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A Quantitative Model for Optimal Budget Distribution and Allocation to Construction Projects (Case Study: Shiraz University)

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Abstract

Findings from previous studies indicate that despite the existence of extensive research, comprehensive models that simultaneously consider criteria such as project desirability, marketability, performance quality, and expert preferences have received limited attention. Therefore, the present study focuses on developing a quantitative model for optimizing the distribution and allocation of budgets to development projects in 2024. From an applied perspective, the research incorporates all the aforementioned criteria. The research population consists of selected experts from Shiraz University. To solve the model, a comprehensive approach method is employed due to the multivariate nature of the problem, while data analysis is conducted using GOM software. For validation, data collected from Shiraz University were tested under both deterministic and fuzzy conditions with different utility values. The results of implementing the proposed model indicate that, in each period, the projects selected for budget allocation are clearly identified and the corresponding allocable budget for each development project is determined accordingly.

Keywords: Allocation, Budget, Distribution, Quantitative model.

1 | Introduction

Budget as a political process measurement achieves agreements on targets and resource allocation among various priorities and provides a system for cost control. Budget is the most important governmental document as the financial statement of government function helps organizations to achieve targets of the National Development Plan and Perspective Document and their effective duties. The operational budgeting system, aimed to achieve the financial document, links the budget credits to governmental actions and achieves the budget saving, clarity, efficiency and effectivity [1]. Budget reflects all government plans and activities and plays a major role to national economy and development. Cost control lost its importance with

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extending government duties and fast increasing government expenditures and its connection with the general economic condition and it seems necessary to improve planning, control and management systems at general resources and help the legislators to extend their views on the results of functions and performance costs. It attracts attention of nations to economic, efficiency and effectivity of governmental resources, or in other words, financial management of government. It requires improvement in current budgeting measures [2].

Today organizations are responsible to simultaneously examine different projects in different sites; and the projects also require resources at different periods of time based on their number of activities. With limited resources, the organization will fail if the manager doesn't allocate the budget successfully. Thus, it is necessary for a given organization to use proper measures in optimal budget allocation. Traditional planning programs (e.g. PERT/CPM) plan with unlimited resources, but these traditional systems would fail to respond to organizational needs in variable conditions of current environment with limited resources and planning should be carried out with mathematic methods systematically [3].

Budgeting is essentially the process of allocating limited resources to address limited needs. Efforts in budgeting and resource allocation aim to ensure the most efficient use of resources, which are often scarce and economically constrained. Therefore, it is necessary to utilize every available resource to the greatest extent possible in order to achieve the desired objectives. In terms of resource-to-money conversion, this implies attaining maximum efficiency with minimum cost [4]. Budgeting translates organizational objectives and strategies into financial statements, clarifies how plans should be implemented, and provides a basis for monitoring and controlling progress. Organizations rely on budgeting because it demonstrates the financial implications of plans, identifies the resources required for their realization, and establishes standards for measuring, supervising, and controlling outcomes in comparison with planned objectives [5].The present study is aimed to design a qualitative model for optimal budget distribution and allocation to civil projects in project-oriented organizations. To do so, it is used multi-objective planning approach, therefore, the first section discussed the necessity to carry out a study and the second section presented the history of study. The third section discussed the recommended mathematical model for optimal budget allocation in civil projects. Presenting the results from the model in section four, the last section explain the results from the recommended model in the study.

2|Literature Review

2.1|Theoretical History

The results show that man during the history, relying on his efforts and using measures and tools, has utilized very primary methods to supply his natural and initial needs and preserve cost and income statements and daily income and expenses and the traditional methods replaced by modern methods of planning. The history of performance-based budget dates back to late 1950s, when the US Army used this sort of planning. In 1960s Canada also started performance-based budgeting system and; it was the decade in which more focus were on arranging expenses with results and products. In 1970s the Canadian Government set an agenda for evaluation of plans and their effectiveness. Later other countries turned to this budgeting.

