RESEARCH NOTE

A COMPREHENSIVE MODEL FOR R AND D PROJECT PORTFOLIO SELECTION WITH ZERO-ONE LINEAR GOAL-PROGRAMMING

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Abstract Technology centered organizations must be able to identify promising new products or process improvements at an early stage so that the necessary resources can be allocated to those activities. It is essential to invest in targeted research and development (R and D) projects as opposed to a wide range of ideas so that resources can be focused on successful outcomes. The selection of the most appropriate projects is the aim of R and D project selection models. The project selection is complicated by many factors, such as vision and preferences of decision makers, allocating the right human resources, interrelationships between projects, and changes over time and success factors that are difficult to measure. In this article we formulate essential factors in R and D project portfolio selection by a mathematical model, which consider a multi- objective function for maximizing corporate benefit through quantitative and qualitative criteria as well as insight and preferences of decision makers and human resource allocation which does not exceed organization's constraints such as planning horizon, available resources and interrelationships between projects.

Key Words Mathematical Programming, Project Management, R and D Project Portfolio Selection

چکیده در بیشتر سازمان‌ها انتخاب پروژه های تحقیق و توسعه محصول یا خدمات از بین تعداد زیادی پروژه پیشنهادی که معمولاً برای پژوهش یا توسعه امکان پذیرند، تصمیمی حیاتی و بسیار مهم تلقی می‌گردد. مشکلات اصلی در فرآیند انتخاب سبد پروژه های تحقیق و توسعه را می‌توان در وجود تعداد زیاد اهداف کمی و کیفی که اغلب با یکدیگر ناسازگارند، وابستگی بعضی از پروژه ها به یکدیگر، یکنواخت نبودن مقدار منبع در دسترس، میزان مصرف، تعداد نیروی انسانی متخصص و مجرب، بینش، تجربه، ترجیحات مدیران و تصمیم گیران، برقراری توازن در ریسک، زمان تکمیل و زمانبندی دانست. مدل ارائه شده در این پژوهش یک مدل برنامه ریزی هدف صفر-یک خطی می‌باشد که تلاش می‌کند با ارایه راه حل های بهینه به تصمیم گیرندگان کمک نماید.

1. INTRODUCTION

R and D project portfolio selection is a critical interface between the product development strategy of an organization and the process of managing projects. There are many different techniques that can be used to estimate, evaluate, and choose project portfolios. Some of these techniques are not widely used because they address only some of the above issues, they are too complex and require too much input data, they may be too difficult for decision makers to understand and use, or they may not be used in the form of an organized process [1]. Among all of the techniques that are available, optimization techniques are the most fundamental quantitative tool for project portfolio selection [2] and address most of the important issues. R and D project selection methods can usually be placed into one of the following categories:

- Unstructured peer review;
- Scoring;
- Mathematical programming, including integer programming (IP), linear programming (LP), nonlinear programming (NLP), goal programming (GP), and dynamic programming (DP);
- Economic models, such as internal return rate (IRR), Net present value (NPV), return on investment (ROI), Cost-benefit analysis, and option pricing theory;
- Decision analysis, including multi-attribute utility theory (MAUT), decision trees, risk analysis, and the Analytic hierarchy process (AHP);
- Interactive methods, such as Delphi, Q-sort, Behavioral decision aids (BDA), and Decentralized hierarchical modeling (DHM);
- Artificial intelligence (AI), including expert systems and fuzzy sets;
- Portfolio optimization.

Any logical combination of the indicated techniques can be used to construct an organization’s “optimal R and D portfolio”. For example, Delphi may be used to obtain and weigh relevant criteria, scoring to carry out preliminary screening, IP to construct the portfolio, and NPV to allocate resources. The successful implementation of these techniques often depend upon the type of decision being made, availability of project information, resource availability during the decision-making process, a decision maker’s understanding of the technique, and a decision maker’s perception that a rigorous, quantitative approach may lead to eliminating pet projects [3]. In addition we face other major difficulties such as balancing project portfolio in terms of certain factors, like risk and time to completion; constraints such as finance, and equipment [4].

