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Web-Based DSS for Resource Allocation in Higher Education

Carolina Lino Martins, Production Engineering Department, Universidade Federal de Mato Grosso do Sul, Brazil
https://orcid.org/0000-0002-5531-335X

Pascale Zaraté, Toulouse Capitole University, France
https://orcid.org/0000-0002-5188-1616

Adiel Teixeira de Almeida, Production Engineering Department, Universidade Federal de Pernambuco, Brazil
https://orcid.org/0000-0002-2757-1968

Jônatas Araújo de Almeida, Production Engineering Department, Universidade Federal de Pernambuco, Brazil
https://orcid.org/0000-0001-8158-1342

Danielle Costa Morais, Universidade Federal de Pernambuco, Brazil

ABSTRACT

The allocation of scarce resources is a complex higher education decision problem, especially when it comes to budget constraints. Therefore, the authors propose a multicriteria web-based decision support system for resource allocation in higher education organizations. To do so, they define an MCDA/M resource allocation model, based on a project portfolio selection problem to set the percentage of the total budget that every alternative should receive. For the web-based DSS, they develop a database model to store and retrieve data, define the user's interface, and they use a web platform to transform the prototype into a web-based system. Also, they run an empirical analysis with an end-user to test the DSS. They show that the system can provide a clear vision of how the resource allocation system works; the mechanism as a whole becomes more transparent to those involved, enabling them to make efficient and reasonable decisions.

KEYWORDS

Budget, Higher Education, MCDA/M, Resource Allocation, Web-Based DSS

INTRODUCTION

One of the significant higher education problems is resource allocation, once it involves contrasting decisions, it affects the performance of universities (Ho et al., 2006), and their ability to borrow funds has practical limits (Kleinmuntz, 2007). Universities of all dimensions, types, and objectives face this problem. At public universities, dealing with budgeting problems is even more difficult as they use funds from their taxpayers to provide educational services.

Governments, however, have cut funding for higher education because of public pressure in several countries, which has prompted many of them to look for ways to meet the needs of society without spending too much money on taxpayers (Ho et al., 2006; Liefner, 2003). Hence, universities

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must manage their processes optimally and maintain their performance in order to collect adequate funding to meet their necessary expenditures.

Higher education institutions' goals are different and conflicting in many aspects, and they must improve the provision of beneficial results for the interests of society, given an extremely complex and competitive environment (Martins et al., 2019). Within this context, circumstantial evidence suggests that web-based Decision Support Systems (DSSs) combined with multiple criteria decision aiding/ making (MCDA / M) methods is an appropriate way to assist decision-makers in solving resource allocation or budgeting problems (Ho et al., 2006; Montibeller et al., 2009; Mustafa & Goh, 1996; Power, 2016; Efrain Turban et al., 2011). They can improve decision quality, change the structure and functioning of organizations (Bhargava et al., 2007; Efrain Turban et al., 2011), they can represent all the objectives in a single decision problem (de Almeida et al., 2015), and this is the reason why we focus on these methods.

By definition, a Decision Support System is a computer-based information system that supports decision-makers to use data and models to solve semi-structured and unstructured problems (Sprague Jr. & Carlson, 1982). Also, DSSs help stakeholders assess and lead current situations for better decision-making (Edelhauser & Ionică, 2014). All kinds of DSS can be implemented using Web technologies and can become web-based DSS. Its application can increase access and use, reduce support and training costs, allows extensive capabilities to the users (Power, 2016), and that is the reason we consider its applicability for this research.

Furthermore, there is the concept of Multiple Criteria Decision Support Systems (MCDSSs), considered as a "specific" sort of system within the broad family of DSS (Korhonen et al., 1992). The aim is to provide support for structuring the problem, eliciting preferences, and analyzing the results so that the decision-makers (DMs) can focus on the core of the problem while the technical issues are taken care of by the computer (Mustajoki & Hämäläinen, 2007). The use of an effective web-based Decision Support System (DSS) to incorporate MCDA / M research into the decision-making process is, therefore, an essential tool for addressing the challenge of allocating resources in universities.

Besides, according to Ho, Dey & Higson (Ho et al., 2006), there are four major higher education decision problems: resource allocation, performance measurement, budgeting, and scheduling. Performance measurement is the most common decision problem studied (Carlucci et al., 2019; Ho et al., 2006; Mustafa & Goh, 1996). However, in most Higher Education institutions, funding is performance-related. Therefore, the quality of all universities is heavily dependent on how much funding they receive (Ho et al., 2006).

Moreover, most approaches related to resource allocation problems consider only one single objective, unlike MCDA / M methods, that can handle multiple conflicting objectives at the same time, and they coincide with real situations faced by the universities (Ho et al., 2006; Mustafa & Goh, 1996). Consequently, it is possible to go beyond in the decision sciences literature on how to apply these models in practice.

Thus, we propose a multicriteria web-based decision support system for resource allocation in higher education organizations. For this purpose, the MCDA model we propose relies on a project portfolio selection problem, and the web-based decision support system relies on a Database model to store and retrieve data, define the user interface, and use a web platform to turn the prototype into a web-based system. Furthermore, our study considers the results of previous researches related to MCDA and DSS resource allocation problems, such as (de Almeida, Vetschera, & Almeida, 2014; Martins et al., 2017; Martins et al., 2016, 2019).