2.2|The Experimental History

Azar and Seyed Esfahani [6] model 1995 was one of the most important models in general budgeting; she introduced a mathematical model for budget allocation in governmental organizations, so that the mathematic model of cost planning in research population is an ideal model. Also the phase logic has been used to raise the credit of results and to measure "ambiguity and inaccuracy" of cost data. The results show that the mathematical model designing of budget is increasingly dependent on factors such as budgeting horizon, budget structure and expectations of management and decision makers.

Kasimin and Yusoff [7] in an article used the methodology of soft systems aimed to allocate financial resources to civil projects. Taherpoor Kalantari et al. [8] examined the operational budget in government organizations in order to realize effective agents in law settlement. On other hand, Pourali and Kakovan [9] carried out a study on setting up requirements of operational budgeting in national universities of medical sciences. Also Namazi and Kamali [10] studied on budget allocation optimization based on priorities and different limitation of budget in Fars Province. Naldi [11] carried out a study called profitability exemption maximin in budget allocation. Zamfirescu [12] discussed budget allocation in different plans at different periods and, in fact, it was a period in which every plan's performance was measured and allocated specific budget based on its performance.

Frow [13] carried out a study on budget flexibility conformity with its budget control, how budgeting acts in uncertain conditions and management flexibility in those conditions. Hassan et al. [14] worked on a study called a Lexicographic Goal Planning Model for budget allocation of Kebangsaan library in Malaysia. Dan Dan and Desmond [15] designed a model in connection with budget allocation for Owerri University, Imo State using weight goal planning pattern.

Azar and Seyed Esfahani [6] examined the Iranian general budgeting using the mathematic model of budget allocation in governmental organizations. Wang et al. [16], Presented an optimization models for allocating advertising budget across multiple markets under different objectives and constraints are developed. They formulate two mathematical models to maximize profit/demand under budget limits and show how pricing parameters and market features affect the optimal solution. Fereshtehnejad et al. [17] introduces an Integer Linear Programming (ILP) framework for optimal budget allocation in bridge maintenance. Using element-level inspection data, the model selects Maintenance, Repair, Rehabilitation (MR&R) actions to improve network performance and safety risk under budget constraint.

Nascimento et al. [18] develops a Multi-Criteria Decision-Making (MCDM) framework based on the TOPSIS method to prioritize public projects/programs for budget allocation. By weighting criteria and calculating the closeness to the ideal solution, the model provides mathematical ranking of options and is suitable for implementation in governmental budgeting contexts. Lotfi et al. [19] proposes a robust and risk-averse optimization model for allocating budget among projects while considering sustainability, resilience, and uncertainty in cost/benefit. The model structure enables scenario analysis and sensitivity tests so that decision makers can balance between financial efficiency and risk management. A multi-objective budgeting model presented in an article, in which the objectives included project utility maximizing, project performance quality, experts preferences and project marketability. Later in the article it has been discussed the recommended budgeting model and how multi-objective planning method solves the model.

2.3 | Conceptual Model

The conceptual pattern based on theories related to understudied subject, literature and past studies adopted from the author's ideas in which the elements of patter are defined and the hypothetical relationship between them is determined. *Fig. 1* illustrates the conceptual model.

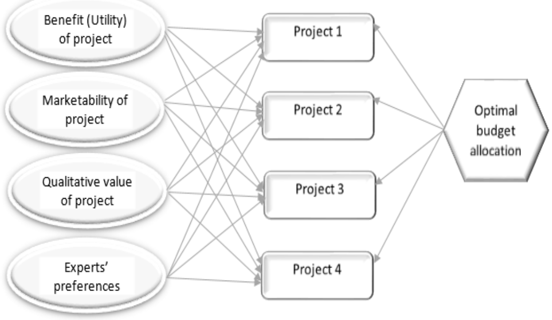

Fig. 1. Conceptual model with budget allocation optimization approach.

3|Methodology

The present study discusses the budget allocation appropriate with the structure (*Fig. 1*). The structure, at one hand, included standards used to allocate budget through the year and, at the other hand, it focused on four civil projects. The aim of research methodology is to help the author determine what method and measure should be used to achieve the answers in more accurate, easier, faster and cheaper fashion. It is typically a qualitative method in which the modelling and analysis has been discussed and objectively it is an applied and developmental study. In this section, we discussed a method to solve multi-objective decision making problems called comprehensive standard method. The comprehensive standard method, depends on the case, minimizes the first, second … ponential sum of relative derivations from their optimal values.