Several methods have been presented to help

TABLE 1. Suitability of Project Selection Methods for Various Problem Characteristics.

Project Selection Method	Parameters are known	Need to Feasible Study	Multiple Criteria	Optimization	Impact of Criteria during Optimization	Interdependence of Projects	Scheduling
Ranking	-	-	Yes	-	-	-	-
Scoring (11)	-	-	Yes	-	-	-	-
AHP and ANP (27,28)	Yes	-	Yes	-	-	-	-
GP (14)	Yes	Yes	Yes	Yes	Yes	Yes	-
ANP and GP (17)	Yes	Yes	Yes	Yes	Yes	Yes	-
Dynamic Programming (29)	Yes	Yes	-	Yes	-	Yes	-
Zero-One Linear (13)	Yes	Yes	Yes	Yes	-	Yes	Yes
Integer Nonlinear (3, 25)	Yes	Yes	-	Yes	-	-	-
Zero-One Linear Quadratic (30)	Yes	Yes	-	Yes	-	Yes	-
Proposed Model in This Paper	Yes	Yes	Yes	Yes	Yes	Yes	Yes

organizations make good project portfolio selection. However, these methodologies have some limitations and do not provide a tool to combine all of the relevant R and D project selection criteria into a single model. In this paper a comprehensive model has been introduced which considers all critical issues (which embrace all common R and D project portfolio selection) that are undertaken in a set of typical R and D project portfolio. Table 1 shows a list of prior research and their suitability in problem situation.

2. PROPOSED MODEL

Our proposed model is focusing on solving the mentioned problems and tries to pay attention to them as they are in the real world. Characteristics of this model are:

- Both quantitative and qualitative objectives are considered–There are quantitative and qualitative objectives in every socioeconomic system. For decision makers, ability for implementation of both types of objectives is critical.
- Needs, vision and preferences of decision makers
- Allocation of skilled human resource
- Project scheduling
- Finishing all of the selected projects within the planning horizon
- Variations of consumed resources in different periods
- Sensitivity analysis tools for decision makers
- Projects interdependencies
- Rapid re-calculations to aim decision makers in evaluation of the effects of changes on optimal project portfolio
- Mutually exclusive–in some programs selecting one project removes other projects from portfolio

We describe these characteristics in the next section.

2.1 Model Characteristics Because of its discrete 'select or not select' nature, choosing a project portfolio is inherently a 'zero-one' problem. For decision makers rapid re-calculations in evaluation of the effects of changes on an optimal project portfolio is vital. They must rapidly evaluate and analyze the optimal portfolio on some parameters such as risk and duration. This speed is not currently possible with non-linear optimization algorithms [4].

One of the most critical problems, which the decision makers face, is multiple objectives and multi-criteria in project portfolio selection. They are often conflicting and are not measured in the same unit. The GP technique has already been identified as a promising model for project selection [5] The general goal programming model typically has two sets of constraints: goal constraints and system constraints [6]. Goal constraints represent objectives that are to be fully or partially achieved in a given decision environment. In R and D portfolio selection, goals would reflect objectives such as "maximize the benefits", "minimize risk or likelihood of failure" and "minimize the cost of a portfolio" etc. System constraints in a GP model limit the decision variables and typically reflect real world restrictions imposed on a given problem. In the R and D project portfolio selection, system constraints would reflect mandatory projects, scarce resources, project interdependencies and etc. These constraints will ensure that the selection provides a feasible set of projects for development. Objective function in a model is a minimum deviation from desired amounts, which is represented in objective constraints. Generally we can say the goal-programming model provides an integrated framework to select a set of projects that are consistent with the goals of the organization [7].

In our model, objective is to select an optimal project portfolio from N proposed projects in the planning horizon with T periods in which we have the least deviation from the following objectives: Minimize total costs which is expressed in each period for every project, Maximize benefits from successful projects, Minimize risk or probability of fail of portfolio in planning horizon, Maximize the qualitative value of portfolio, and Minimize deviation from decision maker's preferences.