We organized the paper as follows to achieve its results: after this introduction, we provide a theoretical background underlying themes related to resource allocation problems, decision support systems, web-based decision support systems for resource allocation. In Section 3, we describe our methodology. Section 4 is related to the development of the multicriteria web-based DSS for resource allocation in higher education organizations; it indicates the method to design the system, the system architecture, the Database model, and details the prototype of the web-based system. The final section presents the impacts and contributions of this research.

THEORETICAL BACKGROUND

Problems of resource allocation seek to find the best compromise alternative for alternatives with a set amount of resources to minimize the cost of allocation or maximize the total return (Katoh et al., 2013). Resources can include human resources, materials, tools, equipment, facilities, finance, and others (Katoh et al., 2013). More precisely, higher education administration resources are usually students, faculty, staff, facilities, external support (including government, community, business, and industry), financial, and time (Mustafa & Goh, 1996).

Because of its simple structure, we can find the resource allocation problem in a diverse range of application areas, for instance, load distribution, production planning, allocation of computer resources, queue management, and portfolio selection (Katoh et al., 2013). The literature gives specific names when dealing with financial resources, the focus of this paper, such as budgeting (Mustafa & Goh, 1996). Budgeting is, in this case, an operational process through which organizational sub-units obtain central financial resources to distribute among them (Lepori et al., 2013).

The simplest form of the problem is to minimize under a single constraint, a separable convex function concerning the total amount of resources to be allocated. Depending on the case, the number of resources to be allocated to each activity will be viewed as a constant or integer parameter (Katoh et al., 2013), according to the formulation below:

$$R = minimize f(c_1, c_2, \ldots, c_n) \quad (1)$$

subject to:

$$\sum_{i=1}^{m} x_i = T \quad (2)$$

$$x_i \geq 0, i = 1, 2, \ldots, m. \quad (3)$$

That is, given one type of resource whose total amount is equal to T, a person wants to allocate it to m alternatives so that the objective value $f(x_1, x_2, \ldots, x_n)$ is minimized. The objective value may be interpreted as the cost or loss, or the profit or reward when maximizing $-f$ (Katoh et al., 2013). Each variable x_i represents the amount of resource allocated to alternative i. If the resource is divisible, x_i is a continuous variable that can take any non-negative value. If it represents persons, processors, or trucks, however, variable x_i becomes a discrete variable that takes nonnegative integer values (Katoh et al., 2013).

Considering the case of a university, for instance, it is possible to apply scarce resources most appropriately if the DMs can allocate their budget efficiently. Once resources and funds distributed for the universities' activities are not effectively applied, this will result in inconsistency with the desired objectives of the government and the population (Aziz et al., 2013). Therefore, DMs can allocate their budget efficiently if they use optimization models and decision support systems in organizations of higher education.

Decision Support Systems and MCDA / M Methods For Resource Allocation

A Decision Support System consists of a class of information systems that uses transaction processing systems and communicates with the other part of the overall information system to support decision-making (Sprague Jr. & Carlson, 1982). Moreover, DSS is an interactive, flexible, and adaptable computer-based information system developed specifically to support the solution of a non-structured management problem for better decision-making (Efrain Turban et al., 2011).

A DSS was meant to be adjuncts to decision-makers, extending their capabilities but not replacing their judgment. They were aimed at decisions that required judgment or at decisions that could not be entirely supported by algorithms (Efrain Turban et al., 2011).

Web-based technologies can be employed to improve the capacity of DSS through decision models, considering the growing demand for fast and accurate information sharing (Dong et al., 2004). Decision-makers can benefit from support for a complex decision process by using Web browser interfaces, which eventually integrate client-side computation technologies (Beraldi et al., 2011). Its application can increase access and use, reduce support and training costs, and allow extensive capabilities to the users (Power, 2016).

Therefore, web-based DSSs are decision support systems accessible on the Web, and they can be identified by supporting individuals in their decision-making process regardless of their physical locations or time of access. There may be several reasons for DSS access from the Internet, such as minimizing system maintenance costs, model improvements, data updates, and other changes that may arise as the system develops (Pick, 2008). Also, decision-makers and users have increased access to the system because it is available from any computer at any time (Zahedi et al., 2008).

When MCDA / M methods are integrated into web-based DSSs, the advantages associated with the adoption of quantitative methodologies is further enhanced by the recent advances in computer science and information technology. The impact from the adoption of DSSs becomes evident in all those operative contexts characterized by a high level of complexity due, for instance, to the presence of uncertainty or the need to analyze a considerable amount of data (Beraldi et al., 2011).

There are several definitions for multiple criteria decision aiding/making, but in a general sense, decision aiding is an activity of the person who, through the use of explicit but not necessarily wholly formalized models, helps obtain elements of responses to the questions posed by a stakeholder in a decision process or a decision problem (Roy, 2016). Therefore, multiple criteria decision problems consist of a situation where there are at least two alternatives of action to choose from, and the desire to meet multiple goals drives this choice, often conflicting with each other (de Almeida et al., 2015).