3.1|Multi-Objective Planning Model for Budget Allocation and Distribution to Civil Projects

The present article discussed budget allocation and distribution, the optimal budget allocated to each project from total (i) projects, in time horizon included J period so that the best optimal answer is obtained.

The analysis results determines the utility of projects and it basically contains the current net values. The marketability standard defines the market attraction degree for each project. The qualitative value of each project is measured as how long the performance indices are fulfilled. The experts' evaluation is the score for each project which is obtained after analyzing some criterion.

Definition of indices

Project parameter (i=1, 2, 3, 4).	**i**
Period parameter (j=1, 2, 3, 4).	**j**

Variables of model

Budget allocation value for project i at period j.	$\mathbf{X_{ij}}$
Binary variable (zero and one), 1: Budget allocation to project i at period j, 0: No budget allocation to project i at period j.	$\mathbf{d_{ij}}$

Model parameters

The model parameters are as follow.

Maximum available budget at period j.	$\mathbf{F_j}$
Benefit (Utility) of project i.	$\mathbf{b_i}$
Qualitative value of project i.	$\mathbf{q_i}$
Experts' preferences.	$\mathbf{p_i}$
Maximum allocable budget to project i at all periods.	$\mathbf{t_i}$
Marketability of project i from people view.	$\mathbf{m_i}$
Minimum required budget for project i at period j.	$\mathbf{Pmin_{ij}}$
Maximum required budget for project i at period j.	$\mathbf{Pmax_{ij}}$

Maximum available phasic budget at period j. $\tilde{F}$

Maximum allocable phasic budget to project i at all periods. $\tilde{t}_i$

Phasic utility of project i. $\tilde{b}_i$

The mathematic model of present study has been developed based on the aforementioned defined variables.

The objective functions

Utility maximization

$$\text{Max } Z_1 = \sum_i \sum_j b_i \, x_{ij} \, d_{ij}.$$

Marketability maximization

$$\text{Max } Z_2 = \sum_i \sum_j m_i \, x_{ij} \, d_{ij.}$$

Performance quality maximization

$$\text{Max } Z_3 = \sum_i \sum_j q_i \, x_{ij} \, d_{ij}$$

Preference maximization

$$\text{Max } Z_4 = \sum_i \sum_j p_i \, x_{ij} \, d_{ij}.$$

The first function maximizes the sum of utilities indicating satisfaction of the project. The second function maximizes the sum of marketability which determines marketability standard of market attraction degree for each project. The third function maximizes the sum of performance quality. It defines qualitative value of each project and multiplies it by the allocated budget (if dij=1). The forth function maximizes the sum of preferences. Evaluation means the score given to each project.

Constraints

$$\sum_i x_{ij} \leq F_{j,} \qquad \text{for all j.} \tag{1}$$

$$\sum_i x_{ij} \leq \tilde{F}_j, \qquad \text{for all j.} \tag{2}$$

$$\sum_j x_{ij} \leq t_i, \qquad \text{for all i.} \tag{3}$$

$$\sum_j x_{ij} \leq \tilde{t}_i, \qquad \text{for all i.} \tag{4}$$

$$\text{Pmin}_{ij} \leq x_{ij}, \qquad \text{for all i, j.} \tag{5}$$

$$x_{ij} \leq \text{Pmax}_{ij}, \qquad \text{for all i, j.} \tag{6}$$

The first constraint guarantees that we don't cross the available limit at each period, that is, at each period the sum of budget allocation should be smaller or equal to the maximum budget. The second constraint guarantees that we don't cross the allocable budget limit to project i at all periods, that is, at each period the sum of budget allocation should be smaller or equal to the maximum allocable budget for that project at all periods. The third constraint guarantees that we don't cross the allocated budget limit to the project i at period j, that is, at each period the minimum allocated budget should be smaller or equal to the budget at that period.

