	Set of labor types $1,\dots n_i$
bp	Set of bid price alternatives $LBP,..,HBP$

(LBP=Lowest Bid Price, HBP=Highest Bid Price)

Parameters

Scenario related parameters

As it is explained, in Penalty-Model parameters, uncertainties exist for the company for financial and technical conditions.

$p(s)$	Probability of scenario s occurrence
$infl(s,t)$	Inflation rate estimation in year t with scenario s
$exch(s,t)$	Exchange rate estimation in year t with scenario s
$cuminfl(s,t)$	Compounded inflation rate estimation from year 1 to t with scenario s
$techrisk(s)$	Technical risk in labor-hour estimation

Bid Price and Probability-of-win related parameters

Highest and lowest bid prices (HBP, LBP) are assumed to be known by the industry expert where the probability of winning is 0 and 1, respectively. Project bid is made in the interval of HBP and LBP.

HBP	Highest bid price for which the probability of winning is 0
LBP	Lowest bid price for which the probability of winning is 1

$BPR(bp)$	Bid Price value with the bpth alternative
$pow(bp)$	Probability of winning with the bp

Cost related parameters

Labor Rate

Labor rate consists of direct labor cost, indirect labor cost, non-project overhead-depreciation and general administrative costs.

$l(i)$	Labor rate of labor type i
$d(i)$	Direct labor rate of labor type i
$ind(i)$	Indirect labor rate of labor type i
$o(i)$	Overhead rate of labor type i (non-project overhead, non-project depreciation and general administrative costs are included into this term)

Their relationship can be shown by the formula $l(i) = d(i) + ind(i) + o(i)$

Material Cost

Material cost can be budgeted for each year t in two currencies; project currency code and national currency code.

$MC(t)$	Material cost in year t in project currency
$M(t)$	Material cost in year t in TRY

Investment Cost

Investment cost can also be budgeted for each year t in two currencies; project currency code and national currency code.

$INVC(t)$	Investment cost in year t in project currency
$INV(t)$	Investment cost in year t in TRY

Miscellaneous Cost

Costs that sum up to 10% of the bid budget is put into the miscellaneous cost category; such as travel cost, education cost, freight-insurance cost, contract costs and government taxes.

$MISCC(t)$	Other Costs in year t in project currency
$MISC(t)$	Other Costs in year t in TRY

Financial Cost

Financial cost is calculated and budgeted by the finance department.

FIN	Total budgeted financial cost in project currency code

Cash Flow related parameters

Yearly payment plan in percentages of the total price for the years is specified in the contract and payment is made in project currency code. Borrowing and lending options are available in the national currency code and project currency code. There may be multiple borrowing or lending options. So as an estimate, borrow rate is assumed to be 5% over the inflation rate for the national currency code. Multipliers for borrow and lend rates are defined in order to make different analyses.

$PC(t)$	Payment percentage in year t according to the payment plan
mb	Multiplier for borrow rate over inflation for TRY
ml	Multiplier for lend rate over inflation for TRY
mbc	Multiplier for borrow rate over inflation for project currency
mlc	Multiplier for lend rate over inflation for project currency

BIGM	Large number for cash flow decisions

Borrow and lend rates are calculated by multipliers and inflation rates for each year and for each scenario.

$br(s,t)$	Borrow rate for TRY in year t in scenario s
$brc(s,t)$	Borrow rate for project currency in year t in scenario s
$lr(s,t)$	Lend rate for TRY in year t in scenario s
$lrc(s,t)$	Lend rate for project currency in year t in scenario s

Calculated Parameters

In order to make formulations simple, some calculations are done over parameters.

PLC(s)	total labor cost of the project in scenario s in project currency
PMC(s)	total material cost of the project in scenario s in project currency
PIC(s)	total investment cost of the project in scenario s in project currency
PMISCC(s)	total miscellaneous cost of the project in scenario s in project currency
CO(s)	Total cost of project in scenario s
EC	Expected Cost in project currency
PCOST(t)	Project costs which are budgeted in TRY in year t
PCOSTC(t)	Project costs which are budgeted in project currency in year t

For each scenario, costs are summed and converted into project currency code in equations (23)-(26).

$$PLC(s) = \sum_t \left(\sum_i l(i) pw(i,t)\, techrisk(s) \right) cuminfl(s,t) / exch(s,t) \quad \forall s \quad (23)$$

$$PMC(s) = \sum_t \left(M(t) cuminfl(s,t) / exch(s,t) \right) + MC(t) \quad \forall s \quad (24)$$

$$PIC(s) = \sum_t \left(INV(t) cuminfl(s,t) / exch(s,t) \right) + INVC(t) \quad \forall s \quad (25)$$

$$PMISCC(s) = \sum_t \left(MISC(t) cuminfl(s,t) / exch(s,t) \right) + MISCC(t) \quad \forall s \quad (26)$$

Total cost of each scenario and expected value of project cost is calculated in equations (27) and (28).

$$CO(s) = PLC(s) + PMC(s) + PIC(s) + PMISCC(s) + FIN \quad \forall s \quad (27)$$

$$EC = \sum_s CO(s) p(s) \quad (28)$$

Yearly costs are calculated for each currency code in (29) and (30) to use in cash flow formulations.

$$PCOST(t) = \left(\sum_i l(i)\, pw(i,t)\, techrisk(s) \right) + M(t) + INV(t) + MISC(t) \quad \forall t \quad (29)$$

$$PCOSTC(t) = MC(t) + INVC(t) + MISCC(t) \quad \forall t \quad (30)$$

Decision Variables

BIDPRICE Bid price is the main decision variable of the model

$$x(bp) = \begin{cases} 1 \text{ if bid price bp is selected} \\ 0 \text{ otherwise} \end{cases}$$

Cash Flow related variables

Since payment is made in terms of project currency code, money will be converted into national currency code in order to pay salaries and costs in national currencies.

CNV(s,t)	Converted money to TRY in year t in scenario s
B(s,t)	Borrowed money in year t in TRY in scenario s
BC(s,t)	Borrowed money in year t in project currency in scenario s
Lend(s,t)	Lent money in year t in TRY in scenario s
LendC(s,t)	Lent money in year t in project currency in scenario s

Indirect variables

These variables are calculated variables and used in equations in order to have simplicity in the model.

EFinCO	Expected financial cost
PFinCO(s)	Project total financial cost in scenario s
TFinCO(s,t)	Total financial cost in scenario s at time t
FinCO(s,t)	Previous period financial cost in scenario s at time t in TRY
FinCOC(s,t)	Previous period financial cost in scenario s at time t in project currency code

Constraints

Cash Flow Constraints

Financial cost is calculated and budgeted by the finance department at the beginning as explained before. Expected financial cost of the bid project must be smaller than or equal to the budgeted financial cost, FIN.

Financial cost for a year results from previous years borrowing or lending activities. Financial cost incurs at the beginning of the next year. In equations (31),(32) financial cost of each year t is calculated in terms of currency codes. (31) is the financial cost of national currency code, whereas (32) is the financial cost that results from borrowing or lending with bid currency code.

$$FinCO(s,t) = B(s,t-1)\left(br(s,t-1)-1\right) - Lend(s,t-1)\left(lr(s,t-1)-1\right) \quad \forall s,t \quad (31)$$

$$FinCOC(s,t) = BC(s,t)\left(brc(s,t)-1\right) - LendC(s,t)\left(lrc(s,t)-1\right) \quad \forall s,t \quad (32)$$

Financial cost of each year in terms of project currency code is calculated by equation (33).

$$TFinCO(s,t) = FinCOC(s,t) + FinCO(s,t)/exch(s,t) \quad \forall s,t \quad (33)$$

In terms of national currency code, project costs (such as labor cost) plus financial cost of the previous year should be covered by the converted money into national currency code. Payments for previous years borrowing or lending $-B(s,t-1)+Lend(s,t-1)$, and current years borrowing or lending effects $B(s,t) - Lend(s,t)$, should be taken into account. Cash flow for each year in terms of TRY is shown in equation (34).

$$CNV(s,t)\, exch(s,t) + B(s,t) - Lend(s,t) - B(s,t-1) + Lend(s,t-1) \\ = PCOST(t) + FinCO(s,t) \qquad \forall s,t \quad (34)$$

Each year, a percentage of the bid price is paid by the customer in project currency code, $PC(t)\, BIDPRICE$. Cash flow in project currency code is similar and shown in equation (35).

$$PC(t)\, BIDPRICE - CNV(s,t) + BC(s,t) - BC(s,t-1) - LendC(s,t) \\ + LendC(s,t-1) = PCOSTC(t) + FinCOC(s,t) \qquad \forall s,t \quad (35)$$

Project financial cost for each scenario and expected financial cost is calculated by equations (36) and (37).

$$PFinCO(s) = \sum_t TFinCO(s,t) \qquad \forall s \quad (36)$$

$$EFinCO = \sum_s PFinCO(s) p(s) \qquad (37)$$

Expected financial cost should be in the allowed budget:

$$EFinCO \le FIN \qquad (38)$$

Variable Bounds

$x(bp)$ is a binary variable: $x(bp) \in \{0,1\} \quad \forall bp$

Monetary variables should be positive (39)-(43).

$$CNV(s,t) \geq 0 \qquad \forall s,t \qquad (39)$$

$$B(s,t) \geq 0 \qquad \forall s,t \qquad (40)$$

$$BC(s,t) \geq 0 \qquad \forall s,t \qquad (41)$$

$$Lend(s,t) \geq 0 \qquad \forall s,t \qquad (42)$$

$$LendC(s,t) \geq 0 \qquad \forall s,t \qquad (43)$$

Objective Function

Objective function's first part is the sum of expected the utilities of the bid project characteristics multiplied by a risk function, all of which determine the willingness of the company. Considering the project characteristics and capacity utilization status, the willingness of the decision maker to the project is determined and the willingness of the decision maker forms the project markup.

For each project characteristic, a single attribute utility function, scaled between 0 and 1, is applied [24]. A multiple attribute utility function with each utility function weighted with a constant w_j (considering the relative importance among these attributes), calculates the bid project utility [7]. With the additive independence form of multiple attribute utility theory (MAU), the total utility is calculated with the additive formula: [28]

$$\sum_j w_j u(attribute_j) \qquad (44)$$

$$\sum_j w_j = 1 \qquad (45)$$

Determining project characteristics:

In a study by Schwartz and Vertinsky [27], six project characteristics are selected as the most important factors by the executives and R&D managers when making a decision in an R&D project selection. These are:

(1) Cost of the project relative to total R&D budget (COST);
(2) Payback period (PAYB)
(3) The probability of technical and commercial success (PSUC)
(4) Market share impact (MKT)
(5) Expected rate of return (ROR).
(6) Availability of government funding for the project (GOVT).

For the defense company under consideration, four of these attributes are relevant in decision making. However, the other two, namely, ‘Payback period’ and ‘Cost relative to total R&D budget’ are not considered in the decision making process of the company. The company prepares bids for production projects as well. These attributes can also be used in the decision making process for the production projects.

All in all, the company specific characteristics in pricing are selected as follows:

- **The probability of technical and commercial success:** One minus “the probability of technical success” is considered a technical risk for an R&D project. Technical risk is the probability of not being able to meet the technical specifications [25]. The commercial risk is not relevant in the defense industry, since production or R&D projects are held upon the request of customer. Probability of technical success will be used as a risk measure for the bid projects. R&D projects are more risky compared to the production projects, for which the probability of technical success is almost 100%.

- **Market share impact:** In R&D projects, new products have the impact of attracting new customers and increasing the market share. The expected know-how gain from the R&D projects is also taken into consideration by means of this attribute. The production projects are assumed to have no market share impact.
- **Availability of government funding for the project:** In Turkey, R&D projects are funded by the government. Some of the investment items and a fraction of employee taxes are funded by the government.
- **Expected rate of return:** Expected rate of return is a measure of profitability. A desired value for the expected rate of return which is not a restricting factor is determined by the decision makers. Other factors of the project may cause the expected rate of return to be below the desired value. By the consideration of all project attributes, willingness of the decision maker forms this attribute. With the uncertainties in the cost, rate of return is a stochastic variable.

Objective Function Parameters

Project characteristics

psuc	Probability of technical success of a project
mshare	Market share impact of a project
govf	Government funding percentage of a project

Weight of utility functions

w_{mshare}	Weight of the market share impact
w_{govf}	Weight of the government funding
w_{ror}	Weight of the rate of return

Probability of technical success

$R(psuc)$	Decision maker's risk function of the probability of technical success

Model robustness parameters

penalty	Expected penalty cost of the project derived from the Penalty-Model
gpw	Penalty rate for infeasibilities, that is, goal programming parameter

Solution robustness parameter

λ	Solution robustness parameter to penalize the deviation from the expected utility
$vminus(bp,s)$	Difference of the ROR utility for a given scenario and a bid price from the expected utility

In order to make a differentiation between the production projects and the R&D projects, the probability of technical success will be used as a risk factor for the bid project. As the risk increases, the project performance and the willingness of the decision maker decreases. The decision maker's attitude towards risk will form the risk function. With the concept of probability of success, the project performance, Z, can be calculated as in Pillai et al. [25]:

$$Z = (1 - risk)^b f(otherfactors),$$

where 'risk' term is the risk in percentage, 'b' is a constant that forms the attitude of decision maker towards risk.

Risk function of *'probability of success'* in our objective function can be built based on the above formula:

$$R(psuc) = (1 - risk)^b = (psuc)^b$$

Then total utility of project attributes multiplied with the project risk function becomes:

$$R(psuc)\sum_j w_j u(attribute_j) \tag{46}$$

In a more detailed representation, the objective function's first part can be formed by the below formula (47); the total utility of the project is multiplied with the risk function.

$$R(psuc)\left(w_{mshare}u(mshare) + w_{govf}u(govf) + w_{ror}u(ror)\right) \tag{47}$$

Since the rate of return (ROR) is a stochastic variable, utility of ROR is also stochastic. In the first part of the objective function, there is a need for the expected ROR. Rate of return, utility of ROR and expected utility of ROR are expressed in (48),(49), respectively.

$$ror(bp,s) = \left(BIDPRICE - CO(s)\right)/CO(s) \qquad \forall bp,s \tag{48}$$

Utility of ROR is a function of the bid price and changes of cost in a scenario also changes the utility of ROR.

$$E(u(ror(bp))) = \sum_{s} u(ror(bp,s))p(s) \qquad\qquad \forall bp, s \qquad\qquad (49)$$

Then the first part of the objective function becomes:

$$R(psuc)(w_{mshare}u(mshare) + w_{govf}u(govf) + w_{ror}E(u(ror(bp)))) \qquad\qquad (50)$$

Now the objective function can be totally formed. Objective function consists of four parts: maximization of the expected project utility, minus the deviation of utility of ROR penalized by the solution robustness term, minus the penalty cost weighted by a goal programming parameter *gpw* and minus the expected financial cost minimization (EFINCO) divided by a very big number (BIGM) to form the cash flow decisions without affecting the objective function.

$$\begin{aligned}
&maximize \\
&\sum_{bp} x(bp)\ pow(bp)\ R(psuc) \sum_{s} \left(u(mshare)\ w_{mshare} + u(govf)\ w_{govf} + E(u(ror(bp)))\ w_{ror}\right) \\
&- \lambda \sum_{bp} x(bp)\ pow(bp) \left(\sum_{s} p(s) \left(vminus(\mathrm{bp,s})\ / E(u(ror(bp)))\ \right)^{0.5} \right) \\
&- gpw \left(\sum_{bp} x(bp)\ pow(bp)\ penalty \right) - EFINCO\ /\ BIGM \qquad\qquad (51)
\end{aligned}$$

vminus is the deviation of the scenario utility of ROR from the expected utility of ROR. Only negative deviations are penalized by the solution robustness term.

$$vminus(bp,s) = \left(E\left(u\left(ror\left(bp\right)\right)\right) - u(ror(bp,s))\right) \rightarrow u(ror(bp,s)) - E\left(u\left(ror\left(bp\right)\right)\right) < 0 \qquad \forall bp, s \quad (52)$$

Then $vminus(bp,s) > 0$ is penalized only.