When considering resource allocation problems, DSS and MCDSS have been applied in different fields, such as healthcare management (Aktaş et al., 2007); project management, location-allocation and mobilization planners in the army (Gantt & Young, 1987); disaster management (Kondaveti & Ganz, 2009); water planning (Andreu et al., 1996); public services (AD, 1998); and education (Hasanzadeh et al., 2014; Mansmann & Scholl, 2007). Still, some of the software packages for multi-criteria resource allocation are (Lourenco et al., 2008): Equity, HiPriority, Expert Choice Resource Aligner (ECRA), Logical Decisions Portfolio (LDP) and PROBE (Lourenço et al., 2012).

Furthermore, the main focus of decision theory was to formulate the fundamental principles and techniques of model-based decision support systems (DSS) for academic environments (Kassicieh & Nowak, 1986; Mansmann & Scholl, 2007; Efraim Turban et al., 1988). In higher education, there are different DSS approaches, such as (Mansmann & Scholl, 2007): resource allocation (Barlas & Diker, 2000; Franz et al., 1981); performance evaluation (Deniz & Ersan, 2002; I. E. Livieris et al., 2019; Ioannis E. Livieris et al., 2017); course scheduling (Deris et al., 1997); admission policy (Eliman, 1991; Kaur & Hasija, 2015); and strategic planning (Barlas & Diker, 2000). More recent approaches are about *data warehouse* (Mansmann & Scholl, 2007).

Regarding MCDA / M methods for resource allocation in higher education, performance measurement is the most common decision problem studied (Carlucci et al., 2019; Ho et al., 2006; Mustafa & Goh, 1996). The most common multicriteria approaches for all higher education problems are goal programming (GP) (Colapinto et al., 2017; Ho et al., 2006; Kwak & Lee, 1998; López, 2006; Mustafa & Goh, 1996), based on a linear programming model, with multiple objectives and resources constraints; prioritization methods (Bana e Costa et al., 2006; Phillips & Bana e Costa, 2007), mainly based on benefit-cost ratios analysis (Kleinmuntz, 2007); and the Analytic Hierarchy Process (AHP)

(Ho et al., 2006; Kwak & Lee, 1998; Ramanathan & Ganesh, 1995), based on a hierarchical structure of goals, an additive aggregation model, and on pairwise comparison of alternatives (Belton & Stewart, 2002; de Almeida et al., 2015).

Lastly, authors widely use MCDA project portfolio selection problems to solve resource allocation problems (Dong et al., 2004; Lourenço et al., 2012; Pavlou et al., 2019), based on outranking methods, for instance, PROMETHEE (Abu-Taleb & Mareschal, 1995; Brans & Mareschal, 1992; Mavrotas et al., 2006; Vetschera & de Almeida, 2012), and additive value functions (Kleinmuntz, 2007; Phillips & Bana e Costa, 2007; Salo et al., 2011). One of the most important perspectives on portfolio resource allocation decisions derives from decision analysis, where the model relies on a linear-additive multi-attribute value function (Phillips & Bana e Costa, 2007):

$$v\left(a_i\right) = \sum_{j=1}^{m} k_j v_j \left(x_{ij}\right) \tag{4}$$

Where according to de Almeida *et al.* (de Almeida, Vetschera, & de Almeida, 2014): 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.

The value function v_j represents the decision maker's preference for performance differences on a single attribute or criterion, scaled to a standard range (from 0 to 1) and the scaling constant k_j captures the DM's assessment of the relative importance of the evaluation attributes over the range of values observed for the particular set of candidate projects, typically scaled to sum to 1 (Kleinmuntz, 2007).

Although the increasing attention given to modeling methods for multicriteria web-based DSS for resource allocation in higher education, operational research, and literature on decision-making lacks studies on how to develop such models in practice, emphasizing the importance of this research. Since higher education has faced a problem of budget cuts or constrained budgets over the past decades (Ho et al., 2006), managing the process of resource allocation in higher education systems is, thus, a critical and urgent activity for university decision-makers to improve their performance or competitiveness (Ho et al., 2006).

MULTICRITERIA WEB-BASED DSS FOR RESOURCE ALLOCATION

To propose the multicriteria web-based decision support system for this study, we considered the four phases of the decision-making process (Sprague Jr. & Carlson, 1982; Efrain Turban et al., 2011): (1) intelligence, based on the identification, definition and understanding the problem; (2) design phase, that establishes the decision model to solve the problem. We must develop all interaction with the decision-maker that is part of the preference modeling at this stage, as well as the choice of the MCDA method; (3) choice, which involves an evaluation of the alternatives to solve the problem according to its attributes, validations, and tests; and, finally, the (4) implementation phase, that implements the chosen alternative and monitors the solution (Martins et al., 2019).

Also, we considered the procedure proposed by de Almeida *et al.* (de Almeida et al., 2015) to model a multicriteria problem based on the decision-making phases of design and choice. Figures 1 and 2 summarize the steps of our study.