There are some objectives, which are qualitative in nature or could not be expressed in quantitative ones. Qualitative objectives in nature such as contribution to organizational goals/missions, aid the organization in competing in the market, importance in organizing for future success, required by regulations, customer satisfaction, and etc. Meanwhile some objectives are quantitative but the organization could not use them because of lacking sufficient experiments or data. In this case they can estimate them or give them scores. For example NPV or IRR calculations may be a difficult task in organization then they may estimate or rank.

Needs, vision and preferences of decision makers are vital in R and D project portfolio selection. Algorithms should not be used to prescribe solutions without allowing for the judgment, experience, and insight of the decision makers [4]. Consideration of decision makers' preferences plays an important role in the success of portfolios and acceptance of models.

In research and development organizations human knowledge is the most important and most scarce resource. Allocating the right human resources to a project is vital [8]. In the proposed model we consider a separate constraint for allocation of human resource to R and D project portfolios.

For scheduling at commencement of each project, each project in the model can start in a period t that belongs to planning horizon T. With this feature decision makers can start projects when they have enough resources. If this feature is not considered, all projects must start at the beginning of planning horizon or never start. Since the sources are scarce, some projects might be chosen at other periods.

Finishing all selected projects in planning horizon: All of the selected R and D projects should finish within the planning horizon. With this constraint, decision makers can balance the optimal project portfolio.

Variations of consumed resources in different periods: The amount of resources available to carry out a set of projects may vary over time. Almost none of R and D projects consume resources linearly over their life cycle [15]. This is true for progress and cost deviation of R and D projects.

There are some projects based on special considerations in a portfolio that may not be neglect. In addition decision makers and need a tool for considering some projects in portfolio in a balancing and sensitive fashion. So they may want to omit one or more of them to see the results.

We consider the projects that are being developed. These projects are in progress and consuming organizational resources. Of course with this option decision makers can perform sensitive analysis and balance in the portfolio.

One of the most important issues in R and D project portfolio is projects a interdependency. In the real world some projects are pre-requirement of others. These requirements may be economic, technological, etc. Assumption of independency between all projects in a project portfolio usually is not true.

In some programs we have several alternatives for achieving the target then selecting one project removes other projects from the portfolio projects. In our model the decision maker can define as many as mutually exclusive projects he wants.

2.2 Zero-One Linear GP Model In regard to model characteristics, we develop a model that covers all constraints and can be considered as a comprehensive model. The model is defined as follows.

Decision variables:

X_{ij}	Decision variables
$X_{ij} = 1$	if project i is included in portfolio and starts in period j
$X_{ij} = 0$	if project i in period j is not selected
N	Total number of projects being proposed
T	Planning horizon is divided into T periods
AF_k	Permitted amount of cost for each period k
$C_{i,k-j+1}$	Financing required by project i in period k
B	Expected benefit or income for organization thorough project portfolio
b_i	Expected benefit or income from project i
RB	Maximum benefit under risk that can be tolerated
r_i	Risk or chance of failure of project i
M	Total number of skilled human resource in R and D Department
m_i	Number of skilled people in project i
Q	Minimum expected value from qualitative objectives
q_i	Qualitative weight or score of project i
D_i	Duration of project i

p_i	The overall preference of decision makers about project i
P	Right-hand-side of preference equation

Goal constraints The first goal constraint is minimizing total costs where the allowed cost in each period k is AF_k and $C_{i,k-j+1}$ is the financing required by project i in period $k-j+1$ of selected project.

$$\sum_{i=1}^{N}\sum_{j=1}^{T} C_{i,k-j+1}X_{ij} + d_1^+ - d_1^- = AF_k \quad \text{for } k = 1,...,T \qquad (1)$$

b_i is expected benefit or income from project i and expected benefit or income for organization thorough project portfolio is B then the second goal constraint is to maximize benefits from successful projects

$$\sum_{i=1}^{N}\sum_{j=1}^{T} b_i X_{ij} + d_2^+ - d_2^- = B \qquad (2)$$

B could also be set to equal a large number that exceeds the sum of the individual benefits.