Equation (53) is the requirement of making only one bid.

$$\left(\sum_{bp} x(bp)\right) = 1 \qquad (53)$$

Assignment of weights to the project characteristics

A questionnaire is prepared and filled out by several managers and responsible personnel in the company to determine the weights of project characteristics, as in the study of Schwartz and Vertinsky [27]. In Table 5, the results of the questionnaire are shown. Weights of the utility functions, $w_{mshare}, w_{govf}, w_{ror}$, for the company are determined through this questionnaire. Market share impact, w_{mshare}, is the top rated project characteristic by the company's decision makers, having a value of 0.417. The order of significance of the attributes is as follows:

1. Market share impact – weight = 0.417
2. Rate of return – weight = 0.349
3. Government funding – weight = 0.235

In the questionnaire, managers and responsible personnel in the company are asked to give a score out of 10 to each of the three project characteristics. The scores of the personnel are given in Table 5 below.

Converted weight of market share is calculated as dividing the sum of market share score (128) by the total score of the three project characteristics (307). The other converted weights' calculations are done by dividing their respective scores to the total score.

Table 5- Relative scores given to the project characteristics (out of 10)

Name	**Position**	**Market Share Impact**	**Government Funding**	**Expected Rate of Return**
S.A.	Project Manager	9	5	7
C.C	Project Manager	9	1	5
E.K	Finance Manager	8	5	10
K.O	Senior Cost Accountant	8	5	10
C.O	Production Manager	7	5	8
C.S	Bid Responsible	8	3	7
L.T	Project Manager	9	6	8
E.P	Project Manager	8	3	5
D.B	Project Responsible	10	8	5
S.E	Project Responsible	10	5	8
B.C	Project Responsible	9	5	7
D.S	Project Tech. Responsible	9	5	7
M.I	Production Planner	7	4	7
E.A	Production Planner	10	5	7
L.C	Project Manager	7	7	6
Total		128	72	107
Converted Weight		0.417	0.235	0.348

Utility functions for the project characteristics

For single parameter utility functions, popular form of the single-attribute utility function is used as in Clemen [13,19]:

$$u_i(x_i) = A_i + B_i(e^{x_i RT_i})$$

where RT_i is the decision maker's assessed risk tolerance, A_i and B_i are the scaling constants for the measure i, and x_i is the value of i^{th} measure. Since it is flexible enough to model a wide variety of preferences, single parameter exponential utility function is commonly used [7].

Market share impact:

According to the questionnaire held in the company, a range or a single value weight for the market share impact is defined as hard to identify. After the recommendations of the company experts, market share impact is constructed as an index between values 0 and 5 (as the highest impact).

Market share impact utility is considered to be calculated as a linear utility function:

$$u(mshare) = mshare / 5 \tag{54}$$

Availability of government funding for the project:

The government funds to the defense industry projects up to 60 % of total costs. Because of this, a linear utility function is formed in the range of 0 to 0.6.

$$u(govf) = govf / 0.6 \tag{55}$$

Expected rate of return:

15% of ROR is the desired value that is specified by the board of directors; however, this value can fall to -5% (loss) depending on the other project characteristics. Range for ROR is selected as -5% to

30%. 15% ROR is the desired value for top managers with the utility of 0.5.

Three different behaviors for the utility of ROR have been observed through the meetings of the questionnaire:

More Prone to 15%: Since 15% is the desired value, values below 15% are prevented by a fast decrease in utility. Also ROR values above 15% are welcomed by a fast increase in the utility. ROR below 0% have the utility of 0.

Around 15% sufficient: Values around 15% are considered as the desired value. Variations from 15% ROR change the utility slowly, and then it fastens.

Linear: ROR is a monetary term so it can be treated by a linear utility function.

ROR utility functions can be built according to these parameters:

RA, RB, RC	Scaling factors for ROR
$ROR_{\max}$	ROR value where utility is maximum
ROR_{des}	Desired ROR value

More Prone to 15%:

$$u(ror(bp,s)) = \max\Big(\min\Big(\Big(RA - RB\, e^{\max((ROR_{\max} - ror(bp,s)),0)^2}\Big), 1\Big), 0\Big) \forall bp, s \quad (56)$$

Linear:

$$u\left(ror(bp,s)\right) = \max\left(\min\left(\left(ror(bp,s) / ROR_{\max}\right), 0\right), 1\right) \qquad \forall bp,s \quad (57)$$

Around 15% sufficient:

$$u\left(ror(bp,s)\right) = \max\left(\min\left(\left(RA - RB\, e^{(ROR_{des} - ror(bp,s))^2 / RC\, sign(ROR_{des} - ror(bp,s))}\right), 1\right), 0\right) \qquad \forall bp,s \quad (58)$$

Clemen's [8] utility function model is used as a base to develop the utility functions of ROR which are shown in the Figure 11 below.

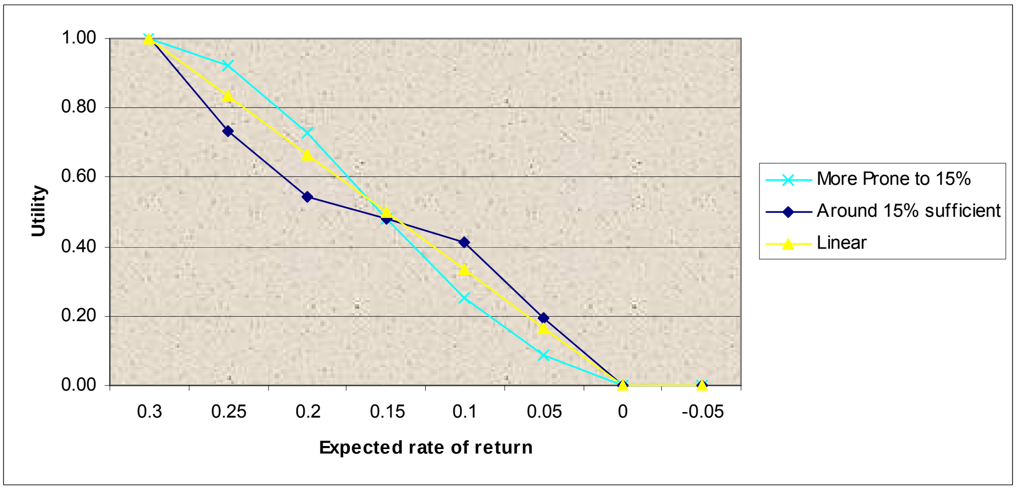


Figure 11-Three different observed ROR utility functions

Risk Function of Probability of Technical Success

Schwartz and Vertinsky [27] state that probability of technical success for projects undertaken are averaged between 71% and 80%, based on the studies of Mansfield [18] and Gerstenfeld [14].

After the meetings held and questionnaires conducted in the company, the minimum probability of technical success for a project to be accepted is determined as 70% for the company. Projects with probability of technical success values less than 70% are not preferred by the decision makers.

To analyze the problem, three different risk functions are formed. Since projects with 70% of success probability are undertaken, 60% of success probability is assumed to be the lowest level of preference. The decision maker's risk preference depends on the project's characteristics, such as project's engagements and failure penalties.

Risk Function Parameters

PA, PB, PC	Scaling factors for the risk function
$PSUC_{acc}$	Minimum acceptable probability of success value

Three different risk functions can be modeled as it is shown in Figure 12.

Risk Seeking: A concave risk function defined between 60% and 100% of probability of technical success:

$$R(psuc) = PA - \left(PB\, e^{-psuc / PSUC_{acc}}\right) \tag{59}$$

Risk Neutral: A linearly decreasing risk function down to 60% from 100%:

$$R(psuc) = PA - \left(PB\ psuc / PC\right) \tag{60}$$

Risk Averse: A convex risk function defined between 60% and 100% of probability of technical success:

$$R(psuc) = PA - \left(PB\ psuc^{PC}\right) \qquad (61)$$

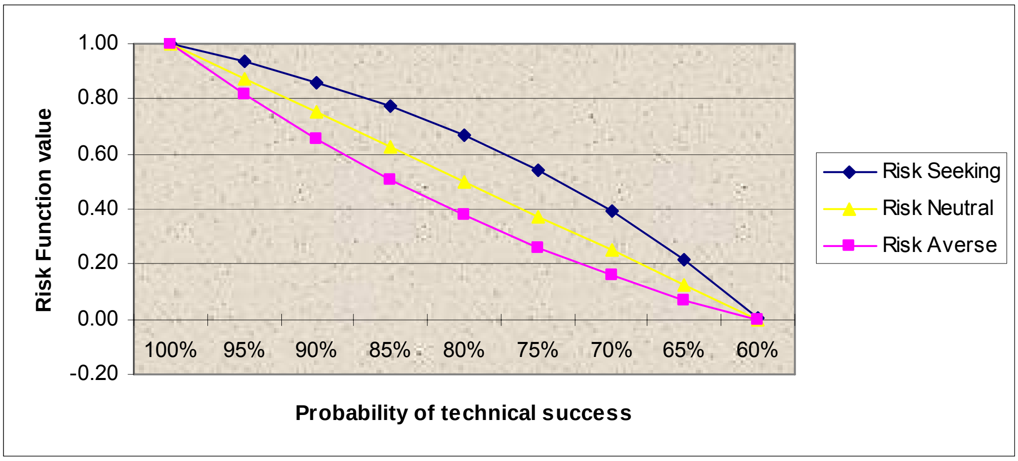


Figure 12- Three different risk functions

Forming the Probability-of-Win (pow) function

In defense industry most of the R&D projects are unique. The number of companies that have the capability of meeting the project requirements or that are allowed to operate in defense industry is limited. In the defense projects, bid firms face less competitors compared to the commercial business bids. However, winning a certain bid still includes many uncertainties.

In order to take the company's environment into account, the factors that affect the probability of winning is determined by several meetings with the bid responsible and a project manager in the company.

Factors that affect the probability of winning (pow) a bid:

Capability of the firm: If the firm has already got experienced with products similar to the required final product of the bid project, it is a positive factor that increases the probability of winning.

Competitors: Customer may be working with several contracting firms and bid has lower probability of winning in such a competitive environment.

Reference: Customer and the company may have relationships in the previous projects. This is a positive factor in the probability of winning function when the performance of the company in the project is at a satisfactory level and a negative factor if the company can not achieve the project requirements.

Industrialization of the country: When working with the Ministry of Defense of Turkey, this factor increases the probability of winning.

Price: Price is the main determinant of the probability of winning a bid.

In Naert and Weverberg [23] and Friedman [12], probability of winning is a function of cost estimate and markup. The functions of probability of winning in these studies are used to construct the probability of win function (Figures 13 and 14). In Figure 13, σ_x represents the level of uncertainty with the assumption that X is normally distributed with mean $\mu_x = 1$, and five different levels of uncertainty are considered as: $\sigma_x = 0.05, 0.075, 0.10, 0.125$ and 0.15.

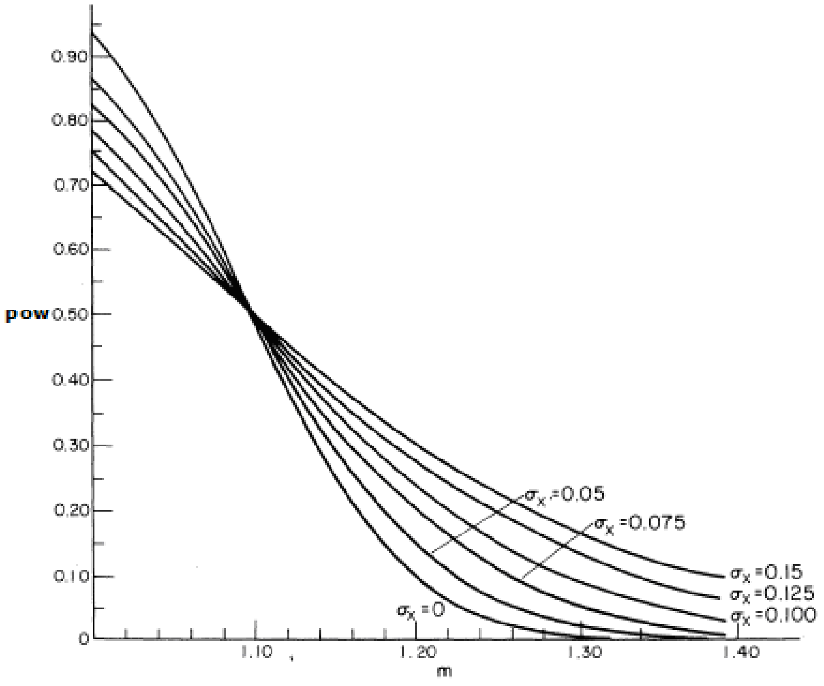


Figure 13- Probability of win (pow) as a function of markup (m)

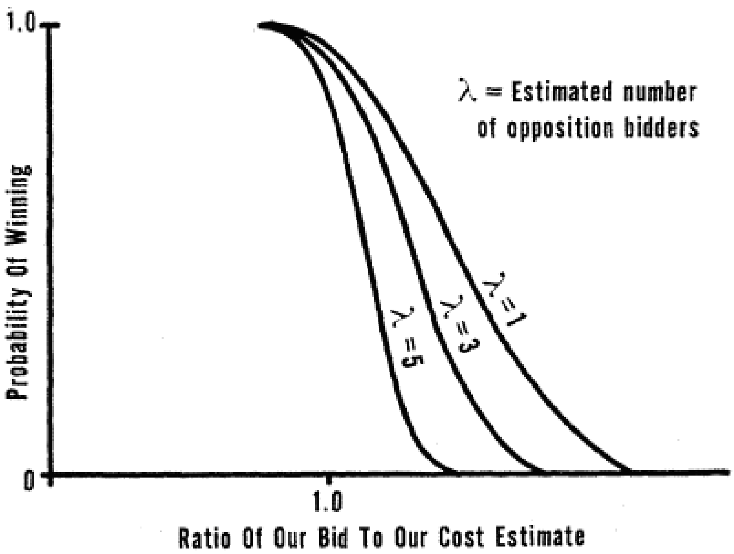


Figure 14- Probability of win as a function of ratio of bid to the cost estimate

It is assumed to be unbiased for the cost estimate of both the customer and the company. A function is formed by considering the above factors that affect pow.

pow Parameters

d	Scaling factor to represent the environment, (-80 for high pow environment, -40 for low pow environment)
ref	Reference factor (includes capability of the firm, reference company and industrialization effect of the country)
C	Number of competitors for the bid (When there is no other firm competing for the bid, C is set to 1)

Then the probability of winning for certain conditions can be expressed as follows:

$$pow(bp) = 1 - ((1 - ref)e^{(HBP-bp)^2/(HBP^2/d)})(C)^{0.25} \qquad \forall bp \quad (62)$$

where HBP is the highest bid price defined before.