In the intelligence phase, it is necessary to understand how the resource allocation model from the universities considered works, the variables from the model, how they calculate them, and how they allocate the budget among them. Second, data must be collected to make a study of all universities that receive resources from these models.

Figure 1. Steps of this research to define a multicriteria web-based DSS for resource allocation in higher education

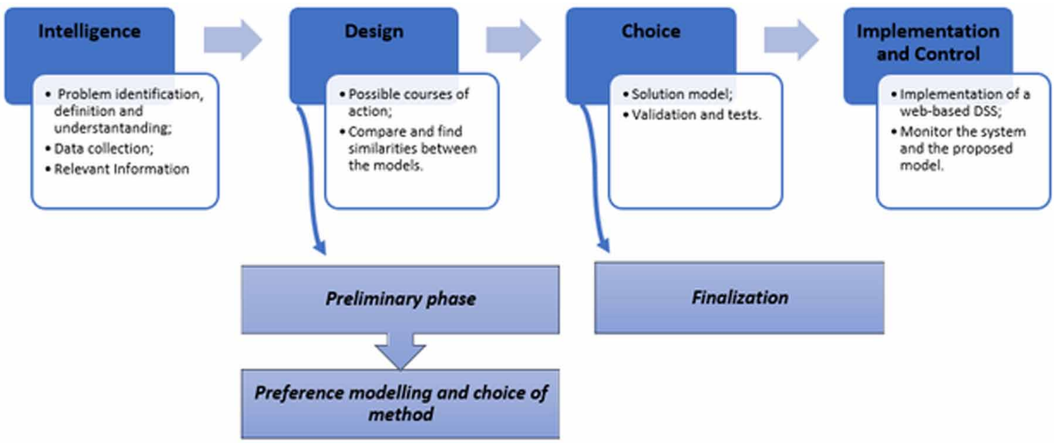
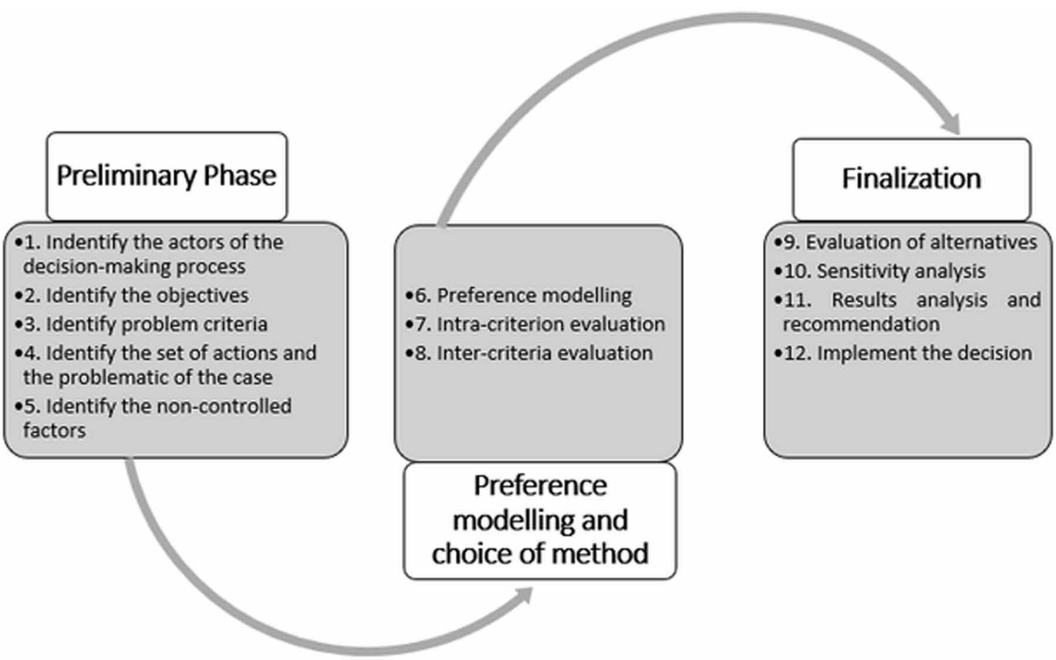


Figure 2. Procedure for solving a multicriteria decision problem, adapted from (*de Almeida et al., 2015*)



The design phase of the web-based DSS consists of analyzing possible courses of action for the case, identifying and exploring several solutions to the problem (Zaraté, 1991). Hence, we performed a study of the resource allocation models from the situation studied to separate them into "affinity groups", so that similar models remain in the same group, and they will depend on the parameters considered by them.

Moreover, preliminary and preference modeling phases correspond to the design stage, and the finalization phase is related to the step of choice from the decision-making process (de Almeida et al., 2015). Thus, in the preliminary phase, we must identify the actors of the decision problem. The actors here could be the decision-maker (DM), analyst, client, experts, and *stakeholder*s (de Almeida et al., 2015). Then, we need to identify the objectives of the problem.

