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Multicriteria Web-Based Dss for Resource Allocation in Higher Education Organizations

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ABSTRACT

The allocation of scarce resources is a complex problem, specially when it comes to budget constraints. Therefore, this work aims to propose a multicriteria web-based Decision Support System for resource allocation in the context of higher education organizations, more precisely, public universities that have budget constraints, such as Brazilian federal universities. To do so, a Brazilian federal university was chosen as a parameter to make a numerical application to validate the multicriteria model for resource allocation proposed and, afterward, a web-based DSS was developed. For the MCDM resource allocation model, an additive value function was considered to set the percentage of the total budget that every alternative should receive. The problem was seen as a particular case of project portfolio selection problem because its approach is deemed to be appropriate for a resource allocation decision context. The results were satisfactory, and the system provided a clear vision on how the resource allocation procedure works, the entire process became more transparent to the ones that are affected by it, to the decision makers and the government, enabling them to take more efficient and reasonable decisions.

Keywords: Resource allocation, Budgeting, MCDM /A, Universities, Web-based DSS, Model-driven DSS.

INTRODUCTION

Resource allocation problems usually involve conflicting decisions and are confronted by organizations of every size, type, and purpose, once their capacity to borrow funds or raise equity capital, for instance, has practical limits [1]. For public universities, it is even more challenging to deal with budgeting problems because they use their taxpayers' money to provide education services [2]. Hence, there is a tremendous societal interest (or at least should exist) in the way such money is allocated, where the cost of failure is seen as something unacceptable [3].

Multiple criteria decision making/aid (MCDM / A) area has been claimed as an effective way to assist decision makers (DMs) to deal with the challenges that involve resource allocation problems or budgeting problems [4], specially in higher education organizations [5]. Also, Turban *et. al.* and Power [6, 7] affirm that Decision Support Systems (DSS) can improve decision quality. Therefore, the use of a suitable web-based Decision Support System (DSS) meant to integrate MCDA / M analysis into the decision aiding process is an essential tool to respond to this ongoing challenge.

Multiple Criteria Decision Support Systems (MCDSS) are considered a "particular" type of system within the broad family of DSS [8]. MCDSS use different multicriteria decision methods to estimate efficient solutions, and they incorporate user's input in numerous phases of modelling and solving a problem [8].

According to [4], despite the growing attention to MCDA-based modelling approaches for resource allocation [9, 1, 10], there is still little indication in the operational research and decision sciences literature on how to structure these models in practice.

Besides, when considering the case of a university, the use of a suitable multi-attribute decision method integrated with a web-based Decision Support System to better distribute the limited budget could mean to reach the best compromise solution, to apply all the available resources with efficiency.

Thus, this work aims to fill this gap by proposing a multicriteria web-based Decision Support System to solve a resource allocation problem in the context of higher education organizations, more specifically, public universities that have budget constraints. For this reason, a Brazilian public university was chosen to validate the model; once, currently, the university does not have a model or system for such a problem. The research can contribute to the decision question of how to allocate universities internal budget properly [2].

The case study conducted in this work considers the results of previous studies related to MCDM portfolio selection problems, such as: [2, 11, 12, 13].

METHODOLOGY

The problem considered here is a special case of portfolio problematic, seen as a resource allocation problem. The decision maker of the problem was the director of the budget and planning department of the university, and the analyst was the author of this study. The university studied has 21 sectoral administrative units (called *UAS*) that are divided by areas, such as human sciences, biological sciences, engineering, faculty of medicine, etc. These administrative units are the alternatives, projects or budgetary units of the MCDM model.

Therefore, the set of alternatives is $A = \{UAS\ 1, UAS\ 2, UAS\ 3, UAS\ 4, UAS\ 5, UAS\ 6, UAS\ 7, UAS\ 8, UAS\ 9, UAS\ 10, UAS\ 11, UAS\ 12, UAS\ 13, UAS\ 14, UAS\ 15, UAS\ 16, UAS\ 17, UAS\ 18, UAS\ 19, UAS\ 20, UAS\ 21\}$.

The criteria of the model, defined by the DM, are evidenced in Figure 1.