In Figures 15 and 16, a total of 12 pow functions are shown developed based on an example bid project.

These pow functions are developed from the concepts of Naert-Weverberg's and Friedman's probability of win function shape. In order to build the company's sample pow functions, the constants such as scaling factor d and reference factor ref are determined after consulting the bid responsible.

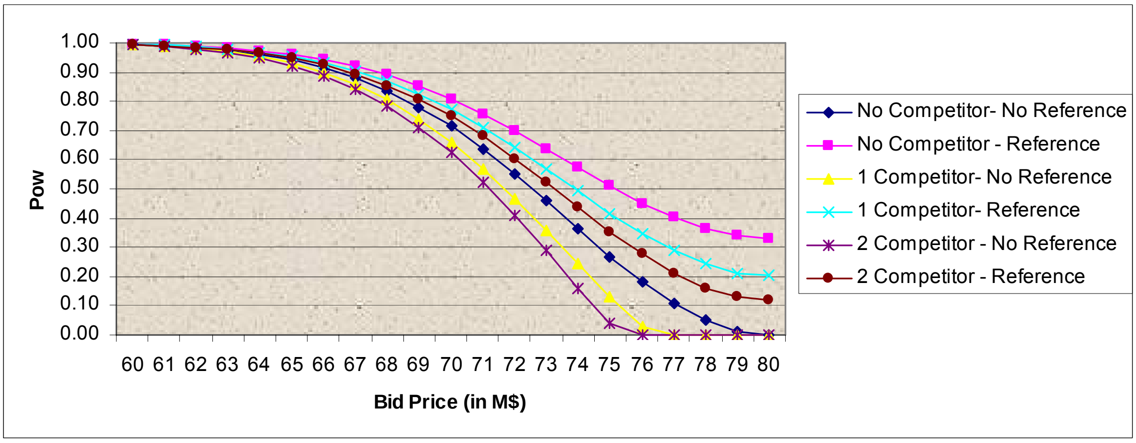


Figure 15- pow for 6 different situations (d=-80,high pow environment)

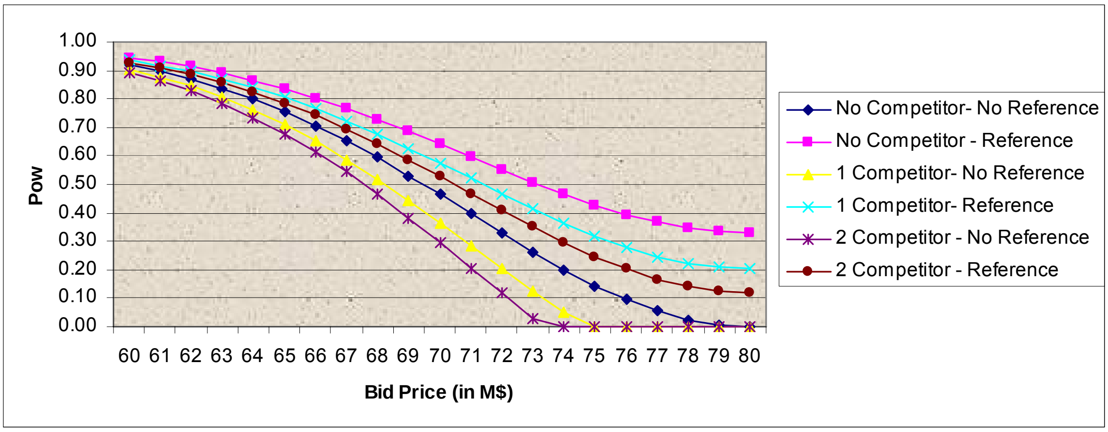


Figure 16- pow for 6 different situations (d=-40, low pow environment)

For the selected utility and risk functions, our Robust Optimization Model is then as follows:

maximize

$$\sum_{bp} x(bp)\ pow(bp)\ R(psuc) \sum_{s} \left(u(mshare)\, w_{mshare} + u(govf\,)\, w_{govf} + E(u(ror(bp)))\, w_{ror}\right)$$

$$-\lambda \sum_{bp} x(bp)\ pow(bp) \left(\sum_{s} p(s) \left(vminus(\mathrm{bp,s})\ / E(u(ror(bp))) \right)^{0.5} \right)$$

$$-gpw \left(\sum_{bp} x(bp)\ pow(bp)\ penalty \right) - EFINCO/BIGM$$

s.t

$$PLC(s) = \sum_{t} \left(\sum_{i} l(i) pw(i,t)\ techrisk(s) \right) cuminfl(s,t) / exch(s,t) \qquad \forall s$$

$$PMC(s) = \sum_{t} \left(M(t) cuminfl(s,t) / exch(s,t) \right) + MC(t) \qquad \forall s$$

$$PIC(s) = \sum_{t} \left(INV(t) cuminfl(s,t) / exch(s,t) \right) + INVC(t) \qquad \forall s$$

$$PMISCC(s) = \sum_{t} \left(MISC(t) cuminfl(s,t) / exch(s,t) \right) + MISCC(t) \qquad \forall s$$

$$CO(s) = PLC(s) + PMC(s) + PIC(s) + PMISCC(s) + FIN \qquad \forall s$$

$$EC = \sum_{s} CO(s) p(s)$$

$$PCOST(s,t) = \left(\sum_{i} l(i)\ pw(i,t)\ techrisk(s) \right) + M(t) + INV(t) + MISC(t) \qquad \forall s,t$$

$$PCOSTC(t) = MC(t) + INVC(t) + MISCC(t) \qquad \forall t$$

$$FinCO(s,t) = B(s,t-1)\big(br(s,t-1)-1\big) - Lend(s,t-1)\big(lr(s,t-1)-1\big) \qquad \forall s,t$$

$$FinCOC(s,t) = BC(s,t)\big(brc(s,t)-1\big) - LendC(s,t)\big(lrc(s,t)-1\big) \qquad \forall s,t$$

$$TFinCO(s,t) = FinCOC(s,t) + FinCO(s,t)/exch(s,t) \qquad \forall s,t$$

$$\begin{aligned} &CNV(s,t)\,exch(s,t) + B(s,t) - Lend(s,t) - B(s,t-1) + Lend(s,t-1) \\ &= PCOST(s,t) + FinCO(s,t) \end{aligned} \qquad \forall s,t$$

$$\begin{aligned} &PC(t)\,BIDPRICE - CNV(s,t) + BC(s,t) - BC(s,t-1) - LendC(s,t) \\ &+ LendC(s,t-1) = PCOSTC(t) + FinCOC(s,t) \end{aligned} \qquad \forall s,t$$

$$PFinCO(s) = \sum_t TFinCO(s,t) \qquad \forall s$$

$$EFinCO = \sum_s PFinCO(s)p(s)$$

$$EFinCO \le FIN$$

$$ror(bp,s) = \big(BIDPRICE - CO(s)\big)/CO(s) \qquad \forall bp,s$$

$$u\big(ror(bp,s)\big) = \max\Big(\min\Big(\Big(RA - RB\,e^{\max((ROR_{\max} - ror(bp,s)^2),0)}\Big),1\Big),0\Big) \qquad \forall bp,s$$

$$E\big(u\big(ror\big(bp\big)\big)\big) = \sum_s u\big(ror(bp,s)\big)p(s) \qquad \forall bp,s$$

$$u(mshare) = mshare/5$$

$$u(govf) = govf/0.6$$

$$R(psuc) = PA - \Big(PB\,e^{-psuc/PSUC_{acc}}\Big)$$

$$pow(bp) = 1 - ((1-ref)e^{(HBP-bp)^2/(HBP^2/d)})(C)^{0.25} \qquad \forall bp$$

$$vminus(bp,s) = \left(E\left(u\left(ror\left(bp\right)\right)\right) - u(ror(bp,s))\right) \rightarrow u(ror(bp,s))\text{-}E\left(u\left(ror\left(bp\right)\right)\right) < 0 \qquad \forall bp,s$$

$$CNV(s,t) \geq 0 \qquad \forall s,t$$

$$B(s,t) \geq 0 \qquad \forall s,t$$

$$BC(s,t) \geq 0 \qquad \forall s,t$$

$$Lend(s,t) \geq 0 \qquad \forall s,t$$

$$LendC(s,t) \geq 0 \qquad \forall s,t$$

$$\left(\sum_{bp} x(bp)\right) = 1$$

The relation between Penalty-Model and Robust Optimization model is shown in Figure 17.

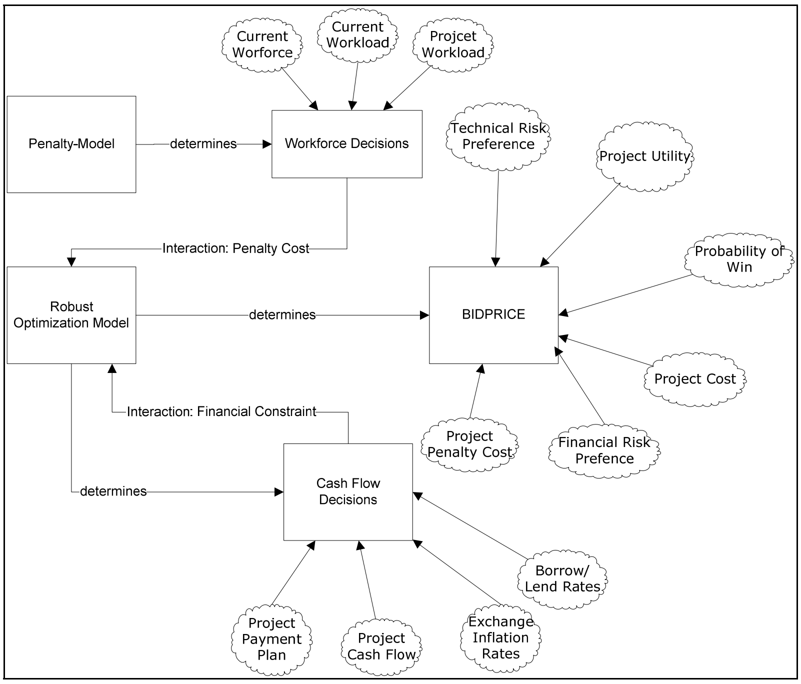


Figure 17- The relation between Penalty-Model and Robust Optimization Model

The influence diagram of the Robust Optimization Model is shown in Figure 18.

In the next chapter, we describe the scenarios (s) that we include in the Robust Optimization Model.

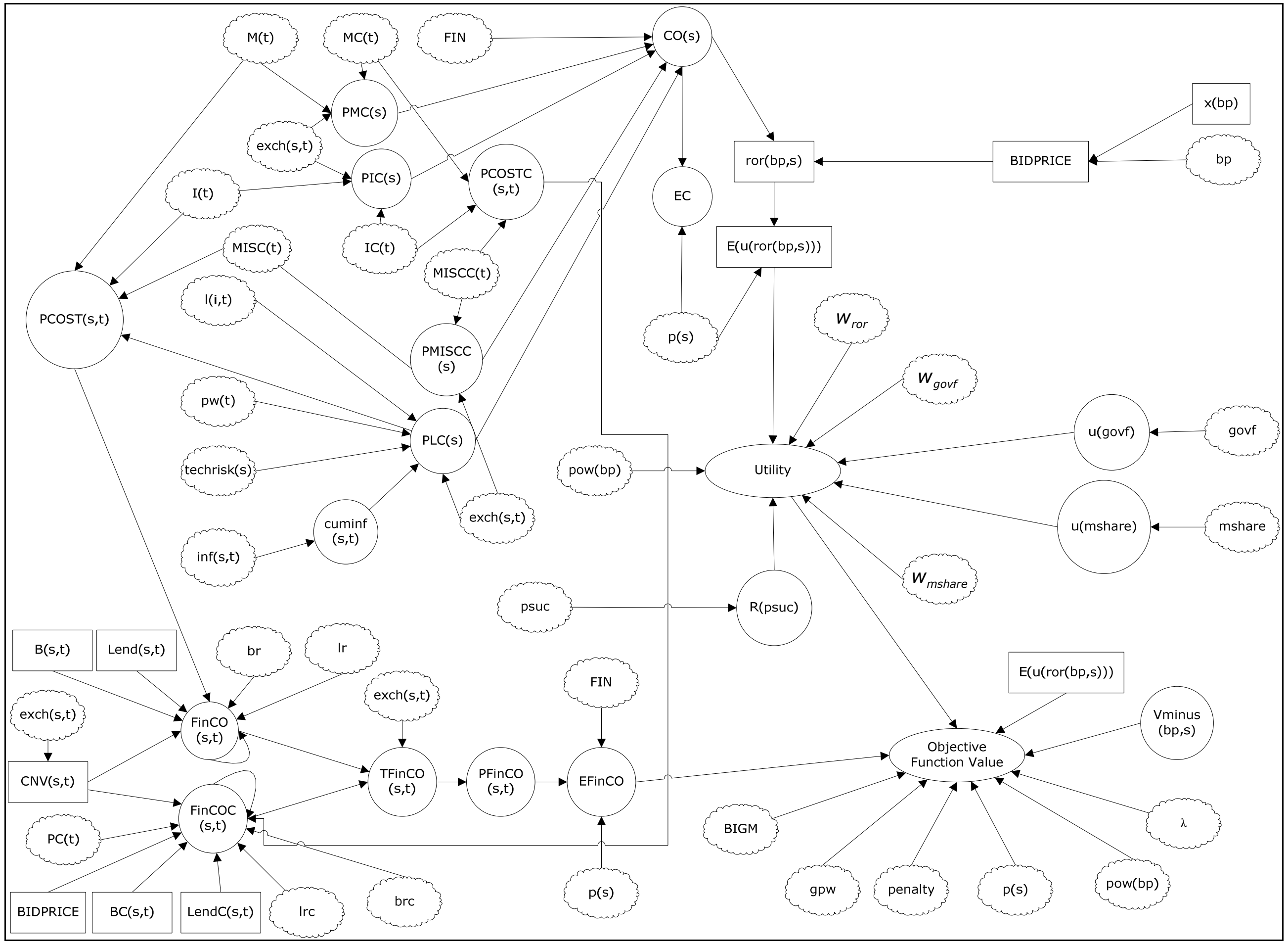


Figure 18- Influence diagram of the Robust Optimization model

CHAPTER 5

SCENARIO GENERATION

5.1. Financial Risk Scenarios

Uncertainty in long-term project pricing mainly stems from the monetary values, as the exchange rate and the inflation rate, which are used in the phase of bid preparation. Uncertainties in the exchange rate and the inflation rate are identified as the financial risk.