In the third step, for each objective established, there should be criteria or attributes that represent them in the modeling process. The last two steps of this phase involve establishing the structure of the set of actions, the determination of the problematic, the generation of alternatives and the identification of non-controlled factors, which consists of the evaluation and identification of relevant factors that are not under the control of the DM (de Almeida et al., 2015).

In Section 4, there is a numerical application where this study suggests some criteria and present the alternatives from the model. The alternatives from the model proposed here can represent budgetary units, administrative units, as academic faculties or academic departments from a university, which are usually divided by areas, such as human sciences, biological sciences, engineering, faculty of medicine, for instance. They will denote the set of alternatives for solving the decision problem.

In the second phase, the step of preference modeling must be developed in an integrated way with intra-criterion and inter-criteria evaluation steps, so that the results of them provide the most critical elements for selecting the multicriteria method. A critical issue to evaluate in this step is the assessment of rationality regarding compensation amongst criteria, which depends on the problem considered (de Almeida et al., 2015). In the model proposed here, the compensation of the loss on a given criterion by a gain on another one may be acceptable for the DM. These conditions require the use of procedures for compensatory aggregation (Greco et al., 2016).

In the finalization phase, we consolidated the model and applied the multicriteria method. Also, it is necessary to perform a sensitivity analysis to verify the robustness of the proposed model. In this context, this study recommends a sensitivity analysis, such as a Monte Carlo simulation, to test the robustness of the model. We developed the final steps to analyze the results, developed a recommendation, and implemented the recommended action. However, at this stage, one can still return to previous phases and make modifications or revisions in the decision model (de Almeida et al., 2015). Section 3.1 presents the consolidated model proposed.

Then, data may be placed in spreadsheets to flexibly analyze the models to enable users to explore various options quickly and because the spreadsheets possess analytical tools for modeling data (Power, 2016). Still, a prototype from the web-based DSS can be developed, with the help of a DM, seen as an end-user.

Lastly, the decision-making phases of choice, implementation, and control consist in developing a DSS Database model, using an appropriate language for the case, the user's interface must be defined, and, finally, a prototype of the multicriteria web-based system must be implemented, with a programming language.

When people include a DSS in a decision process, it affects the process and its outcome in at least one of these characteristics: productivity, agility, innovation, reputation, and satisfaction (called PAIRS) (Hartono & Holsapple, 2004).

Description of The Multicriteria Model For Resource Allocation

The model we adopted was an additive aggregation procedure for portfolio problematic with compensatory rationality because of the characteristics of the problem. The additive model is one of the most applied models for aggregating criteria, being part of the group of methods of unique criterion of synthesis. This model follows the preference structure (P, I), in which it is possible to obtain a complete pre-order or a complete order from the DM. Therefore, one of the assumptions of this model is that the DM can compare all consequences and order them (de Almeida et al., 2015).

The weights elicitation procedure for the additive model aggregation used was the *swing weighting* method, where the determination of the scale constants relies on direct information given by the DM, considering the range of the consequences (de Almeida et al., 2015).

We normalized the scores from the problem to define the decision matrix using a ratio scale to obtain equivalent evaluations of alternatives (represented in Table 1 and Figure 8). The DSS automatically calculates this transformation. According to de Almeida *et al*. (de Almeida, Vetschera, & de Almeida, 2014), for a portfolio problematic one should consider the scales of the value function $v_j(x)$ very carefully. For the unique criterion of synthesis methods, based on the additive model, the value function $v_j(x)$ should use a ratio scale instead of an interval scale, which many of the elicitation procedures use.

Hence, the main goal of the model is to maximize the objective function, considering the given constraints, which is a budget constraint (Kleinmuntz, 2007). We can define the objective function (5) and the constraints (6) as:

$$\sum^{n} z_i v\left(A_i\right) \tag{5}$$

Subject to:

$$\sum^{n} z_i c_i \le \tag{6}$$

Where i represents every academic department 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 (Kleinmuntz, 2007). $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation (de Almeida, Vetschera, & Almeida, 2014). C and c_i are related to the constraints, where C is the budgeted amount available to fund all the academic departments, and c_i is the budget of each one of them.

When considering a university, the administrative units cannot stay without receiving a part of the budget because of the minimum amount required for their maintenance, in services such as security, for example. Thus, the decision problem resides in the definition of the academic departments receiving part of the budget above the minimum value that each one must receive, that is, the total budget requested by them, taking into account their performance for the set of criteria defined by the DM, and this is the project portfolio selection problem.