There is probability of fail for every R and D project due to technical or management-related problems. Risks in R and D have several sources, such as technical, financial, market-related, and administrative. The levels of these risk components typically vary from project to project. Many researchers suggest that the risk level of each project be assessed and the risk profile of selected projects be minimized [9]. In third goal constraint risk of each project i is calculated between zero to one and formulated as below. RB is the maximum risk (in terms of monetary unit) that can be tolerated by company.

$$\sum_{i=1}^{N}\sum_{j=1}^{T} r_i b_i X_{ij} + d_3^+ - d_3^- = RB \qquad (3)$$

In R and D projects human resource is crucial. We consider this goal constraint in our model and formulate it to minimize from M -Total number of skilled human resource in Rand D Dept.

$$\sum_{i=1}^{N}\sum_{j=1}^{T} m_i X_{ij} + d_4^+ - d_4^- = M \qquad (4)$$

Qualitative objectives are our fifth goal constraint. Score q_i for each project i can be obtained by AHP or other appropriate techniques.

$$\sum_{i=1}^{N}\sum_{j=1}^{T} q_i X_{ij} + d_5^+ - d_5^- = Q \qquad (5)$$

Sixth goal constraint is overall preference of decision makers and we would like to minimize deviation from decision maker’s preferences. If rank n (n > 1) is the best preferred, for example in Likert scale n is 5, the right-hand-side may be set to a large number.

$$\sum_{i=1}^{N}\sum_{j=1}^{T} p_i X_{ij} + d_6^+ - d_6^- = P \qquad (6)$$

System constraints A constraint for ensuring that each project, if selected, will only start once during the planning horizon.

$$\sum_{j=1}^{T} X_{ij} \le 1 \quad \text{for } i = 1,..., N \qquad (7)$$

All of selected projects should finish within the planning of the planning horizon. The following constraints refer to this issue.

$$\sum_{j=1}^{T} jX_{ij} + D_i \le T+1 \quad \text{for } i = 1,..., N \qquad (8)$$

Mandatory projects come in the model by what comes after. S_m is the set of mandatory projects.

$$\sum_{j=1}^{T} X_{ij} = 1 \quad \text{for } i \in S_m \qquad (9)$$

And similar constraint for ongoing projects which in that S_o is the in progress projects

$$X_{i1} = 1 \quad \text{for } i \in S_o \qquad (10)$$

Decision makers for sensitivity analysis may want to exclude some ongoing projects from the portfolio. In this manner we can use the next constraint. S_d is a set of ongoing projects.

$$\sum_{j=1}^{T} X_{ij} = 0 \quad \text{for } i \in S_d \tag{11}$$

In some cases, a project cannot be developed unless a related project can be implemented. These situations are to be included as contingency constraints to ensure that the dependent projects are chosen only if its related project is also selected [6]. In the model the implementation of a given project i is contingent upon the implementation of all of the projects in the set S_i where $|S_i|$ is the number of elements in the set S_i. H is set of dependent projects.

$$\sum_{l \in S_i} \sum_{j=1}^{T} X_{lj} \geq |S_i| \sum_{j=1}^{T} X_{ij} \quad \text{for } i \in H \tag{12}$$

and constraint 13 guarantees that all of the precursor projects in set of S_i will be finished before the successor project starts.

$$Y_i = \text{Max}\left(\sum_{j=1}^{T} jX_{lj} + D_l \sum_{j=1}^{T} X_{lj} \quad \text{for all } l \in S_i \right) \quad \text{for } i \in H$$

$$\sum_{j=1}^{T} jX_{ij} + (T+1)(1 - \sum_{j=1}^{T} X_{ij}) \geq Y_i \quad \text{for } i \in H \tag{13}$$

When we have some versions of one project or there are several solutions for one program we must select one version or solution within several projects. In such cases the following constraint must be added. S_p is the P th set of mutually exclusive projects.

$$\sum_{i \in S_p} \sum_{j=1}^{T} X_{ij} \leq 1 \quad \text{for } p = 1, \ldots, P \tag{14}$$

Depending on the situation at hand, we can add several other types of constraints to this model. For example project type, investment type, sponsor(s) of project, number of ongoing or proposed projects, high technology and etc.