For the uncertain parameters, several scenarios are generated. The time horizon is selected as 5 years, in other words, project lifecycle is assumed to be 5 years. In order to predict exchange rate and inflation rate values, the company requests predictions for USD, EUR and consumer price indices for 5 years ahead from the national and international banks. Some of the predictions given by the banks are complete, while some of them are only for 3 years or less. Incomplete data are filled with some estimations based on the complete data. A total of 14 scenarios are generated:

- 6 scenarios based on the predictions of the six banks given in September 2009

- 2 scenarios based on the predictions of two banks given in March 2010
- 1 scenario based on the average of the banks' predictions given in September 2009
- 1 scenario based on the assumption of 5% increase in the average of the banks' predictions given in September 2009
- 1 scenario based on the average of the banks' predictions given in March 2010
- 1 scenario based on the assumption of 5% increase in the average of the banks' predictions given in March 2010
- 2 scenarios based on yearly ratios for 2005 to 2009 and 5% increase over these yearly values to estimate years 2010 to 2014

The 14 scenarios generated, reflecting the possible outcomes for years 2010 to 2014, are assumed to have identical probabilities of occurrence.

Bid project currency code is assumed to be USD and labor wages are assumed to increase by the yearly consumer price index changes. Also, a crisis scenario for the company affecting the bid project's cost is generated. In this scenario, it is assumed that exchange rate for the bid project's currency code does not increase in the following 5 years and consumer price index increases by the average of the 14 scenarios. This scenario is assigned a lower probability of 2%.

Scenario 1: First scenario values are the averages of the estimated values of the six national and international banks. Some of the banks cannot give all 5 years estimates. Averages are calculated for the years for which estimates are given.

Scenario 2: A 5% increase in the exchange and inflation rates is assumed to generate this scenario from scenario 1.

Scenario 3: Garanti Bank's expected values are used in this scenario. However, Garanti Bank has only 2 years' estimations for USD exchange rate and inflation rate. Rate of change from 2011 to 2012 is calculated by the other banks' rate of change, from considering the banks' asset size. Missing values of other years' estimations by Garanti Bank is filled with this approach.

Scenario 4: TEB has estimations for 4 years. The 4th year estimations for the inflation rate is the minimum among the other banks' estimations. Other banks' estimations for the rate of change in inflation may cause inflation rate to be unrealistic (too small). So the 5th year inflation rate is assumed to be the same as the 4th year. Exchange rate estimation method is the same as in scenario 3.

Scenario 5: ING bank has estimations for 3 years. The data filling method for the missing exchange rates for the remaining two years is the same as in scenarios 3 and 4. Considering the banks' asset size, rate of change for the next year is the arithmetic average of other banks' rates of change.

Scenario 6: HSBC Bank has also complete estimations for 3 years. Assumption to fill the incomplete data is the same as in scenario 5.

Scenario 7: FORTIS Bank end–of-year estimates for the exchange rate are complete. Yearly averages are assumed to be the average of the last two years' end-of-year values. Inflation rate prediction is not given for the 5th year. Since the 4th year value is the minimum among others, the 5th year value for the inflation rate is assumed to be the same as the 4th year.

Scenario 8: İşbank has two periodical estimations in these scenarios. First one is prepared in September 2009. 5 years' estimations for the exchange and inflation rates are complete for İşbank. The second periodical estimation is explained at Scenario 11.

Scenario 9: Only two banks' estimations by İşbank and Garanti Bank are averaged in March 2010.

Scenario 10: A uniform 5% increase in the average of estimations by banks, prepared in March 2010, is assumed to generate this scenario.

Scenario 11: İşbank's second prediction is made in March 2010. All estimations are complete.

Scenario 12: Garanti Bank's other estimations are made in March 2010. Estimations are missing for years 2013 and 2014. Since March 2010 predictions include only two banks, İşbank's rates of change for years 2013 and 2014 are used to estimate for Garanti Bank.

Scenario 13: In this scenario, January 1 2010 exchange rate value is taken as the base value for prediction of next 5 years' exchange rates. Then, change ratios between 2004 to 2009 are used to estimate future values between 2010 to 2014 (Table 6).

For inflation rate prediction, consumer price index values for years 2005 to 2009 are directly used to estimate future values for years 2010 to 2014.

Table 6- Estimations for years 2010 to 2014 based on TCMB values for years 2004-2009

Year	**USD Exchange rate**	**Rate of Change**
2004	1.42	
2005	1.34	0.94
2006	1.43	1.07
2007	1.30	0.91
2008	1.29	0.99
2009	1.55	1.20
2010	1.46	0.94
2011	1.56	1.07
2012	1.42	0.91
2013	1.41	0.99
2014	1.68	1.20

Table 7- Estimations for years 2010 to 2014 based on TÜİK values for years 2004-2009

Year	Inflation Rate	Consumer Price Index (2003=100)
2004	1.094	120.16
2005	1.077	129.42
2006	1.097	141.93
2007	1.084	153.84
2008	1.101	169.33
2009	1.065	180.37
2010	1.077	194.28
2011	1.097	213.06
2012	1.084	230.94
2013	1.101	254.18
2014	1.065	270.77

Scenario 14: The same approach as scenarios 3 and 10, but a 5% increase in exchange and inflation rates is assumed to generate this scenario.

Scenario 15: No increase in exchange rate, an unexpected USD exchange rate for the company, consumer price index increase by the average of other scenarios. In terms of project currency code, project cost increases by an unexpected amount, since labor wages are paid in national currency code and there are other expenditures which are budgeted in national currency code.

All 15 scenarios generated based on financial characteristics are listed in Table 8 below.

Table 8- Financial scenarios and descriptions

Scenario	**Prob.**	**Scenario Description**
1	7%	Average of estimated bank values prepared in September-2009
2	7%	The same pattern with scenario 1 but with 5% increase
3	7%	Garanti Bank estimated values prepared in September-2009
4	7%	TEB estimated values prepared in September-2009
5	7%	ING Bank estimated values prepared in September-2009
6	7%	HSBC Bank estimated values prepared in September-2009
7	7%	FORTIS Bank estimated values prepared in September-2009
8	7%	İşbank estimated values prepared in September-2009
9	7%	Average of estimated bank values prepared in March-2010
10	7%	The same pattern with scenario 9 but with 5% increase
11	7%	İşbank estimated values prepared in March-2010
12	7%	Garanti Bank estimated values prepared in March-2010
13	7%	Starting with 01-01-2010, yearly ratios 2005-2009 used for estimates
14	7%	The same pattern with scenario 13 but with 5% increase
15	2%	Unexpected USD rate with an increase in consumer prices index

Scenario values for inflation rate, consumer price index values, are listed below in Table 9.

Scenario values for USD exchange rate, bid project currency code, are listed below in Table 10.

Table 9- Scenario values for inflation rate (consumer price index)

Scenario	**Prob.**	**Inflation Rate**				
		2010	**2011**	**2012**	**2013**	**2014**
1	7%	6.5%	6.1%	5.5%	4.6%	5.5%
2	7%	6.8%	6.4%	5.8%	4.8%	5.8%
3	7%	5.8%	6.3%	6.1%	5.5%	5.3%
4	7%	6.4%	6.3%	6.0%	4.0%	4.0%
5	7%	6.0%	6.0%	5.4%	4.9%	4.7%
6	7%	7.7%	6.5%	5.9%	5.3%	5.1%
7	7%	6.5%	5.5%	4.0%	4.0%	4.0%
8	7%	6.5%	6.0%	6.2%	5.7%	5.5%
9	7%	7.4%	6.9%	6.8%	6.5%	5.5%
10	7%	7.8%	7.2%	7.1%	6.8%	5.8%
11	7%	7.0%	7.5%	8.0%	6.5%	5.5%
12	7%	7.9%	6.3%	5.6%	4.6%	3.9%
13	7%	7.7%	9.7%	8.4%	10.1%	6.5%
14	7%	8.1%	10.1%	8.8%	10.6%	6.9%
15	2%	7.0%	6.9%	6.4%	6.0%	5.3%

Table 10– Scenario values for exchange rate (USD value)

Scenario	Prob.	Exchange Rate				
		2010	2011	2012	2013	2014
1	7%	1.56	1.66	1.66	1.80	1.91
2	7%	1.64	1.75	1.75	1.89	2.01
3	7%	1.50	1.60	1.45	1.44	1.73
4	7%	1.57	1.68	1.53	1.52	1.81
5	7%	1.55	1.61	1.64	1.71	1.81
6	7%	1.61	1.96	1.76	1.81	1.92
7	7%	1.46	1.54	1.54	1.61	1.70
8	7%	1.61	1.58	1.53	1.60	1.70
9	7%	1.62	1.66	1.68	1.69	1.71
10	7%	1.56	1.63	1.70	1.79	1.91
11	7%	1.52	1.61	1.73	1.85	1.96
12	7%	1.55	1.61	1.69	1.79	1.90
13	7%	1.46	1.56	1.42	1.41	1.68
14	7%	1.53	1.63	1.49	1.48	1.77
15	2%	1.46	1.46	1.46	1.46	1.46

5.2. Technical Risk Scenarios

There are also technical risks involved when preparing a bid for a long term project; which result in not being able to realize the project with the pre-determined budgeted work-hour, material, investment and other expenses. If the bid project is in a new area for the company, technical risk in the work-hour predictions may be very high. We identify three levels of uncertainty for R&D projects in the work-hours required: expected, 5% more work-hours needed and 10% more work-hours needed. Production projects are assumed to have no technical uncertainty.

Departments are assumed to estimate the correct work-hours for 50% of the time. "5% more work-hours required" situation is assumed to occur 30% of the time and "10% more work-hours required" situation is assumed to occur 20% of the time.

Table 11- Scenarios for technical risk (work-hour needed)

Scenario	Probability	Value
Expected	50%	0%
5% more work-hours needed	30%	5%
10% more work-hours needed	20%	10%

15 financial risk scenarios combined with 3 technical risk scenarios result in 45 scenarios. Scenario probabilities, then, are calculated by multiplying financial risk scenario probability with the technical risk scenario probability.

Developed “Unexpected exchange rate” scenario is not likely for the current economic conditions. The purpose of generating an unexpected scenario is to check whether the robust solution has preventive actions when probability of this scenario is increased up to 30% in the sensitivity analysis section.

CHAPTER 6

COMPUTATIONAL RESULTS

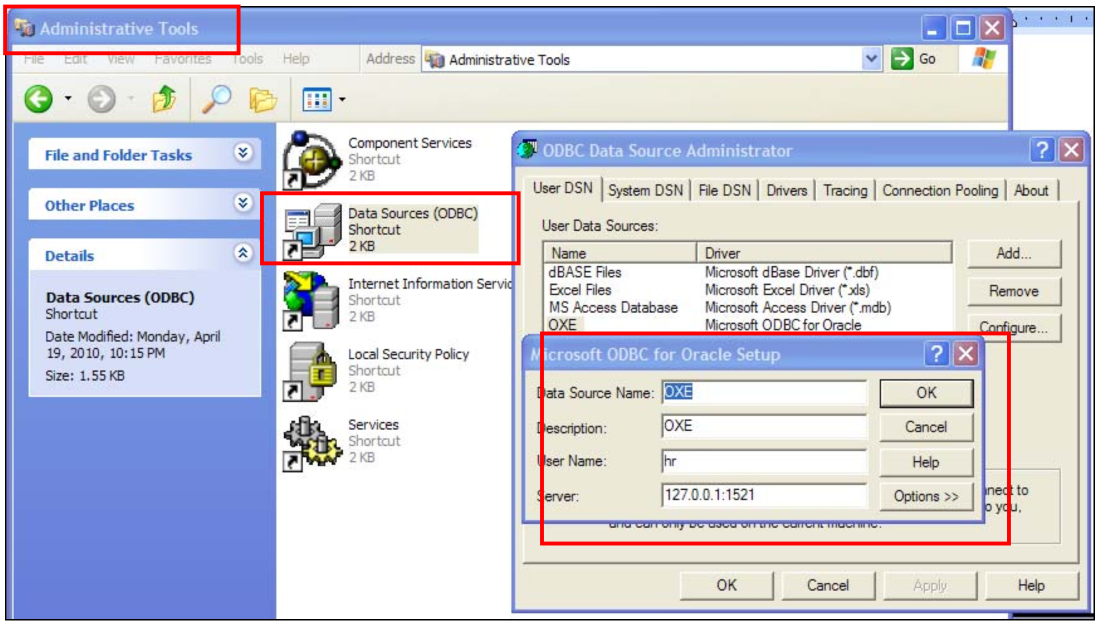
6.1. Development of the software

The Penalty-Model and Robust Optimization Model are developed in GAMS version 23.02. The company uses Oracle ERP; hence all data are stored in Oracle Database 10g. Since parameters are retrieved from Oracle Database, the mathematical models are so designed that they can communicate with Oracle Database.

Integrating GAMS with Oracle Database

Firstly, GAMS models are run in Windows platform. To retrieve data from the database, there should be a data source description in User Data Source Name (DSN) section through Windows Data Sources (ODBC) (Figure 19).

In the GAMS code, the User DSN is used for Database connection. As an example, in Figure 20 GAMS and Oracle Connection code, C refers to Connection parameter, while Q refers to script to be queried and O refers to the output file.



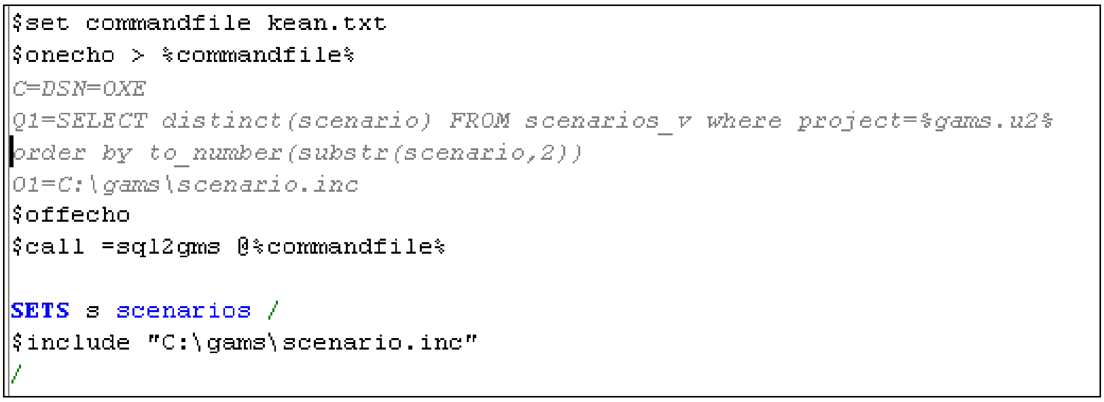
Data Sources (ODBC)
Shortcut
Date Modified: Monday, April 19, 2010, 10:15 PM
Size: 1.55 KB

User Data Sources:

Name	Driver
dBASE Files	Microsoft dBase Driver (*.dbf)
Excel Files	Microsoft Excel Driver (*.xls)
MS Access Database	Microsoft Access Driver (*.mdb)
OXE	Microsoft ODBC for Oracle

ata Source Name: OXE
escription: OXE
ser Name: hr
erver: 127.0.0.1:1521

Figure 19- User Data Source Description for Windows



```
$set commandfile kean.txt
$onecho > %commandfile%
C=DSN=OXE
Q1=SELECT distinct(scenario) FROM scenarios_v where project=%gams.u2%
order by to_number(substr(scenario,2))
O1=C:\gams\scenario.inc
$offecho
$call =sql2gms @%commandfile%

SETS s scenarios /
$include "C:\gams\scenario.inc"
/
```

Figure 20- Example of a GAMS-Oracle Database Connection script

Database Design Schema

For handling parameters in Oracle database, a database design is held in Oracle, which is shown in Figure 21.