Criteria	Description	Objective
InAlEqv	General index of equivalent students. Number of students entering, enrolled and graduated from undergraduate, postgraduate courses (master's and doctorate), and medical residences.	Maximize
IQCD	Faculty qualification criterion, that measures the academic staff qualification by the number of lecturers with Phd and master's degrees.	Maximize
IVO	Dropout rate criterion, defined by the summation of vacancies not filled in the regular admission process, plus vacancies arising from withdrawing, dismissed students and transfer.	Minimize
IPP	Total of research projects with external financial support.	Maximize
IPE	Total of extension projects with external financial support.	Maximize
ITS	Graduation success rate. Performance criterion indicator that measures the relationship between the number of graduates and the number of new entrants.	Maximize
IDEAE	Teaching efficiency. Measured by the relation between the total of equivalent students and the total of equivalent professors.	Maximize
IDGQ	Quality of the undergraduate courses, based on the evaluations from the National Institute of Studies and Educational Research Anísio Teixeira – INEP / Brazil.	Maximize
IDQM	Quality of the master's degrees courses, based on the evaluations from the Coordination for the Improvement of Higher Education Personnel – CAPES / Brazil.	Maximize
IDQD	Quality of the doctorate degrees courses, based on the evaluations from the Coordination for the Improvement of Higher Education Personnel – CAPES / Brazil.	Maximize

Figure 4: Criteria of the Model

The weights (scale constants) of the model were also defined by the DM and are presented in Figure 2.

Criteria	InAlEqv	IQCD	IVO	IPP	IPE	ITS	IDEAE	IDGQ	IDQM	IDQD
Weights	0,2505	0,0405	0,145	0,124	0,124	0,150	0,038	0,044	0,042	0,042

Figure 2: Weights of the Model

The model adopted was an additive aggregation procedure for portfolio problematic with compensatory rationality, because of the characteristics of the problem. The primary goal of the model is to maximize the objective function, considering the given constraints [1], that is a budget constraint. Therefore, the objective function (1.0) and the constraints (2.0) are written as:

$$\sum_{i=1}^n z_i v(A_i) \quad (1.0)$$

Subject to:

$$\sum_{i=1}^n z_i c_i \leq C \quad (2.0)$$

Where i represents every UAS from the university, z_i is defined as a binary variable indicating whether item A_i is included or not in the portfolio, thus $z_i = 1$ if it is included and $z_i = 0$ if it is not [14]. $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation [15].

C and c_i are related to the constraints, where C is the budgeted amount available to fund all the UAS and c_i is the budget of each administrative unit, and it could be seen, for instance, as the cost to develop project i .

When considering a public university, no administrative unit can stay without receiving a part of the budget because of the minimum amount required to maintain the UAS, in services such as security, for example. Consequently, the decision problem here lies in defining which are the administrative units that will receive a part of the budget above the minimum value that

each one must receive, that is, the total budget requested by the UAS, considering their performance for the set of criteria, and that is a project portfolio selection problem.

Moreover, to adequate the model in this study and taking into account equation (1.0) and inequation (2.0), the variables of the model can also be described as:

c_i = the budget requested by the administrative unit or the budget above the minimum limit that each UAS want to receive;

$min c_i$ = minimum percentage of the budget that each UAS should receive;

z_i = binary variable that is equal to 1 when the UAS will receive the requested budget or equal to 0 otherwise;

$z_i c_i$ = the budget allocated to UAS "i", which is equal to c_i when z_i is equal to 1;

B = total budget from the university available to be allocated;

C = total budget amount that is above the minimum percentage of the budget that each UAS should receive, that is:

$$- \sum_{i=1}^n min c_i = C \quad (3.0)$$

Finally, the evaluation results from an additive value function it is of the form [15]:

$$v(A_i) = \sum_{j=1}^m k_j v_j(x_{ij}) \quad (4.0)$$

Where x_{ij} is the outcome obtained by item A_i in attribute j , v_j is the marginal value function of attribute j , k_j is the weight (scaling constant) for attribute j , and its summation must be equal to 1; $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation [15].

The total budget available (B) considered for the problem was R\$ 850,000.00, a value that represents 85% from 2018 total budget of the university, once that was the amount released by the Ministry of Education in 2018, due to government budget cuts. The minimum value considered that each administrative unit must receive ($min c_i$) was 70% from the last budget, a total of R\$ 700,000.00 since that is the minimum amount considered to maintain the UAS. Thus, $C = R\$ 150,000.00$. Following, the results from the model are shown in Table 1.