Moreover, to adequate the model in this study and taking into account equation (5) and inequality (6), we can describe the variables of the model as c_i = the budget requested by the administrative unit or the budget above the minimum limit that each academic department wants to receive; *min* c_i = minimum percentage of the budget that each unit should receive; z_i = binary variable that is equal to 1 when the academic department will receive the requested budget or equal to 0 otherwise; $z_i c_i$ = the budget allocated to the academic department "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 administrative unit should receive, that is:

$$B - \sum_{i=1}^{n} \min\ c_i = C \tag{7}$$

Finally, as already explained in Section 2.1, the evaluation results from an additive value function it is of the form (de Almeida, Vetschera, & de Almeida, 2014):

$$v\left(A_i\right) = \sum_{j=1}^{m} k_j v_j\left(x_{ij}\right) \quad (8)$$

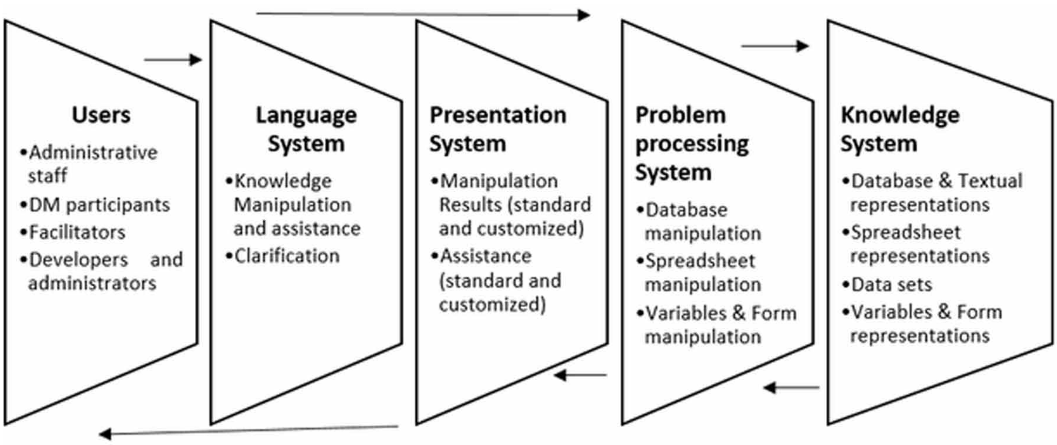
Description of The Multicriteria Web-Based DSS For Resource Allocation

Having defined the model, we can integrate it with a web-based DSS. For our study, the dominant DSS component is the multicriteria model based on a project portfolio selection model for a resource allocation procedure. The target users can be the administrative staff from the budgeting department of the considered university, DMs participants from every academic department since they are affected by the allocation procedure, facilitators, developers, and administrators.

Figure 3 evidences the problem-solving process, adapted from (W. Holsapple, 2008), that we used for the web-based DSS.

Analyzing *Figure 3*, the language system consists of all messages the DSS can accept. A knowledge-manipulation request, for instance, could look very much like standard requests made to single-technique. On the other hand, the presentation system consists of all messages the DSS can emit, and, for this case, manipulation or assistance requests and responses may be standardized or customized for a specific user (W. Holsapple, 2008).

Figure 3. Problem-solving process for the web-based DSS, adapted from (*W. Holsapple, 2008*)



The knowledge system involves all knowledge the DSS has stored and retained. The knowledge system here comprises a database, a model base, spreadsheet representations, variables, and forms representations. Finally, the problem processing system (PPS) is the DSS's software engine, that is, what tries to recognize and solve problems during the decision-making process. It is essential to clarify that the user does not need to know about the database, rule set, or solver manipulations, for example. These activities happen beneath the customized DSS surface provided by the PPS (W. Holsapple, 2008).

RESULTS AND DISCUSSIONS

We performed a numerical application of the proposed framework to test the web-based DSS. The purpose of this application is to allocate a limited budget to each academic department, considering the available resources, to maximize the overall portfolio value.

Therefore, we conducted an application to evaluate how the budget released by the Ministry of Education (MEC) in Brazil should be allocated among 21 academic departments from a specific Brazilian Federal University (called university administrative units or "UAS"), which are divided by areas, such as human sciences, biological sciences, engineering, faculty of medicine, and other. The

Figure 4. Criteria of the MCDA model

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 Anisio 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

idea is that the MCDA model can indicate the total amount from the budget that each UAS should receive.

The administrative units are the alternatives, projects, or budgetary units of the MCDA 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}. Figure 4 evidences the criteria of the model, defined by the DM.

To identify the criteria from Figure 4, the DM, aided by the analysts and staff members from the university, considered quantitative and qualitative variables already established by the Ministry of Education in Brazil to allocate budget credits for costing and investment activities. We also adapted these variables from the English resource allocation model for universities, developed by the *Higher Education Funding Council for England – HEFCE* (Hicks, 2012; Martins et al., 2019). After that, we validated the criteria to confirm if they were reasonable and consistent with the DM and other decision-making actors' objectives and preferences.

Table 1 presents the decision matrix and the weights from the numerical application, that we in the multicriteria web-based DSS.

To solve the problem, the total budget available considered was R$ 850,000.00. Each administrative unit must receive 70% of the total budget, the minimum value considered to maintain their activities, which represents R$ 700,000.00. Thus, B= R$150,000.00.