Flowchart of the Solution Approach

Solution approach, GAMS-Oracle Database integration, Penalty-Model and Robust Optimization Model flows are shown in Figure 22.

6.2. Bid Project Cases

In order to analyze different project characteristics, model runs are held with 3 different project types. The case projects are based on a real R&D project with a high-level of market share expectation CP, a big real R&D project with a low probability of technical success GJ, and a real production project PM of the company.

In order to decide on the case projects, factors to be observed are project cost scale, market share impact and project technical probability of success. Projects which have significant levels for these factors will help to understand the model behavior better.

Projects analyzed

Project CP:

CP is a R&D project in a new area for the company, having 85% of probability of success. Market share impact is expected to be very high, 4 over 5 points. Since the customer is foreign, there is no government funding. Expected cost of Project CP is 60 M $. The highest bid price that the customer restricts the company with is 80 M $. This case project’s most descriptive factor is the market share impact of the project.

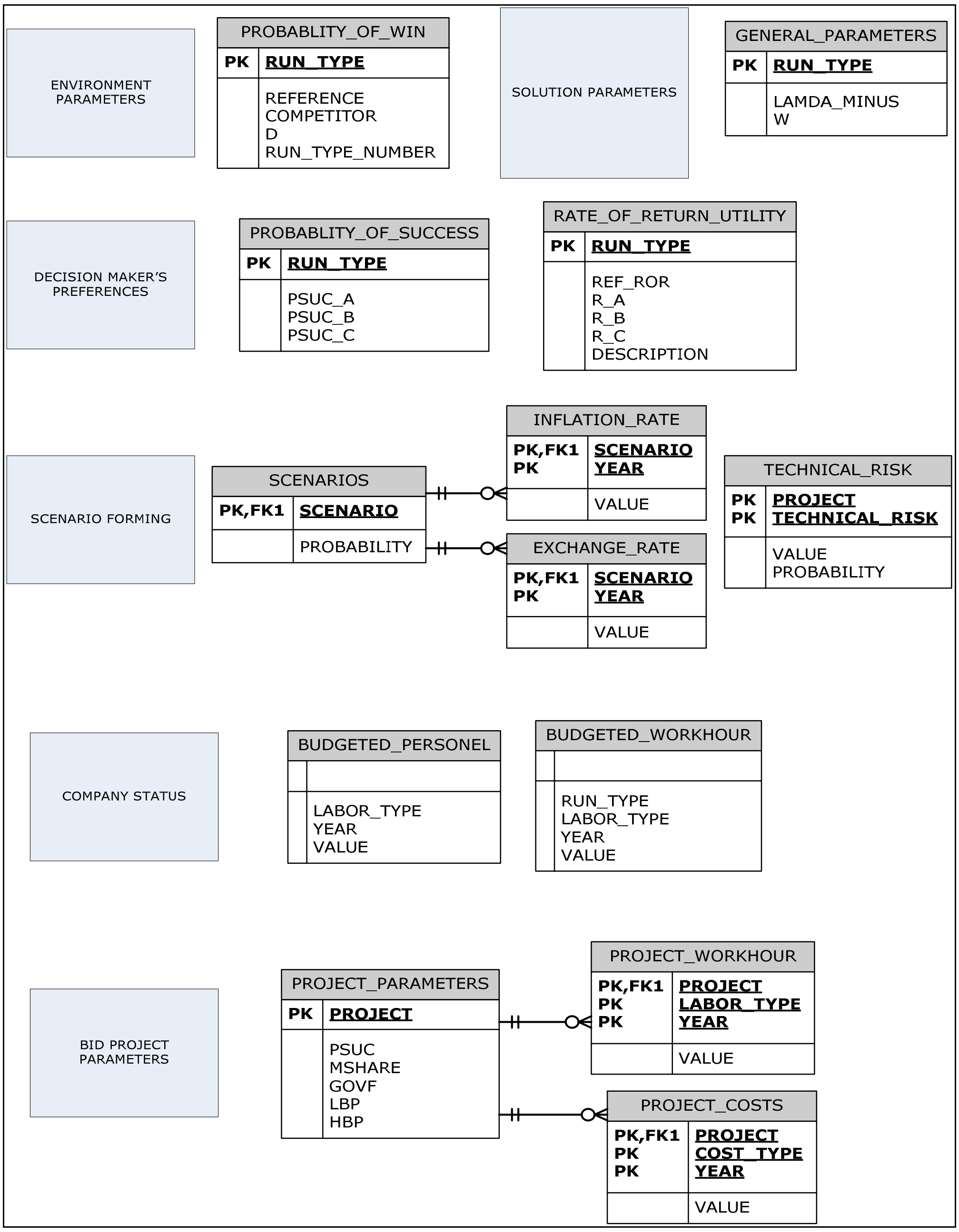


Figure 21- Database design schema for parameters

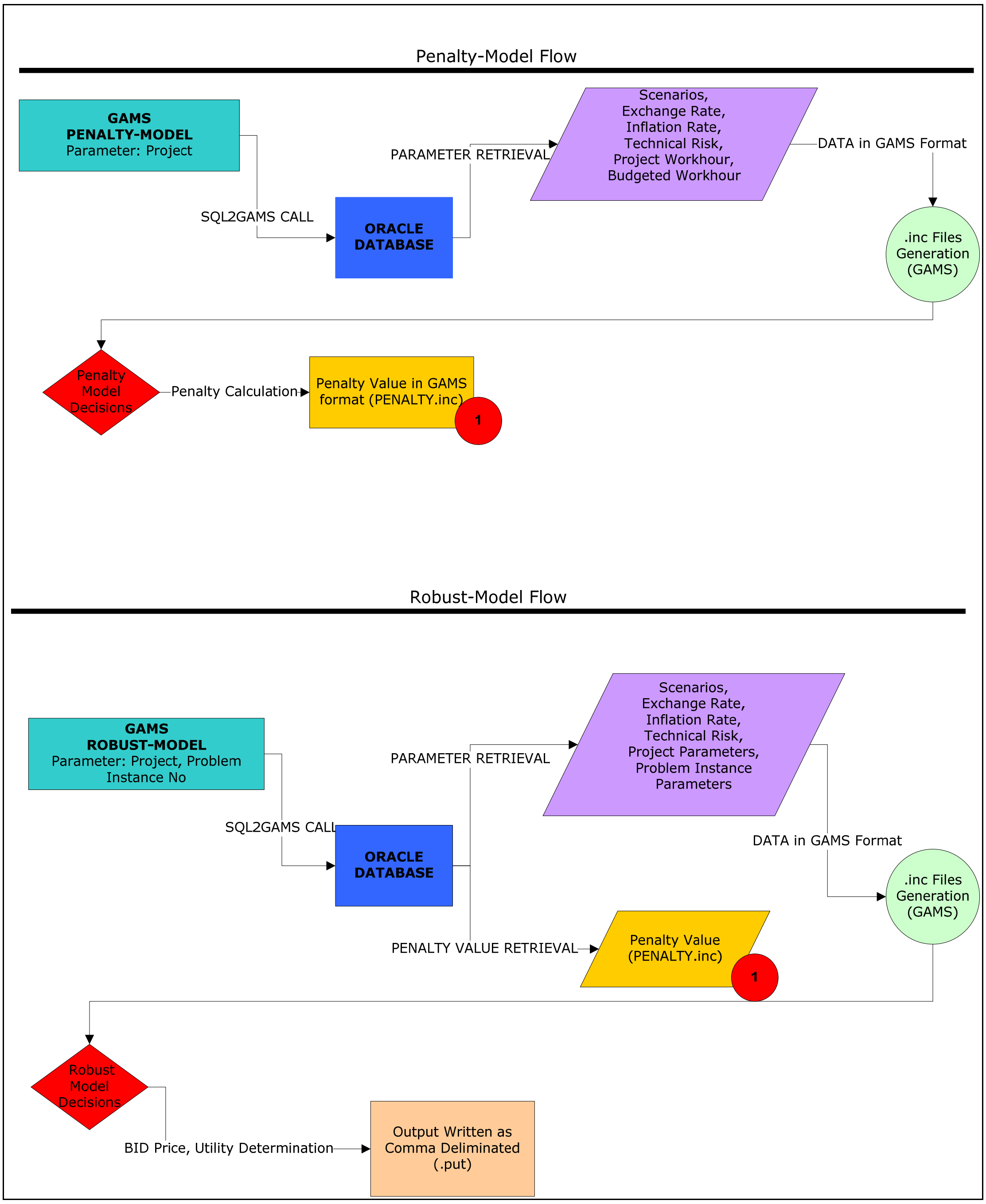


Figure 22- Flowchart of the solution approach

Project GJ:

GJ is also a R&D project, but having a lower probability of success, 80%. Also market share impact is expected to be less, 1 over 5 points. However, there is a government funding of 10%. This project is a big project compared to the other projects. Expected project cost is 242 M $. The high cost of the project and low probability of success are the discriminating features of the project.

Project PM:

PM is a production project, with a probability of success of 98%. The project is carried out for many times in the company and no market share impact is expected. Also, government funding is not available for production projects. Since there is no utility gain with the exception of the ROR and no technical risk involved, project PM may be considered a commercial project. In this project, the only criterion will be the ROR criterion in pricing of the project.

Table 12 below summarizes the characteristics of these three projects.

Table 12- Characteristics of the projects

Project	**Characteristics**				
	psuc	**mshare**	**govf**	**Exp Cost (in M $)**	**Highest Bid Price (in M $)**
CP (R&D)	0.85	4	0	60	80
GJ (R&D)	0.8	1	0.1	242	320
PM (Production)	0.98	0	0	75	100

6.3. Parametric Analysis

6.3.1. Factors

Parametric analysis is carried out to analyze the solution and get insight of the model through the defined utility, risk and probability of win (pow) functions.

For every project, risk behavior regarding the probability of success, rate of return utility attitude and probability of win situations are to be analyzed with the robust optimization approach. Table 13 describes the 972 runs made for a sample project.

6.3.2. Results obtained from the parametric analysis

First of all, solutions of the problem instances are analyzed through the model parameters: penalty term (3 levels) and robustness term (3 levels). ‘Solution description’ conventions that will be used through the analyses are explained in Table 14. Solutions are grouped according to the robustness term, since the robustness term is a dominating decision factor over the penalty term.

Determining the robustness parameter

Several runs are made to learn about the robustness term, λ, in order to search for solutions that are less sensitive to uncertainties. For large values of λ, greater than 0.4, the model places the highest bid price for many runs, even when there is a reference factor for the company. This makes the probability of win values very low. Selected

λ values at two levels are 0.2 and 0.4 in order to minimize the possible financial losses due to uncertainties, which result in reasonable probability of win values.

Table 13- Factors for the parametric analysis

Definition of parameters	**Alias**	**# of Parameter levels**	**Levels of parameters**		
Form of Risk Function	psuc	3	Risk Seeking	Risk Neutral	Risk Averse
Form of u(ROR)	ROR	3	More Prone to 15%	Linear	Around 15% sufficient
Probability of Win- Competitor	pow	3	No Competitor	1 Competitor	2 Competitors
Probability of Win- Reference	pow	2	No Reference	Reference	
Probability of Win- Environment	pow	2	High pow	Low pow	
Model Parameters- Penalty	gpw	3	gpw= 0	gpw= $5x10^{-10}$	gpw= $10x10^{-10}$
Model Parameters- Robustness	λ	3	$\lambda=0$	$\lambda=0.2$	$\lambda=0.4$
Total		**972**			

Table 14- Solution description conventions

Solution Set	**Parameter Setting**
Expected (Exp)	$\lambda=0$, gpw=0
	$\lambda=0$, gpw=5×10^{-10}
	$\lambda=0$, gpw=10×10^{-10}
Robustness 1 (R1)	$\lambda=0.2$, gpw=0
	$\lambda=0.2$, gpw=5×10^{-10}
	$\lambda=0.2$, gpw=10×10^{-10}
Robustness 2 (R2)	$\lambda=0.4$, gpw=0
	$\lambda=0.4$, gpw=5×10^{-10}
	$\lambda=0.4$, gpw=10×10^{-10}

In order to eliminate the probability of suffering a financial loss, worst-case solutions may be implemented. But worst-case solutions are more conservative and have lower probability of win values. The robust solution provides a tradeoff between probability of win and financial risk. "Robustness" solution sets are less sensitive to uncertainty than the "Expected" solution set, but with a little decrease in the probability of win.

The selected robustness parameter (λ) values (0.2 and 0.4) provide more consistent results; because higher robustness parameters, greater than 0.4, have been observed to provide solutions that have very low probability of win results, like for example, pow=0. Actually, the determination of the value of λ depends on the company's current workload and decision maker's risk preference related to the project utility functions. If the company has already had many pre-contracted projects on hand, higher values of λ may be used in order not to have financial risk due to uncertainties. Then these solutions may return higher bid prices.

If, on the other hand, the company has already had only a few pre-contracted projects, then the decision maker may be more willing to allocate the company’s overhead costs. In this situation, lower values of λ should be selected in order to increase the probability of winning the bid.

6.3.2.1. Results for the sample projects

Project CP

Penalty Term

Since Project CP is a small project compared to the company’s size, penalty costs do not affect the solution significantly. For every combination of ROR, psuc and pow, solutions are compared and Figure 23 shows that the numbers of bid price occurrences are almost the same for every combination, irrespective of the penalty term.