The objective function The objective function will attempt to minimize the sum of the deviations associated with the constraints in the model.

$$\begin{aligned} \text{Min } Z = {} & P_1(w_1 d_1^+ + w_2 d_1^-) + P_2(w_3 d_2^+ + w_4 d_2^-) \\ & + P_3(w_5 d_3^+ + w_6 d_3^-) + P_4(w_7 d_4^+ + w_8 d_4^-) \\ & + P_5(w_9 d_5^+ + w_{10} d_5^-) + P_6(w_{11} d_6^+ + w_{12} d_6^-) \end{aligned} \tag{15}$$

$P_1, \ldots, P_6$ are preemptive priorities and $w_1, \ldots, w_{12}$ are set of weights for every deviation from target.

2.3. A case example In this section, a model is developed and solved based on data from a company in Tehran. The Name of all projects have been renamed due to reasons of privacy the company involved is a domestic. MSE telecommunications company and is well known for making electronic appliances in its business operations. In this company before a project proposal is considered seriously, it must undergo a careful feasibility study to estimate the costs and revenues as well as technical and financial risk. A team including executives, project managers and some advisors accomplish this task. In addition "contribution to organizational goals/missions" as a qualitative objective is estimated and overall preference of decision makers for each project is obtained by filling out a questionnaire. Each question is replied on a Likert scale 1-5, with 1 representing "Strongly disagree" and 5 representing "Strongly agree". The Likert scale is a rating scale measuring the strength of agreement with a clear statement. The decision makers want to select a portfolio of new product development projects from ten candidate projects and schedule them over an eight-period planning horizon, while satisfying existing constraints. Each period lasts six months. Management has provided a budget to finance new projects in the coming four years, at maximum of 250,000 in monetary unit. Minimum expected benefit is 2,000,000 monetary units. Maximum accepted risk of project portfolio for the company is 40%. Each project is unique. The total numbers of researchers in R and D are 32 people. Selected projects, which cannot begin immediately, scheduled so as to minimize the total deviations from target values. All amounts are

TABLE 2. Projects Information.

Project	Mandatory	Total investment	NPV (Benefit)	Risk	Manpower	Quality score	Overall preference
1	No	1000	750	0.8	8	0.211	4
2	No	1100	584	0.2	8	0.349	4
3	No	1100	533	0.7	7	0.131	4
4	No	230	241	0.5	5	0.059	2
5	No	70	71	0.4	2	0.026	4
6	No	70	38	0.2	2	0.162	5
7	No	1400	237	0.3	10	0.021	2
8	No	1700	548	0.3	10	0.011	2
9	No	500	115	0.4	6	0.019	3
10	No	140	94	0.2	3	0.012	3

given in1000 in monetary unit. Quality score for each project is calculated by AHP method.

Other information is shown in Table 2 and Table 3.

Our analysis of the problem situation in team reveals the goals cannot be ranked on the basis of preemptive priorities. Therefore a weighted GP model was used for our problem. But the goals are expressed in different measurement units and hence the integration of various goal-deviations in their original form has no practical significance. For this case we utilized a simple approach of dividing each goal constraint by its target value [5]. Team members and some other exterior experts were our respondents.

The model was solved by LINDO on a 1.4GHz-Pentium based personal computer in a few seconds (almost one second) of computer time. The result or optimal project portfolio is derived from an extensive discussion and is shown in

TABLE 3. Projects Information, Costs.

Period	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6	Project 7	Project 8	Project 9	Project 10
1	90	150	150	25	10	15	200	150	50	25
2	160	200	400	75	30	25	350	250	125	50
3	220	300	350	70	20	-	350	350	125	35
4	220	300	200	60	10	-	300	350	100	30
5	150	150	-	-	-	-	200	300	100	-
6	160	-	-	-	-	-	-	175	-	-
7	-	-	-	-	-	-	-	125	-	-
8	-	-	-	-	-	-	-	-	-	-