The fourth constraint guarantees that we don't cross the maximum required budget to the project i at period j, that is, at each period the allocated budget to each project should be smaller or equal to the maximum allocated budget at the same period.

As multiplication of d_{ij} (binary variable) by x_{ij} (decision variable) make the aforementioned functions nonlinear and, due to the long time nonlinear solution the following change of variables occurred and should be included into the functions and finally linear constraints should be added from *Constraints 7-9*.

Linearization constraints

If we have $XD_{ij} = x_{ij} * d_{ij}$ thus the constraints related to XD_{ij} is written as follow:

$$XD_{ij} \leq x_{ij}. \tag{7}$$

$$XD_{ij} \leq RR * d_{ij}. \tag{8}$$

$$XD_{ij} \geq x_{ij} - RR(1 - d_{ij}). \tag{9}$$

At other hand, as it should be guaranteed that only if $d_{ij} = 1$ (when budget is allocated), necessarily the budget value ($x_{ij} \neq 0$) for the project i should be allocated at the period j, therefore, we added two constraints to the previous constraints:

$$d_{ij} \leq x_{ij}. \tag{10}$$

$$x_{ij} \leq RR * d_{ij}. \tag{11}$$

As we suggested some parameters such as $\tilde{F}_j$ and $\tilde{t}_i$ in the mathematic model as phasic parameters, thus we should convert phasic model to final model to solve the mathematic model.

As we have taken the maximum budget, maximum allocable budget and project utility as trapezius phasic numbers, given the following phasic parameters, the phasic *Constraints 2* and *4* are converted to final constraints.

$$\tilde{F}_j = \left(F_j^1, F_j^2, F_j^3, F_j^4 \right).$$

$$\tilde{t}_i = \left(t_i^1, t_i^2, t_i^3, t_i^4 \right).$$

The phasic constraint No.2 is changed to the following final constraint:

$$\sum_i x_{ij} \leq (1 - \alpha)\frac{F_j^3 + F_j^4}{2} + \alpha\frac{F_j^1 + F_j^2}{2}, \qquad \text{for all j.}$$

The phasic constraint No.4 is changed to the following final constraint:

$$\sum_j x_{ij} \leq (1 - \alpha)\frac{t_i^3 + t_i^4}{2} + \alpha\frac{t_i^1 + t_i^2}{2}, \qquad \text{for all i.}$$

The objective functions and other constraints (final constraints) remain intact.

3.2 | Problem solution using Comprehensive Standard Method

A new objective function is obtained using the comprehensive standard method:

$$\text{Min } Z_5 = \sum_{k=1}^{4} \frac{Z_k^* - Z_k}{Z_k^*}.$$

$$\text{Min } Z_5 = \frac{Z_1^* - Z_1}{Z_1^*} + \frac{Z_2^* - Z_2}{Z_2^*} + \frac{Z_3^* - Z_3}{Z_3^*} + \frac{Z_4^* - Z_4}{Z_4^*} = \frac{Z_1^* - \sum_i \sum_j b_i\ XD_{ij}}{Z_1^*} + \frac{Z_2^* - \sum_i \sum_j m_i\ XD_{ij}}{Z_2^*} + \frac{Z_3^* - \sum_i \sum_j q_i\ XD_{ij}}{Z_3^*} + \frac{Z_4^* - \sum_i \sum_j p_i\ XD_{ij}}{Z_4^*}.$$

Meanwhile, the constraints remain the same as before.

4 | Findings

Application and abilities of the method presented here using the numbers from the studied location. Also, using the Chimney Expected Interval it is stressed on importance of subject in multi-objective decision making problems. At the end of section, the results from final and phasic methods will be compared.

4.1 | Numeric Results

The model introduced at the previous section for budget allocation to four civil project tested for a 4-year period. *Tables 1-4* contain the input parameters.

Table 1. Model input parameters.

	bi	qi	Pi	mi	ti
P_1	0.75	0.95	0.95	2	32600
p_2	0.68	0.93	0.88	4	31800
p_3	0.50	0.90	0.80	3	22147
p_4	0.80	0.98	0.98	1	36547

Table 2. Continue the input parameters of the model.