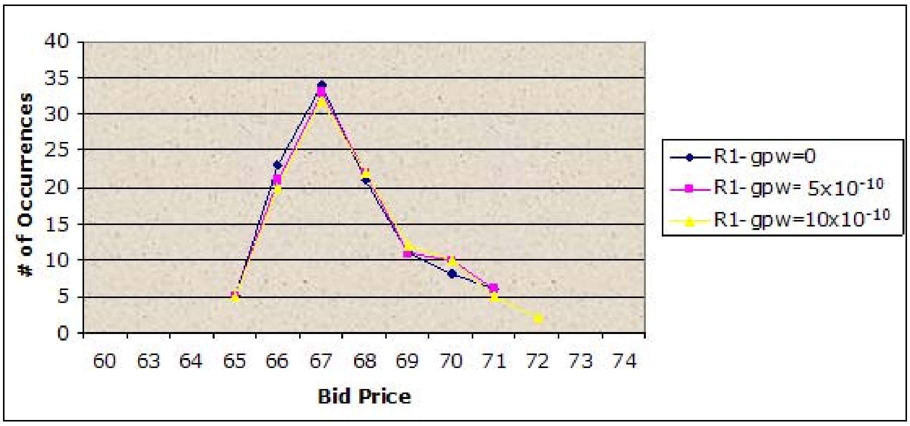


Figure 23- Effects of the penalty term on the bid prices

Robustness Term

Solutions are compared by the effect of robustness term, since the penalty term does not have a major effect on the decision makers. After a brief look at the results, it is observed that in 207 problem instances of the "Expected" solution set, the company has the probability of suffering from a financial loss based on the realization of scenarios. Also, being at a financial loss position with a probability of 38.4 % is observed in 30 problem instances. Moreover, probability of falling below the desired ROR value (15%) is greater than 60% for 95% of the problem instances in the "Expected" solution set.

On the other hand, in the "Robustness" solution sets, the solutions have lower probabilities of suffering from a financial loss. It is also observed that there is no financial loss in more than 85% of the problem instances in the "Robustness" solution sets (R1 and R2). In the R1 solution set, it is observed that in 79 problem instances (out of 324), ROR values are above the desired ROR value with a probability of more than 60%. On the other hand, in the "Expected" solution set, in 306 problem instances (out of 324), ROR values are below the desired ROR value with a probability of more than 60% (Table 15).

The expense of these benefits, like being in a position with no financial loss, is the decrease in the probability of winning the bid. In the "Expected" solution set, in 85% of the time, the company wins the bid. In the "Robustness" solution sets, the probability of suffering from a financial loss drops down to 1%, whereas the probability of win drops to 70% from 85% (Table 15).

Table 15- Project CP solution details

BID PRICE (million $)	Solution Set # of problem instances, Exp	 # of problem instances, R1	 # of problem instances, R2	Prob. (ROR<15%)	Prob. of suffering a financial loss
60	30			100.00%	38.40%
61	6			100.00%	21.60%
62	9			100.00%	13.90%
63	18			100.00%	6.90%
64	27	3		100.00%	2.40%
65	36	38	3	96.50%	1.00%
66	81	46	25	90.90%	0.40%
67	54	84	44	79.70%	0.00%
68	45	84	105	60.10%	0.00%
69	18	38	69	38.40%	0.00%
70		22	44	38.40%	0.00%
71		9	22	21.60%	0.00%
72			9	13.90%	0.00%
73			3	6.90%	0.00%

R1 with a value of λ=0.2 provides better solutions for Project CP, since probability of win values are, on the average, above 75%. Expectation of the market share impact affects the solution in selecting the bid prices with higher probabilities of win. Robustness parameter, λ, decreases the probability of suffering from a financial loss to 2.4% (from 38.4%) at the expense of only a 9% decrease in the probability of win (Table 16).

Table 17 is a summary of the robustness effect on Project CP solutions.

Table 16- Probability of win for different solution sets

BID PRICE	**Average pow values for the solution sets**		
	Exp	**R1 (λ=0.2)**	**R2 (λ=0.4)**
60	90%		
61	86%		
62	84%		
63	81%		
64	79%	73%	
65	79%	70%	68%
66	86%	70%	63%
67	88%	79%	66%
68	83%	81%	73%
69	84%	78%	74%
70		74%	69%
71		71%	67%
72			65%
73			51%
Average pow	85%	76%	70%

Table 17- Project CP analysis

Project	**Average pow**			**# of problem instances with more than 2% prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
	Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
CP	85%	76%	70%	90	3	0	38.4%	2.4%	0.4%

Project GJ

GJ is a R&D project with a probability of success of 80%. There is a government funding for this project. However, market share impact of this project is expected to be less than Project CP. Cost of the project is higher and probability of success is lower for this project than the other projects, CP and PM.

Robustness Term

Bid prices and expected ROR values are higher for project GJ due to the lower utility of market share impact and the limited government funding availability. Because of the higher expected ROR values, probability of suffering from a financial loss is low. Again, R1 with a value of λ=0.2 results in a probability of suffering from a financial loss of 1%. Also with an acceptable decrease in the probability of win (10%), robustness parameter, λ, for R1 decreases the probability of suffering from a financial loss to 1% (from 7%) (Table 18).

Table 18- Project GJ analysis

Project	**Average pow**			**# of problem instances with more than 2% prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
	Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
GJ	73%	62%	52%	63	0	0	7%	1%	0.4%

Project PM

Robustness Term

Since there is only ROR gain, bid prices and expected ROR values appear to be higher than Project CP's. R1 with a value of λ=0.2 results in a probability of suffering from a financial loss of 2%, which is only for the scenario of the unexpected USD exchange rate. According to the decision maker's preferences, all of the problem instances with R2 at the value of λ=0.4 have a ROR value greater than the desired ROR value with a probability of more than 50%; while in the R1 solution set, 90% of all problem instances have a ROR value greater than the desired ROR value with a probability of more than 50%. An average pow of 56% is more preferable with the R1 solution set, since the results related to the probability of suffering from a financial loss are almost the same for R1 and R2 solution sets (Table 19).

Table 19- Project PM analysis

Project	**Average pow**			**# of problem instances with more than 2% prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
	Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
PM	64%	56%	50%	270	0	0	9%	2%	2%

6.3.2.2. Parameter behaviors

Rate of Return

The preference curve of 'Around 15% Sufficient' has a narrower interval of the expected ROR, compared to that of 'Prone to 15%' and

‘Linear’ ROR preference curves. Since utility in ROR is more stable around 15% due to the shape of the utility function, more consistent ROR values are observed for the preference curve of ‘Around 15% Sufficient’. However, in a low ‘probability of win’ environment, the minimum ROR (0%) is observed for the “Expected” solution set for Project CP with the ‘Prone to 15%’ and ‘Linear’ ROR preference curves. This is because the Robust Optimization model tends to increase the probability of win in order to get the market share impact utility. The interval of the expected ROR values gets narrower by means of the robustness term, and the minimum expected ROR value for the “Robustness” solution sets (R1, R2) rises to 7% (Table 20).

Table 20- ROR intervals for the three preference curves (Project CP)

ROR Preference	**Exp**	**R1**	**R2**
	Expected ROR interval		
Prone to 15%	0%-15%	8%-18%	10%-22%
Linear	0%-13%	7%-15%	8%-18%
Around 15% sufficient	5%-12%	8%-13%	10%-15%

Compared to Project CP, Project GJ has a lower utility gain for the market share impact and government funding characteristics. For Project GJ, the Robust Optimization model expects higher ROR values. ‘Prone to 15%’ and ‘Linear’ preference curves have still a large interval in the expected ROR values, demanding high ROR in the high probability of win environments, especially when there is a reference factor for the company. Again, ‘Around 15% Sufficient’ preference curve has a narrower interval of the expected ROR, but about 2% higher interval limits compared to Project CP, which are on the average 10%-15% (Table 21).

Table 21- ROR intervals for the three preference curves (Project GJ)

ROR Preference	**Exp**	**R1**	**R2**
	Expected ROR interval		
Prone to 15%	9%-18%	12%-25%	15%-32%
Linear	7%-17%	10%-20%	12%-21%
Around 15% sufficient	7%-13%	10%-16%	12%-16%

For Project PM, the Robust Optimization model has similar responses as Project GJ, expecting a higher ROR, because the utility gain is limited with only ROR. This time, in R1 solution set, 'Around 15% Sufficient' ROR preference curve yields a higher ROR interval [12% 33%] with a probability of win limited to 59% caused by the high bid price it calls for. Although Project PM is technically risk free, the limited utility gain, that is only the ROR utility, causes the Robust Optimization model to choose higher bid prices.

Based on the scenario realizations, the probability of suffering from a financial loss for the solutions may get as high as 38% for Project CP. Robustness parameter, λ, prevents the company from suffering a financial loss, whereas for every ROR utility curve, the minimum expected ROR in "Robustness" solution sets is 7% (bid price=64 M $), which ensures less than 2.4% probability of suffering from a financial loss.

Probability of Success

Projects CP and GJ include technical risk due to the uncertainty of R&D projects; however, PM is a technical risk free production project. 'Probability of success' behaviors is analyzed for projects GJ and CP.

As expected, risk-averse solutions result in higher expected ROR values. In Figure 24, for Project GJ, it can be observed that with R2 solution set, decision maker's risk averse preference results in higher expected ROR values. Number of problem instances which yield solutions above a specific expected ROR level is always the highest for the risk-averse preference for the 'Probability of success'.

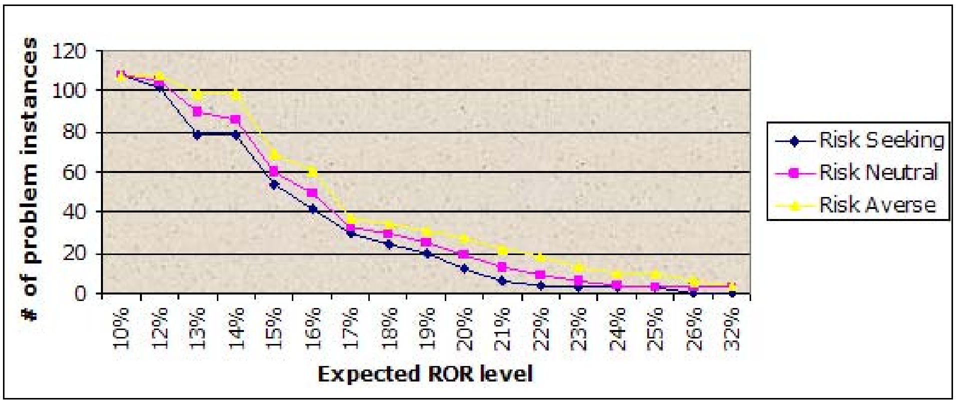


Figure 24- Number of problem instances that yield solutions above a specific expected ROR level

Probability of Win

Environmental conditions have a major effect on determining the optimum bid price. When there is a reference factor, there will be a competitive advantage over other companies. For some instances, reference factor results in the possibility of placing the highest bid price. Also, as expected, number of competitors gives rise to a result that suggests lower bid prices. So, before solving the problem, environmental conditions should be reflected in the most realistic manner.

For Project CP, utility of market share impact enforces the Robust Optimization model to place lower bids with a high probability of winning the bid, that is around 83%, for the environments with a ‘High pow’; and 70% for the environments with a ‘Low pow’ (Table 22).

Since GJ has a lower utility in the market share impact and a limited government funding utility, bid prices appear to be higher. Due to the high bid prices, compared to other R&D project -Project CP, Project GJ has lower probability of win values (Table 22).

Project PM can be considered a commercial project which results in higher ROR and lower probability of win values. In Table 22, it is shown that in environments with ‘High pow’, probability of win value is around an acceptable value as 65% for Project PM.

Table 22- Intervals for the ‘Probability of Win’ values for different environmental conditions

Project	**Environment**	**Exp**	**R1**	**R2**
		‘Probability of winning the bid’ intervals		
CP	High pow	86%-89%	82%-84%	77%-79%
	Low pow	78%-83%	68%-70%	59%-65%
GJ	High pow	80%-81%	69%-72%	59%-64%
	Low pow	66%-67%	49%-56%	39%-46%
PM	High pow	68%-74%	63%-68%	57%-64%
	Low pow	53%-58%	43%-50%	33%-45%

6.3.3. Sensitivity analyses on scenario probabilities

In the main solution set, in the previous sections, the probability of the 'unexpected exchange rate' scenario is set at only 2%. As an example, for Project CP, an average of 17% of the robust solutions only fail in this unexpected scenario, with a probability of not more than 1%; whereas there will be an average of 8% probability of suffering from a financial loss in 81% of the "Expected" solution set. Worse still, in 30 of the problem instances, probability of suffering from a financial loss is 38.4% (Table 23).

Table 23- Project CP solution details (part of Table 15 repeated)

BID PRICE (million $)	Solution Set			Prob. (ROR<15%)	Prob. of suffering a financial loss
	# of problem instances, Exp	# of problem instances, R1	# of problem instances, R2		
60	30			100.00%	38.40%
61	6			100.00%	21.60%
62	9			100.00%	13.90%
63	18			100.00%	6.90%
64	27	3		100.00%	2.40%
65	36	38	3	96.50%	1.00%
66	81	46	25	90.90%	0.40%

When the probability of the crisis scenario is increased from 2% to 16% and then to 30%, as in Table 24, Project CP's expected costs change in minor amounts. "Expected" solution set results do not improve with these minor cost changes and the average of probability of winning the bid remains the same. However, the increased effect of the ‘unexpected exchange rate’ scenario on the probability of suffering from a financial loss is alleviated by the “Robustness” solution sets. In R2 solution set, the financial loss situations are totally eliminated, at the expense of 26% decrease in the probability of winning the bid (Table 24).

By and large looking at the “Robustness” solutions, with the increased probability of the ‘unexpected exchange rate’ scenario, 30% of the problem instances yield the maximum bid price in the R2 solution set, which corresponds to the least possible probability of winning the bid. The occurrences for giving the maximum possible bid price are when there is no competitor and there is a reference factor which raises the minimum probability of winning the bid to as high as 33%. “Robustness” solution sets are more aware of the increased probability of the ‘unexpected exchange rate’ scenario than the “Expected” solution set. When the probability of the ‘unexpected exchange rate’ scenario is raised, “Robustness” solution sets’ reactions are more sensible than those of the “Expected” solution set. However, as explained before, higher values for the robustness parameter, λ, result in placing the highest bid price, causing the least probability of winning the bid. Tables 25 and 26 are summary tables for projects GJ and PM, respectively, for the sensitivity analyses through scenario probability.