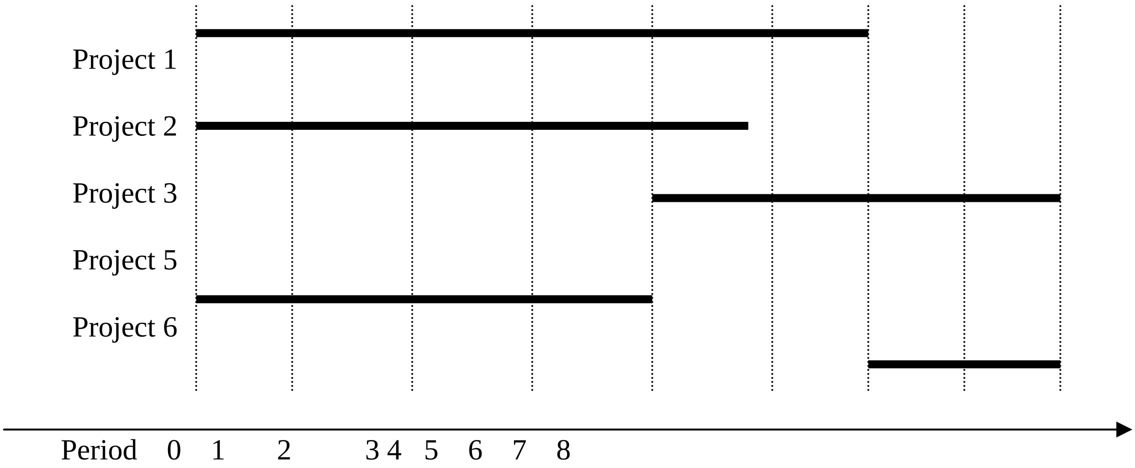

Figure 1. Project portfolio schedule.

Figure 1. Project 1, 2, 3, 5, and 6 were selected by model as optimal project portfolio and other projects have been removed. Projects 3 and 6 don't start immediately after planning and they start at periods 5 and 7 respectively. In addition all of them will be finished at the end of planning horizon.

For sensitivity analysis and getting a balanced portfolio we can keep some projects or delete some others thorough constraints 9, 10, and 11.

2.3.1. Discussion…Since essential factors or goals are distinct, the model provides an appropriate tool for decision makers to reach a consensus due to the changing of each weight hence several modes can be distinguished. The results are shown in table 4. A monetary unit is expressed in 1000. The first column is associated with the basic or benchmark scenario. For this mode total cost is 3340 monetary unit with total benefit of 1976 monetary unit. In addition, qualitative goals and preference satisfaction is fulfilled at almost a maximum possible amount. Also, all employees in R and D section are not put to use.

An attempt has further been made to generate some alternative plans, so that the company executives may recognize the most acceptable and appropriate solution depending on current situation. The following plans or scenarios have been generated.

In the first, plan cost weight has been increased to some degrees while other weights have stayed unchanged. In the first step most projects have been changed, reduction in total benefit has occurred more than total cost and risk. Achievement in qualitative and preference goals has been decreased but numbers of employees are in maximum. As shown in table 4 when the weight of cost has been increased no change occurred. In these situations the beginning of each project is changed.

In the next plan, benefit weight has been increased to some degree while other weights have been stayed unchanged.

In regard to benchmark scenario, total benefit has been increased and other parameters have not changed considerably and increasing the weight of benefit has no effect on the result.

In third plan, weight of risk has changed. The Risk is almost decreased to target value and total benefit is decreased substantially. A noticeable point is the number of projects that have increased to 6 proposals. This may cause an unbalanced project portfolio.

Changing in weight of skilled manpower has no change on solution, as well as two other goals, qualitative and preference.

TABLE 4. No Preemptive Priorities Results.