Period j	j=1	j=2	j=3	j=4
Fj	16860	93300	14200	80400

Table 3. Maximum required budget for project i at period j ($Pmax_{ij}$).

	j=1	j=2	j=3	j=4
P_1	8000	10000	9000	5200
p_2	9700	8500	7500	3760
p_3	9596	5000	10000	3280
p_4	5235	7600	9000	6100

Table 4. Minimum required budget for project i at period j ($Pmin_{ij}$).

	j=1	j=2	j=3	j=4
P_1	4000	3000	3600	0
p_2	4850	0	3000	1760
p_3	4847	1500	4000	1280
p_4	0	2280	0	2100

After implementing the model, the following tables illustrate the results. *Table 5* shows d_{ij} values (budget allocation status in a project at each period of planning horizon) for different periods and projects. *Table 5* shows the optimal answer to these variables given the collected data.

Table 5. Projects that receive in each budget period.

	j=1	j=2	j=3	j=4
P1	1	1	1	1
p2	1	1	1	1
p3	1	1	1	1
p4	0	1	0	1

Zero and one variables indicate non-allocation of budget to project i at the period j and allocation of budget to project i at the period j, respectively. If the variable equals 1 it means that the budget has been allocated and if it is zero the budget has not been allocated.

For instance, after implementing the model to the P4 project, the budget only allocated to second and fourth periods and the remaining projects have received their budget at all periods. *Table 6* shows X_{ij} (budget allocation to the project i at the period j) for different projects and different periods of planning.

Table 6. Amount of budget allocation to each project per period (figures to million rials).

	j=1	j=2	j=3	j=4
P_1	4000	10000	3600	5200
p_2	8013	8500	6600	3760
p_3	4847	5000	4000	3280
p_4		7600		6100

For example, P_4 project has received 7600 m Rls at the second period and 6100 m Rls at the fourth period and the P_3 project received 4000 m Rls at the third period.

The first, second, third and fourth optimal objective functions after implementing the model given the data are as follow.

Z1= 55708.700.

Z2= 218173.000.

Z3= 75830.340.

Z4= 73112.140.

Z5= 0.028.

The optimal values show that the first to fourth functions are there for maximization as they are Max functions and have their maximum values but Z_5 is for minimization and has the minimum value as it is a Min function.

Validation

We obtain the objective functions of final and non-phasic model using Chimney method for different α values for different values of utility parameter. *Table 1* shows different b_i (project utility) values. *Table 7* shows the first objective function for different project utility values.

Table 7. Objectives of the objective function The definitive and non-fuzzy models for different values of project desirability.

Issue Number	bi	Jimenez Method Definitive Method	$\alpha = 0.1$	$\alpha = 0.2$	$\alpha = 0.5$	$\alpha = 0.8$
1	$\mathrm{bi} - 15$	43633.700	43672.700	51698.700	43568.700	43490.700
2	$\mathrm{bi} - 10$	47658.700	47700.700	47672.700	47588.700	47504.700
3	$\mathrm{bi} - 5$	51728.800	51683.700	43646.700	51608.700	51518.700
4	bi	55708.700	55756.700	55724.700	55628.700	55532.700
5	$\mathrm{bi} + 5$	59733.700	59784.700	59750.700	59648.700	59546.700
6	$\mathrm{bi} + 10$	63758.700	63812.700	63776.700	63668.700	63560.700
7	$\mathrm{bi} + 12$	65368.700	65423.900	65381.100	65276.700	65166.300
8	$\mathrm{bi} + 15$	67783.700	67840.700	67802.700	67688.700	67574.700

The second, third and fourth objective functions remain intact for different project utility values. For instance, *Figs. 2* and *3* compare different objective functions.