Table 24- Project CP overview – with **different** extreme scenario probabilities

Project	**Probability of extreme scenarios**	**Expected Cost (M $)**	**Minimum Bid Price (M $)**			**Maximum Bid Price (M $)**			**Average pow**			**# of problem instances with prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
			Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
CP	Unexpected USD rate =2%	60	60	64	65	69	71	73	85%	76%	70%	207	87	28	38%	2%	1%
	Unexpected USD rate =16%	61	60	64	66	69	71	74	86%	75%	67%	207	69	12	48%	9%	3%
	Unexpected USD rate =30%	61.5	60	65	67	69	72	80	88%	72%	62%	213	51	0	57%	15%	0%

Table 25- Project GJ overview – with different extreme scenario probabilities

Project	**Probability of extreme scenarios**	**Expected Cost (M $)**	**Minimum Bid Price (M $)**			**Maximum Bid Price (M $)**			**Average pow**			**# of problem instances with prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
			Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
GJ	Unexpected USD rate =2%	242	259	267	270	286	320	320	73%	62%	52%	198	58	12	7%	1%	0%
	Unexpected USD rate =16%	246	258	267	276	287	320	320	73%	56%	43%	187	18	0	20%	8%	0%
	Unexpected USD rate =30%	250	256	270	281	287	320	320	73%	48%	34%	181	5	0	36%	6%	0%

Table 26- Project PM overview – with different extreme scenario probabilities

Project	**Probability of extreme scenarios**	**Expected Cost (M $)**	**Minimum Bid Price (M $)**			**Maximum Bid Price (M $)**			**Average pow**			**# of problem instances with prob. of suffering a financial loss**			**Maximum prob. of suffering a financial loss**		
			Exp	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**	**Exp**	**R1**	**R2**
PM	Unexpected USD rate =2%	75	82	84	86	92	100	100	64%	56%	50%	270	225	175	9%	2%	2%
	Unexpected USD rate =16%	77.5	82	85	88	95	100	100	63%	50%	37%	270	193	88	22%	16%	16%
	Unexpected USD rate =30%	79.5	82	87	90	100	100	100	62%	40%	23%	270	96	0	35%	30%	0%

CHAPTER 7

CONCLUSIONS AND FURTHER RESEARCH ISSUES

In this study, a robust optimization model for pricing a long-term defense project is introduced. The model includes the decision maker’s preferences towards the levels of project utilities, namely the market share, the rate of return and government funding. Also, a risk function is applied in the model in order to handle the technical risk preference of the decision maker. Environmental conditions which determine the bid competition is formulated by the probability-of-win function. Several probability-of-win functions are formulated in order to demonstrate the possible bid competition environment. In order to handle the negative effects of variations in cost due to uncertainty, a robustness term is used in the objective function to minimize the possible unexpected losses. Labor utilization status and possible necessary changes in labor utilization is monitored by the Penalty-Model. Also in the Robust Optimization model, financial cash flow constraints help the decision maker visualize the cash flow of the company.

The purpose of developing several preference functions for utility and risk is to develop a flexible decision support tool. Secondary outputs such as penalty model outputs and financial cash flow outputs also help the decision maker to visualize the change of company status by bidding for the project. All of these factors determine the willingness of the decision maker for the bid project.

Negative effects of uncertainty in financial conditions are tried to be eliminated by the robust optimization techniques, since expected value solutions are blind to the deviations in cost due to the uncertainties. Several runs are held with assumed preference functions and environmental conditions along with implementing the robustness term in order to monitor the solution output under various conditions. It is observed that robust solutions are more sensitive to uncertainties and have improvements on the expected value model solutions.

Integration with Oracle database enables all users to enter data for bid project which accelerate the decision making process in bid pricing.

Changes in cost parameters or decision maker’s preferences are quickly handled by the designed system. Mainly, with the inherent flexibility and integrity, this decision support tool may quickly offer a spectrum of meaningful answers to the decision maker.

Further research issues

In literature, there are several resource constrained project selection methods. However, this study mainly tries to place the optimum bid for one bid project. Elimination of the possible negative effects of uncertainty is the main point of concern. In order to determine the willingness of the company for the bid project; project utilities and risks are taken into account. However, new project possibilities in the company project domain may change the decision maker's willingness for the bid project. Also opportunity costs arising due to contracting the project, such as resource allocation of experienced manpower or allocation of scarce machines of the company may be introduced into the model. When there are many contracted projects and company labor workload is high, project contribution over direct cost (COD) concept may decrease the willingness for labor intense projects. On the other hand, the benefits of overhead allocation due to contracting for the bid project may be attractive for the decision maker in such cases.

In further studies the model may include possible new projects for the company, opportunity costs of resource allocation or overhead allocation benefits of the bid project. As it is mentioned before, the main concern of this study is to place an optimum bid price for one project only with an objective of eliminating negative effects of uncertainty, which is more suitable for the decision making process in the company.

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APPENDIX A

PENALTY-MODEL

```
$title Robust Optimization (penalty of long term projects,SEQ=124)
*--Queries From the database--
$set commandfile penalty.txt
$onecho > %commandfile%
C=DSN=OXE
Q1=SELECT distinct(scenario) FROM scenarios_v where project=%gams.u2% order by
to_number(substr(scenario,2))
O1=C:\gams\scenario.inc
Q2=SELECT scenario, year,value from exchange_rate_v  where project=%gams.u2%
O2=C:\gams\exchange_rate.inc
Q3=SELECT scenario, year,value from inflation_rate_v where project=%gams.u2%
O3=C:\gams\inflation_rate.inc
Q4=SELECT scenario, value from technical_risk_v where project=%gams.u2%
O4=C:\gams\technical_risk.inc
Q5=SELECT labor_type,year,value FROM PROJECT_WORKHOUR where project=%gams.u2%
order by labor_type,year asc
O5=C:\gams\project_workhour.inc
Q6=SELECT labor_type,year,value FROM BUDGETED_WORKHOUR where
run_type=%gams.u3% order by labor_type,year asc
O6=C:\gams\budgeted_workhour.inc
Q7=SELECT labor_type,year,value FROM BUDGETED_PERSONEL order by labor_type,year asc
O7=C:\gams\budgeted_personel.inc
Q8=SELECT scenario,probability FROM scenarios_v where project=%gams.u2% and
run_type=%gams.u4%
O8=C:\gams\scenario_probability.inc
$offecho
$call =sql2gms @%commandfile%
SETS s scenarios /$include "C:\gams\scenario.inc"/
    t time periods /t1*t5/
    i labor types  /i1*i4/
```

```
Parameters
*capacity related parameters
        wh      Workhour in a year for 1 personnel            /2000/;

*capacity related parameters
Parameter  per(i,t)   number  of personnel of labor type i in year t  (number of personnel
planned according to pre-contracted projects)
/$include "C:\gams\budgeted_personel.inc"/           ;

Parameter bw(i,t) Budgeted direct workhour of personnel i in year t by pre-contracted
projects
/$include "C:\gams\budgeted_workhour.inc"/           ;

Parameter pw (i,t)   Required workhour of personnel i in year t by the bid project
/$include "C:\gams\project_workhour.inc"/           ;

Parameter techrisk(s) technical risk of workhour estimation
/$include "C:\gams\technical_risk.inc"/           ;

*Scenarios
Parameter exch(s,t) exchange rate in year t in scenario s
/$include "C:\gams\exchange_rate.inc"/           ;

Parameter infl(s,t) inflation rate in year t in scenario s
/$include "C:\gams\inflation_rate.inc"/           ;

Parameters
*scenario probabilities
        p(s)  probability of a scenario
/$include "C:\gams\scenario_probability.inc"/
*Cumulative inflation rate
        cuminfl(s,t) cumulative inf rate;
        alias (t,k);
        cuminfl(s,t)=(prod(k$(ord(k) <= ord(t)), infl(s,k) ) );

*Penalty Parameters
Parameters
        d(i)    Direct labor rate of labor type i             /i1 34, i2 40, i3 35, i4 22  /
```

```
*penalty rates
        prhire penalty rate for hire /0.25/
        prfire(i) penalty rate for fire
        prextra penalty rate for extra work /0.5/
        prsurp penalty rate for surplus/0.5/
        reqwf(s,i,t) required extra workforce for the bid project;
        prfire(i)=(d(i)*wh/12)*12;
reqwf(s,i,t)$((per(i,t)*wh)-bw(i,t)-(pw(i,t)*techrisk(s))=0)=0;
reqwf(s,i,t)$((per(i,t)*wh)-bw(i,t)-(pw(i,t)*techrisk(s))>0)=0;
reqwf(s,i,t)$((per(i,t)*wh)-bw(i,t)-(pw(i,t)*techrisk(s))<0)=(per(i,t)*wh)-bw(i,t)-
(pw(i,t)*techrisk(s));

*Capacity related variables
integer variables
        h(i,t)   number of hired personnel of type i in year t
        f(i,t)   number of fired personnel of type i in year t     ;

positive variables
        eh(s,i,t)  extra hour worked by employee  type i in year t
        chire(i,t)  Cumulative hire up to year t
        cfire(i,t)  Cumulative fire up to year t
        wf (i,t) Workforce of  of personnel type i in year t
        surp(s,i,t) surplus of workhour of labor type i in year t
        dplus(s,i,t) Surplus due to newly hired personnel

*penalty variables
        Expen           Expected penalty
        pen(s)          penalty cost of hire-fire-extra work in scenario s
        penhire(s)       penalty cost of hire in scenario s
        penfire(s)      penalty cost of fire in scenario s
        penextra(s)     penalty cost of extra work in scenario s
        pensurp(s)      penalty cost of surplus due to hire in scenario s;


*Capacity Constraints
Equations cap(s,i,t)       Direct workhour constraint
         extrahour(s,i,t) 10% of extra workhour allowance
         cumhire(i,t)   Cumulative hire effect
```

```
          cumfire(i,t)   Cumulative fire effect
          workforce(i,t) workforce;
alias (t,tt);
alias (t,ttt);
cumhire(i,t)..  chire(i,t)=e= sum(tt$(ord(tt) <= ord(t)), h(i,tt));
cumfire(i,t)..  cfire(i,t)=e= sum(ttt$(ord(ttt) <= ord(t)), f(i,ttt));
workforce(i,t).. wf (i,t) =e=(per(i,t)+chire(i,t)-cfire(i,t))*wh;

cap(s,i,t)..       bw(i,t)+pw(i,t)*techrisk(s) =e= wf(i,t) + eh(s,i,t) -surp(s,i,t)  ;
extrahour(s,i,t).. eh(s,i,t)         =l= 0.1*wf(i,t)      ;

*Penalty Cost Calculations
Equations
penalty penalty cost of scenario s
penaltyhire(s) penalty cost of hire scenario s
penaltyfire(s) penalty cost of fire scenario s
penaltyextra(s) penalty cost of extra hour scenario s
surplus_hour(s,i,t) surplus hour
penaltysurp(s) penalty cost of surplus hour due to hire in scenario s
Expectedpenalty         Expectedpenalty;

surplus_hour(s,i,t)..    (chire(i,t)-cfire(i,t))*wh+ reqwf(s,i,t)  =e=dplus(s,i,t)-eh(s,i,t);

penaltyhire(s)..   penhire(s)=e=sum(t,(sum(i,(h(i,t)  *  wh  *  d(i)  *  prhire))  *  cuminfl(s,t)/
exch(s,t)  ));
penaltyfire(s)..  penfire(s)=e=sum(t,(sum(i,(f(i,t)* prfire(i)))* cuminfl(s,t)/ exch(s,t) ));
penaltyextra(s)..       penextra(s)=e=sum(t,(sum(i,(eh(s,i,t)*d(i)*prextra))*       cuminfl(s,t)/
exch(s,t)  ));
penaltysurp(s)..       pensurp(s)    =e=sum(t,(sum(i,dplus(s,i,t)*prsurp*d(i)))*    cuminfl(s,t)/
exch(s,t)) ;

penalty(s)..      pen(s)=e= penhire(s)+penfire(s)+penextra(s)+pensurp(s);
Expectedpenalty.. Expen=e= sum(s, pen(s)* p(s) )      ;

Variables
obj objective;
Equations
objdef                  objective function value;
```

```
 objdef..  obj=e=    Expen;

model rosubproblem / all /;
solve rosubproblem min obj us mip;

file penalty_file /C:\gams\penalty.inc/; put penalty_file;
put Expen.l;
```