Items	Benchmark Scenario	Weighted Goals (X)					
Cost weight Benefit weight Risk weight Skilled manpower weight Qualitative goal weight Preference weight	0.188 0.150 0.191 0.138 0.140 0.193	5 1 1 1 1 1	10 1 1 1 1 1	15 1 1 1 1 1	1 5 1 1 1 1	1 10 1 1 1 1	1 15 1 1 1 1
Cost Benefit Risk	3340 1976 1085	3270 1437 816	3270 1437 816	3270 1437 816	3410 1999 1076	3410 1999 1076	3410 1999 1076
Skilled manpower	27	32	32	32	28	28	28
Quality goal Preference	0.879 21	0.322 14	0.322 14	0.322 14	0.865 20	0.865 20	0.865 20
Projects	X11 X21 X35 X51 X67	X13 X41 X71 X94 X101	X13 X45 X71 X91 X105	X13 X41 X71 X94 X101	X11 X21 X35 X67 X101	X11 X21 X35 X67 X101	X11 X21 X35 X67 X101
Cost weight Benefit weight Risk weight Skilled manpower weight Qualitative goal weight Preference weight	0.188 0.150 0.191 0.138 0.140 0.193	1 1 5 1 1 1	1 1 10 1 1 1	1 1 15 1 1 1	1 1 1 50 1 1	1 1 1 75 1 1	1 1 1 100 1 1
Cost Benefit Risk	3340 1976 1085	3270 1437 816	3270 1437 816	3755 1774 803	3270 1437 816	3270 1437 816	3270 1437 816
Skilled manpower	27	32	32	33	32	32	32
Quality goal Preference	0.879 21	0.322 14	0.322 14	0.781 22	0.322 14	0.322 14	0.322 14
Projects	X11 X21 X35 X51 X67	X13 X45 X71 X91 X105	X13 X41 X71 X94 X101	X11 X21 X51 X67 X74 X102	X13 X45 X71 X91 X105	X13 X45 X71 X91 X105	X13 X45 X71 X91 X105

TABLE 5. The Results on Each Individual Goal.

Items	Benchmark Scenario	Weighted Goals (X)					
Cost weight Benefit weight Risk weight Skilled manpower weight Qualitative goal weight Preference weight	0.188 0.150 0.191 0.138 0.140 0.193	1 0 0 0 0 0	0 1 0 0 0 0	0 0 1 0 0 0	0 0 0 1 0 0	0 0 0 0 1 0	0 0 0 0 0 1
Cost Benefit Risk	3340 1976 1085	3270 1437 816	3410 1999 1076	4070 1724 801.5	3780 1723 1059	3340 1976 1086	3340 1976 1086
Skilled manpower	27	32	28	30	32	27	27
Quality goal Preference	0.879 21	0.322 14	0.865 20	0.762 18	0.563 22	0.879 21	0.879 25
Projects	X11 X21 X35 X51 X67	X13 X41 X71 X94 X101	X11 X21 X35 X67 X101	X11 X21 X67 X74 X91	X11 X35 X54 X67 X71 X105	X11 X21 X35 X51 X67	X11 X35 X53 X67 X71 X92 X103

In addition, the team examined the results on each individual goal. The results are shown in table 5. At first glance, it can be seen that the number of selected proposals may be larger than 5. In this situation management must pay attention to portfolio balancing. Moreover these results make clear the importance of each goal. For example, when we only notice the management preference goal, the company may be suffered too many projects while the benefit is as equal as the benchmark scenario.

Each of the above plans or scenarios represents a unique situation. These outcomes may be offered to the management for providing information for helping them to make a decision about this problem. Management may also select the most appropriate plan for each portfolio.

3. SUMMARY AND CONCLUSIONS

Project selection is a vital activity in today's companies. When a variety of promising alternatives exist, the difficulty in carrying out this task can usually be traced to budgetary constraints, time constraints, risk, and a limited number of personnel and facilities. In addition, each project must be assessed on the basis of multitude of technical and commercial criteria, some of which may not be easily quantifiable.

Some of the features of the goal programming model presented in our paper include the implicit consideration of resource limitations, the ranked consideration of multiple conflicting goals, the ability to combine both quantitative and qualitative criteria, and the intuitive comfort in which the model can be understood by decision makers.

A zero-one linear goal-programming model is presented for R and D project portfolio selection and scheduling. The proposed model focuses on the major issues that must be considered in project portfolio selection. For decision makers the model provides a tool to better understand the nature of trade-offs between the different elements that influence the R and D project portfolio.

Further research is required for resource interdependencies. In some industries, such as IT, the sharing of hardware and software resources among several projects is common. Incorporating this issue and level of resource interdependencies in the model for some cases is essential.

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