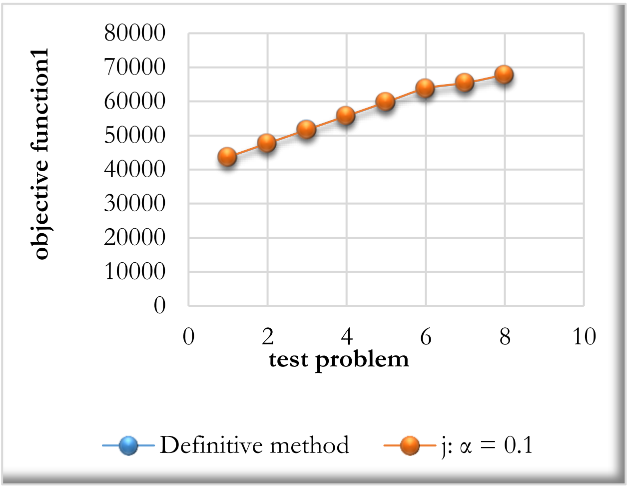

Fig. 2. Comparison of the definitive method and the jimenez method ($\alpha = 0.1$).

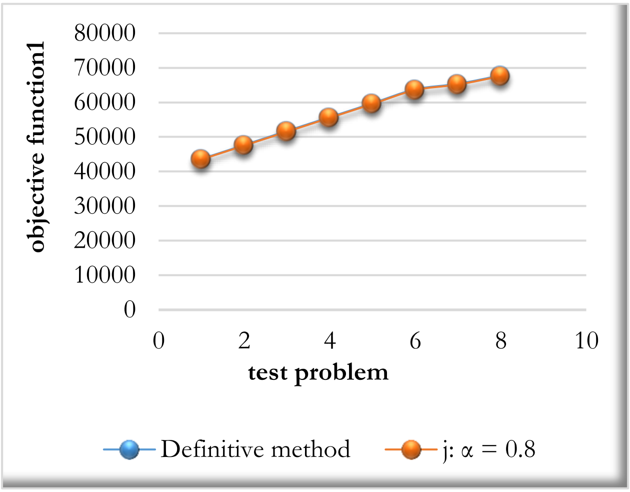

Fig. 3. Comparison of the definitive method and the jimenez method ($\alpha = 0.8$).

The results show that Chimney's phasic ranking gives better answers than the final method. Also, for –α different sections of better objective function are obtained with further values than 1 especially α=0.5 and for those values close to 1, the objective function deteriorates than its previous state, thus, we only have optimal answers at α=0.5 and α=0.2.

5 | Conclusion

Budgeting is a measurement when it is used properly could give positive incentives and make ground for creativity. Budget allocation is amongst the main task for financial managers in organizations. So, planning is regarded as the most important pre-requisite for budget allocation and it is to provide and distribute and allocate limited equipment in order to achieve desired objectives at minimum possible time and minimum possible cost. Today no one denies how important investment is for civil project and in fact, these activities determine the budget allocation. Accordingly the present study presents a budgeting-based multi-objective planning for optimal budget allocation and distribution to civil projects. The objectives are maximization of experts' preferences, maximization of project utility, maximization of project marketability and maximization of performance quality. Finally, the model was solved using multi-objective planning, and the results provided two main outcomes: The identification of projects selected in each period for budget allocation and the determination of the allocable budget for each civil project in a given period.

Future research could expand upon the present study in several ways. While this research introduced a mathematical model based on four objective functions—utility, marketability, performance quality, and expert preferences—future studies may also incorporate project risk into the budget allocation process. Since the rate of return on investment was not considered in the current model, it would be valuable for future authors to examine this aspect in greater depth. In addition, as the present study did not include documentation and bidding costs, further research could account for these factors, especially from the perspective of contractors. Another important direction for future work involves considering the derivation of objectives, which was not addressed in this study. Moreover, parameters such as risk and project marketability, which are inherently uncertain, could be modeled as fuzzy variables. Finally, when the scope of problems increases, the computational time grows significantly; therefore, the application of meta-heuristic algorithms is recommended to handle larger and more complex cases.

Author Contribution

The author was solely responsible for the conception and design of the study, development of the methodology, implementation of the computational framework, validation of the results, sensitivity analyses, and preparation of the manuscript.

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Data Availability

All data generated or analyzed during this study are included in this published article.

Conflicts of Interest

The author declares that there are no conflicts of interest relevant to the content of this article.

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