To integrate the MCDA / M model into a web-based DSS, we developed a PHP web platform on the server side combined with Python and a Database system MySQL was applied to store and retrieve data using Structured Query Language (SQL). The development of dynamic web systems brings the requirement to access some relational database and PHP is one of the languages with the

Table 1. Decision matrix with normalized values and weights from the MCDA/M model

Alternatives	Criteria										
	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	V_i (A_i)
UAS1	0,76	0,95	0,05	0,89	1,00	0,50	0,24	0,81	1,00	0,50	0,67
UAS2	0,70	0,83	0,02	0,89	0,88	0,47	0,19	0,68	0,70	0,50	0,60
UAS3	0,27	0,92	0,07	0,44	0,00	0,61	0,49	0,81	0,15	0,00	0,39
UAS4	0,62	0,71	0,02	0,33	0,00	0,38	0,25	0,72	0,30	0,00	0,38
UAS5	0,52	0,78	0,03	0,56	0,00	0,39	0,33	0,63	0,15	0,00	0,38
UAS6	0,12	0,80	0,11	0,11	0,00	0,36	0,20	0,74	0,00	0,00	0,25
UAS7	0,24	0,92	0,11	0,00	0,00	0,56	0,51	0,90	0,15	0,00	0,34
UAS8	0,20	0,68	0,07	0,00	0,00	0,31	0,26	0,70	0,00	0,00	0,24
UAS9	0,17	0,59	0,10	0,00	0,00	0,61	0,40	0,74	0,00	0,00	0,28
UAS10	0,10	0,70	0,13	0,00	0,13	0,62	0,32	0,81	0,00	0,00	0,30
UAS11	0,16	0,68	0,07	0,00	0,13	0,25	0,25	0,74	0,00	0,00	0,23
UAS12	0,88	0,81	0,02	0,22	0,13	0,31	0,28	0,73	0,35	0,50	0,46
UAS13	0,55	0,84	0,03	0,33	0,13	0,23	0,56	0,81	0,35	0,50	0,40
UAS14	0,23	0,83	0,26	0,22	0,13	0,96	0,59	1,00	0,00	0,00	0,46
UAS15	1,00	0,86	0,03	0,78	0,25	0,33	0,50	0,81	0,35	0,50	0,58
UAS16	0,89	0,77	1,00	0,67	0,00	1,00	1,00	1,00	0,35	1,00	0,80
UAS17	0,65	0,96	0,23	0,78	0,00	0,77	0,83	0,90	0,35	1,00	0,62
UAS18	0,26	0,96	0,48	0,11	0,00	0,41	0,49	0,81	0,15	0,00	0,37
UAS19	0,04	1,00	0,35	1,00	0,38	0,29	0,09	0,81	0,15	0,00	0,41
UAS20	0,07	0,82	0,22	0,00	0,25	0,28	0,10	0,60	0,20	0,50	0,27
UAS21	0,11	0,99	0,18	0,44	0,13	0,31	0,18	0,70	0,15	0,50	0,33
Weights	0,22	0,08	0,12	0,10	0,10	0,16	0,04	0,09	0,04	0,04	

highest availability of database access, since it can access Oracle, SQL Server, PostgreSQL, FireBird, MySQL, SysBase, Informix, SQLite and several other databases (Bhargava et al., 2007; Power, 2016).

The name defined for the web system was: MDSSFRA (Multicriteria Decision Support System for Resource Allocation). Figure 5 illustrates the technological background of the system.

The technological background of the web-based DSS works in the following way: PHP makes a consultation to the Database system MySQL to provide data to the user and, also, to provide data to the Python environment, which will run the script calculation, that is, the MCDA model calculation, and return to PHP with the final result information.

The system has four major components. The first one is a database component, which divides the university data by year, and stores criteria and budget information. Before starting a new analysis, the user can modify these parameters for updates. Figure 6 shows the Database model (MySQL).

In the Database model structure, it is possible to see where the information is stored and used by the web system. The "*indx*" table contains most of the foreign keys, biding with the year (year_year INT), type of model (models_id_models INT), which can be Model 1, 2, or 3, administrative unit (au_id_au INT)) and with universities (au_ufs_UFS). With AU table association, for example, the