APPENDIX B

ROBUST MODEL

```
$title Robust Optimization (bid price of long term projects,SEQ=262)
*For one time queries in total runs
$set commandfile robust.txt
$onecho > %commandfile%
C=DSN=OXE
Q1=SELECT distinct(scenario) FROM scenarios_v where project=%gams.u2% order by
to_number(substr(scenario,2))
O1=C:\gams\scenario.inc
Q2=SELECT labor_type,year,value FROM PROJECT_WORKHOUR where project=%gams.u2%
order by labor_type,year asc
O2=C:\gams\project_workhour.inc
Q5=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='MC'
O5=C:\gams\project_cost_MC.inc
Q6=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='M'
O6=C:\gams\project_cost_M.inc
Q7=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='IC'
O7=C:\gams\project_cost_IC.inc
Q8=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='I'
O8=C:\gams\project_cost_I.inc
Q9=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='MISCC'
O9=C:\gams\project_cost_MISCC.inc
Q10=SELECT year,value FROM PROJECT_COSTS where project=%gams.u2% and
cost_type='MISC'
O10=C:\gams\project_cost_MISC.inc
Q11=SELECT fin FROM PROJECT_PARAMETERS where project=%gams.u2%
O11=C:\gams\project_cost_FIN.inc
Q12=SELECT scenario, year,value from exchange_rate_v  where project=%gams.u2%
```

```
O12=C:\gams\exchange_rate.inc
Q13=SELECT scenario, year,value from inflation_rate_v where project=%gams.u2%
O13=C:\gams\inflation_rate.inc
Q14=SELECT scenario, value from technical_risk_v where project=%gams.u2%
O14=C:\gams\technical_risk.inc
Q15=SELECT psuc from project_parameters  where project=%gams.u2%
O15=C:\gams\PSUC.inc
Q16=SELECT mshare from project_parameters where project=%gams.u2%
O16=C:\gams\MSHARE.inc
Q17=SELECT govf from project_parameters where project=%gams.u2%
O17=C:\gams\GOVF.inc
Q18=SELECT scenario,probability FROM scenarios_v where project=%gams.u2% and run_type=%gams.u4%
O18=C:\gams\scenario_probability.inc
$offecho
$call =sql2gms @%commandfile%

*For retrieveing a specific run parameter
$set commandfile robust.txt
$onecho > %commandfile%
C=DSN=OXE
Q1=SELECT R_B FROM MODEL_RUNS where run=%gams.u1%
O1=C:\gams\ror\R_B.inc
Q2=SELECT R_A FROM MODEL_RUNS where run=%gams.u1%
O2=C:\gams\ror\R_A.inc
Q3=SELECT REF_ROR FROM MODEL_RUNS where run=%gams.u1%
O3=C:\gams\ror\REF_ROR.inc
Q4=SELECT R_C FROM MODEL_RUNS where run=%gams.u1%
O4=C:\gams\ror\R_C.inc
Q5=SELECT pow_run_type_number FROM MODEL_RUNS where run=%gams.u1%
O5=C:\gams\pow\pow_run_type.inc
Q6=SELECT REFERENCE FROM MODEL_RUNS where run=%gams.u1%
O6=C:\gams\pow\REFERENCE.inc
Q7=SELECT D FROM MODEL_RUNS where run=%gams.u1%
O7=C:\gams\pow\D.inc
Q10=SELECT COMPETITOR FROM MODEL_RUNS where run=%gams.u1%
O10=C:\gams\pow\COMPETITOR.inc
Q11=SELECT psuc_run_type_number FROM MODEL_RUNS where run=%gams.u1%
```

```
O11=C:\gams\psuc\psuc_run_type.inc
Q12=SELECT PSUC_A FROM MODEL_RUNS where run=%gams.u1%
O12=C:\gams\psuc\psuc_a.inc
Q13=SELECT PSUC_B FROM MODEL_RUNS where run=%gams.u1%
O13=C:\gams\psuc\psuc_b.inc
Q14=SELECT PSUC_C FROM MODEL_RUNS where run=%gams.u1%
O14=C:\gams\psuc\psuc_c.inc
Q15=SELECT gp_run_type_number FROM MODEL_RUNS where run=%gams.u1%
O15=C:\gams\gp\gp_run_type.inc
Q16=SELECT LAMDA_PLUS FROM MODEL_RUNS where run=%gams.u1%
O16=C:\gams\gp\LAMDA_PLUS.inc
Q17=SELECT LAMDA_MINUS FROM MODEL_RUNS where run=%gams.u1%
O17=C:\gams\gp\LAMDA_MINUS.inc
Q18=SELECT W FROM MODEL_RUNS where run=%gams.u1%
O18=C:\gams\gp\W.inc
Q19=SELECT ror_run_type_number FROM MODEL_RUNS where run=%gams.u1%
O19=C:\gams\ror\ror_run_type.inc
Q20=SELECT run FROM MODEL_RUNS where run=%gams.u1%
O20=C:\gams\run.inc
Q21=SELECT HBP FROM project_parameters where project=%gams.u2%
O21=C:\gams\HBP.inc
$offecho
$call =sql2gms @%commandfile%

SETS s scenarios /$include "C:\gams\scenario.inc"/
    t time periods /t1*t5/
    i labor types  /i1*i4/
    bp bid price opportunities /240*320/

*capacity related parameters
Parameter per(i,t) number of personnel of labor type i in year t (number of personnel
planned according to pre-contracted projects)
/$include "C:\gams\budgeted_personel.inc"/           ;

Parameter bw(i,t) Budgeted direct workhour of personnel i in year t by pre-contracted
projects
/$include "C:\gams\budgeted_workhour.inc"/           ;
```

```
Parameter pw (i,t)   Required workhour of personnel i in year t by the bid project
/$include "C:\gams\project_workhour.inc"/            ;

Parameter techrisk(s) technical risk of workhour estimation
/$include "C:\gams\technical_risk.inc"/           ;



*Scenarios
Parameter exch(s,t) exchange rate in year t in scenario s
/$include "C:\gams\exchange_rate.inc"/           ;

Parameter infl(s,t) inflation rate in year t in scenario s
/$include "C:\gams\inflation_rate.inc"/           ;

PARAMETERS
*capacity related parameters
        wh      Workhour in a year for 1 personnel            /2000/

*labor cost related parameters
        l(i)    Labor rate of labor type i                   /i1 78, i2 91, i3 80, i4 39  /
        d(i)    Direct labor rate of labor type i             /i1 34, i2 40, i3 35, i4 22  /
        ind(i)  Indirect labor rate of labor type i           /i1 33, i2 35, i3 32, i4 11  /
        o(i)    Overhead rate of labor type i                 /i1 11, i2 16, i3 13, i4 6  /

Parameter MC(t)   Material cost in year t with project currency
/$include "C:\gams\project_cost_MC.inc"/
Parameter M(t)    Material cost in year t with TRY
/$include "C:\gams\project_cost_M.inc"/

Parameter INVC(t)   Investment cost in year t with project currency
/$include "C:\gams\project_cost_IC.inc"/
Parameter INV(t)    Investment cost in year t with TRY
/$include "C:\gams\project_cost_I.inc"/
Parameter MISCC(t) Other Costs in year t with project currency
/$include "C:\gams\project_cost_MISCC.inc"/
Parameter MISC(t) Other Costs in year t with with TRY
/$include "C:\gams\project_cost_MISC.inc"/
```

```
Parameter FIN Total financial cost calculated by the finance department
/$include "C:\gams\project_cost_FIN.inc"/

parameter c competitor /$include "C:\gams\pow\COMPETITOR.inc"/  ;

* Bid price and pow parameters
Parameters
        ref /$include "C:\gams\pow\REFERENCE.inc"/
        pow_d Scaling parameter for probability of win function
 /$include "C:\gams\pow\D.inc"/
        HBP Highest bid price /$include "C:\gams\HBP.inc"/
        BPR(bp)   Bid Price with the bp opportunity
        pow(bp)  probability of winning with a the bp opportunity ;
        BPR(bp)=bp.val*1000000;

pow(bp)=min(max(1-((1-ref)*exp(power((HBP-
bp.val),2)/(power(HBP,2)/pow_d))*sqrt(sqrt(c))),0),1) ;

Parameters
*scenario probabilities
        p(s)  probability of a scenario/$include "C:\gams\scenario_probability.inc"/
*Cumulative inflation rate
        cuminfl(s,t) cumulative inf rate;
        alias (t,k);
        cuminfl(s,t)=(prod(k$(ord(k) <= ord(t)), infl(s,k) ) ) ;
*Calculated Parameters
Parameters

PLC(s)    Project total labor cost in scenario s in project currency
PMC(s)    Project total material cost in scenario s  in project currency
PIC(s)    Project total investment cost in scenario s in project currency
PMISCC(s) Project total misc cost in scenario s in project currency
CO(s)     Total cost of project in scenario s
EC        Expected Cost
PCOST(s,t)  Project costs which are budgeted in TRY in year t
PCOSTC(t) Project cost which are budgeted in project currency in year t
;
```

```
        PLC(s)=  sum(t ,(sum(i,(l(i) * pw(i,t)*techrisk(s))))* cuminfl(s,t)/ exch(s,t) );
        PMC(s)=  sum(t , MC(t)+ (M(t)* cuminfl(s,t)/exch(s,t)));
        PIC(s)=  sum(t , INVC(t)+ (INV(t)* cuminfl(s,t)/exch(s,t)));
        PMISCC(s)= sum(t , MISCC(t)+ (MISC(t)* cuminfl(s,t)/ exch(s,t)));
        CO(s) =  PLC(s)+ PMC(s)+PIC(s)+PMISCC(s)+FIN;
        EC =     sum(s, (CO(s))* p(s)) ;
        PCOST(s,t)= (sum(i,(l(i) * pw(i,t)*techrisk(s))))+M(t)+INV(t)+MISC(t);
        PCOSTC(t)= MC(t)+INVC(t)+MISCC(t);

*Variables
Variables
BIDPRICE Bid price
POWOFWIN probability of win
expected_total_utility total_utility;

binary  variable
x(bp) bp th bid to be bid 0 or 1;

*Cash Flow related parameters
positive Variables
CNV(s,t)   Converted money to TRY in year t
B(s,t)     Borrowed money in year t with TRY
BC(s,t)    Borrowed money in year t with project currency
Lend(s,t)     Lend money in year t with TRY
LendC(s,t)    Lend money in year t with project currency;

*Indirect variables
variables
        obj  objective function
*monetary variables
        EFinCO          Expected Financial Cost
        PFinCO(s)        Project financial cost   in scenario s
        TFinCO(s,t)      Converted financial Cost  in scenario s in time t
        FinCO(s,t)       Financial Cost  in scenario s in time t  with TRY
        FinCOC(s,t)      Financial Cost  in scenario s in time t  with project currency code;

Parameters
```

```
PC(t)    Payment percentage in year t with project currency   / t1 0.5 , t2 0.3 , t3 0.0 , t4 0.0,
t5 0.2/
mb       Multiplier for borrow rate over inflation for TRY /1.1/
mbc      Multiplier for borrow rate over inflation for project currency /1.05/
ml       Multiplier for lend rate over inflation for TRY /1.05/
mlc      Multiplier for lend rate over inflation for project currency /1.03/ ;

Parameters
br(s,t) borrow rate  for TRY
brc(s,t) borrow rate for project currency
lr(s,t) lend rate  for TRY
lrc(s,t) lend rate for project currency;

br(s,t)=mb*infl(s,t);
brc(s,t)=mbc*infl(s,t);
lr(s,t)= ml*infl(s,t);
lrc(s,t)=mlc*infl(s,t);

*Cash Flow Part
Equations
CashTRY(s,t)             Cash flow in year t with TRY  in scenario s
CashCurrency(s,t)        Cash flow in year t with project currency  in scenario s
FinCost(s,t)             Financial Cost in year t in scenario s with TRY
FinCostC(s,t)            Financial Cost in year t in scenario s with project currency code
FinancialCost(s,t)       Financial Cost in year t in scenario s
PFinCost(s)              Project financial cost
EFinCost                 EFinCost
FINconstraint            FINconstraint;

FinCost(s,t)..           FinCO(s,t) =e= B(s,t-1)*(br(s,t-1)-1)- Lend(s,t-1)*(lr(s,t-1)-1);
FinCostC(s,t)..          FinCOC(s,t)=e= BC(s,t-1)*(brc(s,t-1)-1)- LendC(s,t-1)*(lrc(s,t-1)-1);
FinancialCost(s,t)..     TFinCO(s,t)=e= FinCOC(s,t) + FinCO(s,t)/exch(s,t);
PFinCost(s)..            PFinCO(s)=e=  sum(t ,TFinCO(s,t));
EFinCost..               EFinCO=e= sum(s, PFinCO(s)* p(s) );
CashTRY(s,t)..                (CNV(s,t)*   exch(s,t))+   B(s,t)-B(s,t-1)-Lend(s,t)+Lend(s,t-1)=e=
PCOST(s,t)+FinCO(s,t)  ;
```

```
CashCurrency(s,t)..  (BIDPRICE*PC(t))-  CNV(s,t)+BC(s,t)-BC(s,t-1)-LendC(s,t)+LendC(s,t-1)
=e= PCOSTC(t)+FinCOC(s,t);

FINconstraint..          EFinCO=l= FIN;

*utility functions
Parameters
psuc probability of success /$include "C:\gams\PSUC.inc"/
mshare market share impact /$include "C:\gams\MSHARE.inc"/
govf government funding /$include "C:\gams\GOVF.inc"/
r_psuc Risk function of probability of success
run run number /$include "C:\gams\run.inc"/
run_ror Run parameter for rate of return /$include "C:\gams\ror\ror_run_type.inc"/
run_pow Run parameter for probability of win  /$include "C:\gams\pow\pow_run_type.inc"/
run_psuc Run parameter for probability of success
 /$include "C:\gams\psuc\psuc_run_type.inc"/
run_gp  Run parameter for general parameters /$include "C:\gams\gp\gp_run_type.inc"/
u_mshare utility of market share impact
u_govf utility of government funding

PSUC_A    /$include "C:\gams\psuc\psuc_a.inc"/
PSUC_B   /$include "C:\gams\psuc\psuc_b.inc"/
PSUC_C /$include "C:\gams\psuc\psuc_c.inc"/ ;

r_psuc$(run_psuc=1)=PSUC_A - (PSUC_B*exp(-psuc/PSUC_C));
r_psuc$(run_psuc=2)=PSUC_A +(psuc*(1-PSUC_B)/(1-PSUC_C));
r_psuc$(run_psuc=3)=PSUC_A+ (PSUC_B*POWER((1-(1-psuc)),PSUC_C));

u_mshare= mshare/5 ;
u_govf= govf/0.6;

Parameters
REF_ROR Scaling parameter for rate of return function
/$include "C:\gams\ror\REF_ROR.inc "/
R_A Scaling parameter for rate of return function
/$include "C:\gams\ror\R_A.inc "/
R_B Scaling parameter for rate of return function
 /$include "C:\gams\ror\R_B.inc "/
```

```
R_C Scaling parameter for rate of return function
 /$include "C:\gams\ror\R_C.inc "/
ror(bp,s) expected rate of return
u_ror(bp,s) utility of expected rate of return
exp_util_ror(bp) expected utiliy of ror ;

ror(bp,s)= (BPR(bp)-CO(s))/CO(s);
u_ror(bp,s)$(run_ror=1)=max(min(R_A-(R_B*exp(power(max((REF_ROR*2-
ror(bp,s)),0),2)/R_C)),1),0);
u_ror(bp,s)$(run_ror=2)=min(max(R_A-(R_B*(EXP(POWER((REF_ROR-
ror(bp,s)),2)/R_C*SIGN((REF_ROR-ror(bp,s)))))),0.0001),1) ;
u_ror(bp,s)$(run_ror=3)=max(min(ror(bp,s)/REF_ROR/2,1),0);

exp_util_ror(bp)= sum(s, u_ror(bp,s)* p(s) );

parameters
vminus(bp,s) vminus
vminus(bp,s)=(exp_util_ror(bp)-u_ror(bp,s))$(u_ror(bp,s)-exp_util_ror(bp)<0);

Parameters
*utility weight parameters
w_mshare  weight of market share impact (know how new customer attracting)    /0.417/
w_govf weight of government funding                                /0.234/
w_ror weight of rate of return                                 /0.349/

*Goal programming parameters
penalty penalty cost of model infeasibilities    /$include "C:\gams\PENALTY.inc "/
Lminus lamda minus /$include "C:\gams\gp\LAMDA_MINUS.inc "/
gpw     penalty for infeasibilities goal programming parameter /
$include "C:\gams\gp\w.inc "/;

Equations
onlyonebid              sum of bid number must be equal to 1
calculatedbid           calculatedbid
calculatedpow             calculatedpow
objdef                 objective function value
utility_calc            utility calculation;
```

```
onlyonebid..          1=e=sum(bp,x(bp));
calculatedbid..       BIDPRICE=e=(sum(bp,x(bp)*BPR(bp)));
utility_calc..
expected_total_utility=e=sum(bp,x(bp)*((w_mshare*u_mshare+w_govf*u_govf+(w_ror*ex
p_util_ror(bp)) )) );
calculatedpow..        POWOFWIN=e=(sum(bp,x(bp)*pow(bp)));

objdef..                                  obj=e=                                    sum(bp,
pow(bp)*x(bp)*(r_psuc*(w_mshare*u_mshare+w_govf*u_govf+(w_ror*exp_util_ror(bp))  ))
) - Lminus* (sum(bp,( sum(s,p(s)*x(bp)*pow(bp)*sqrt(vminus(bp,s)/exp_util_ror(bp)) ))))-
sum(bp,x(bp)*pow(bp)*gpw*penalty) -EfinCO/9000000000000;

model rotkean  /all/;
solve rotkean max obj us mip;

file robust; put robust;
robust.ap = 1;

put 'Run Number ' run
put  "%system.DATE%" '-' "%system.TIME%";
put ' ROR parameter;'
put run_ror;
put ' POW Parameter;'
put run_pow;
put ' PSUC parameter;'
put run_psuc;
put ' GP Parameter;'
put run_gp;

put ' Total Utility;' expected_total_utility.l ';';
put ' BidPrice; '  BIDPRICE.l ';';
put ' Probability of Win;'  POWOFWIN.l ';';
```