RESULTS

Table 1 - Resource allocation model results

Alternatives	$V_i(A_i)$	Go?	P_i %
UAS1	0,6682	0	12,16%
UAS2	0,5981	0	9,98%
UAS3	0,3880	1	2,92%
UAS4	0,3821	1	3,71%
UAS5	0,3804	1	3,58%
UAS6	0,2523	1	1,41%
UAS7	0,3422	1	2,55%
UAS8	0,2352	1	1,62%
UAS9	0,2799	1	1,75%
UAS10	0,2979	1	1,72%
UAS11	0,2319	1	1,57%
UAS12	0,4583	0	5,86%
UAS13	0,4044	0	4,72%
UAS14	0,4584	1	4,36%
UAS15	0,5781	0	10,43%
UAS16	0,7950	0	11,75%
UAS17	0,6195	1	9,78%
UAS18	0,3744	1	2,72%
UAS19	0,4103	1	2,58%
UAS20	0,2689	1	2,20%
UAS21	0,3339	1	2,62%
Total Value	5,2551		

Table 1 shows the alternatives, their respective value from the additive model (V_i) using a ratio scale normalization procedure, considered as the appropriate procedure for this type of

problem [11], the percentage (P_i %) of the total budget that each administrative unit should receive, the alternatives that are selected to receive the budget amount above the minimum budget ($Go?$) and the total value, that represents the objective function of the model.

From the use of the additive model, the results indicate a portfolio with 15 projects, and in terms of budget value, the solution consumes R\$ 148,831.30 from the available budget (R\$ 150,000.00). When deeply analyzing the results, although UAS 1, for instance, has a satisfactory performance in the criteria considered, the summation of the results of more than one UAS brings additional outcomes to the overall portfolio value than choosing only one project with a valuable performance. Such a solution means that the resources are distributed in a more balanced way among all items of the portfolio, and that is the best compromise solution for the case.

Given this consideration on the problem, it was possible to implement the multicriteria web-based DSS, based on the user's primary needs. The name defined for the web system was: MDSSFRA (Multicriteria Decision Support System for Resource Allocation). The principal DSS component is the multicriteria model, and the target users are the administrative staff from the budgeting unit of the university considered, DMs participants from every UAS, since they are affected by the allocation procedure, facilitators, developers, and administrators.

To implement the multicriteria web-based DSS, a PHP web platform was developed on the server side integrated with Python and a Database system MySQL was applied to store and retrieve data using Structured Query Language (SQL). The components of the system are shown in Figure 3, and they evidence results from previous studies [2, 12, 13], which served as the basis for establishing Pages 1, 2 and 3 of the system, already explained in these previous studies. Page 4 was the result of the implementation of the multicriteria model developed by this study

The screenshot displays the MDSSFRA web interface with four distinct pages:

- PAGE 1:** Year Selection. A dropdown menu is set to '2015' with a 'Next!' button.
- PAGE 2:** University Selection. A dropdown menu is set to 'UFMS' with a 'Submit me!' button.
- PAGE 3:** UFMS's indexes (2016). A large table with columns: AU, InAEq, IQCD, IVO, IPP, IPE, ITS, IDEAL, IDQG, IDQM, IDQD, TOTAL (VCL), %1, %2, Part %. It lists 20 administrative units (UA1 to UA20) with their respective index values.
- PAGE 4:** UFMS's Budget (2016). A table with columns: UA, Part %, Budget. It lists the same 20 units with their budget shares and total budget values. Below this is a 'Calculate WERDSS' section with input fields for 'Desired the minimum percentage of the last budget (0.7)' and 'Desired the amount of new budget (85000)', and a 'Calculate' button. A second table shows the results of the simulation, with columns: UA, Part, Valor. It lists units that are selected (Part = 1) and their allocated values.

Figure 3 – Web system pages – user interface

Thus, Page 4 has two main tables. The first one shows the budget in financial and percentage terms and the possibility of simulating the results with a different budget. The last column (Budget) of the first table is the multiplication of the participation percentage of each UAS with the total budget available. The second table represents the MCDM model results evidencing the units that will receive a part of the budget above the minimum established by

the university.

PERSPECTIVES AND CONCLUSION

This study presented a multicriteria web-based Decision Support System for resource allocation in the context of higher education organizations, more specifically, public universities that have budget constraints, with the aim of demonstrating how the use of a suitable multi-attribute decision method combined with a DSS could improve the distribution of a limited budget, which it could mean to reach the best compromise solution, by applying all the available resources with efficiency.

To validate the multicriteria model, a Brazilian federal university was chosen as a parameter to make a numerical application. The model was able to define the percentage of the budget that every budgetary unity of the university should receive. The model established 21 alternatives, which were the sectoral administrative units from the university, and ten criteria were defined by the DM, which was the director of the budget and planning department. A portfolio of 15 projects was found. Also, a multicriteria web-based DSS prototype was established for the problem.

The method proved to be valuable for managing the allocation of resources through a set of alternatives which were distributed rationally by explicit consideration of the real importance of the different criteria. An advantage provided by the system is that when there is a clear vision of how the resource allocation procedure works, the entire process becomes more transparent to the ones that are affected by it. Besides, the multicriteria web-based DSS could be used to provide background for the university considered or other universities when defining strategic resource allocation planning.

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