Figure 5. Problem-solving process for the web-based DSS

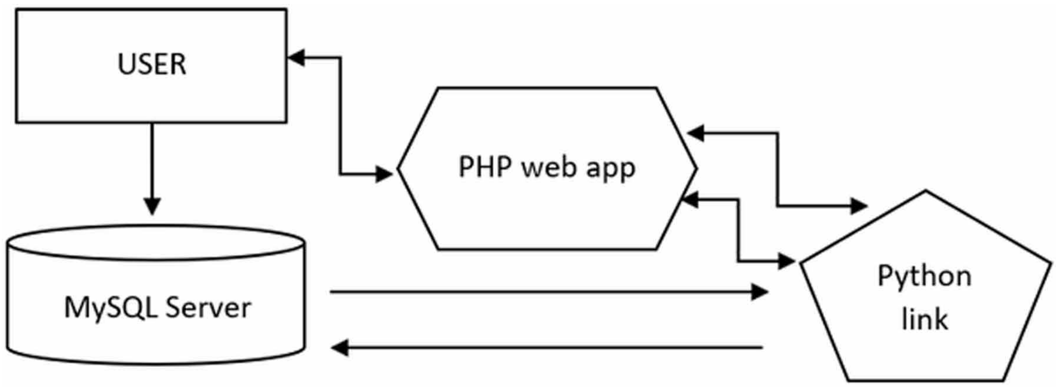
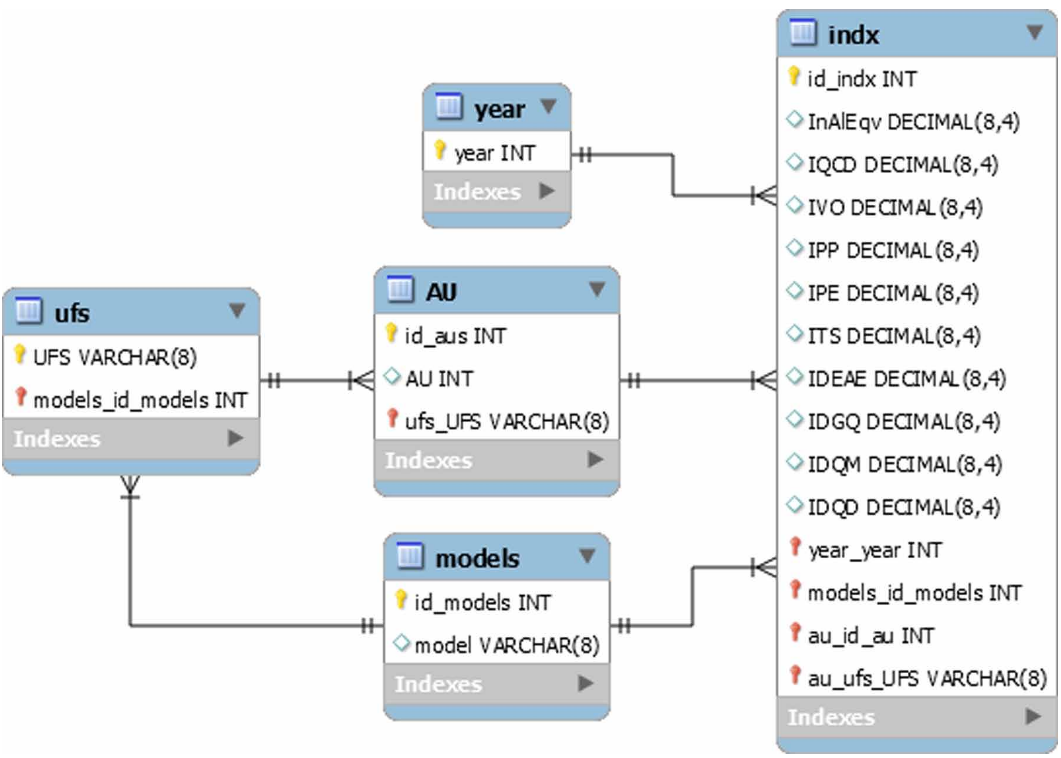


Figure 6. Database model from MySQL



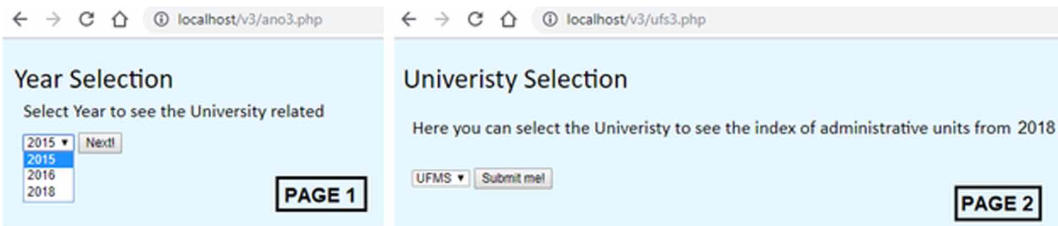
connection type is 1-to-n, that means, one AU can have *n indx* associated with, and we applied the same rule for the year, models, and university tables (ufs) with AU.

The second component is a data processing module that allows the user to make a simulation by selecting an academic department, different criteria, insert criteria values, and can analyze the total budget through the web-based user interface. Here, the Database model (MySQL) retrieves the data. The first, second, and third pages of the MDSSFRA evidence these features. Figures 7 and 8 show the respective PHP pages from the system.

The year selection page it is the first search parameter of the database. At this part, the user can select all year options from the database. Here, the options available are 2015, 2016, and 2018. After selecting the year, the system takes the user to page 2 for the next selection.

Page 2 is the university selection page. Once the university is selected, the system takes the user to page 3 and displays the data. For this example, there is only one university available to be chosen.

Figure 7. Web system pages 1 and 2: user interface



Page 3 shows all the information from every academic department, the alternatives of the model (called "AU" or "UA") with their respective performance for every criterion, the criteria with abbreviated names for each one of them, for instance, "*InAlEqv*" = Criterion 1; "*IQCD*" = Criterion 2; and so on.

To develop a suitable web-based DSS, the user has the option to change any criteria (called "*index*") values from an academic department and the available budget to simulate different scenarios. That is the most critical part of the system because it allows the users to estimate the budget that they could have in case of changing some parameters of the model. From this information, every academic department can establish an action plan, for instance, to improve their performance and, consequently, increase their budget share.

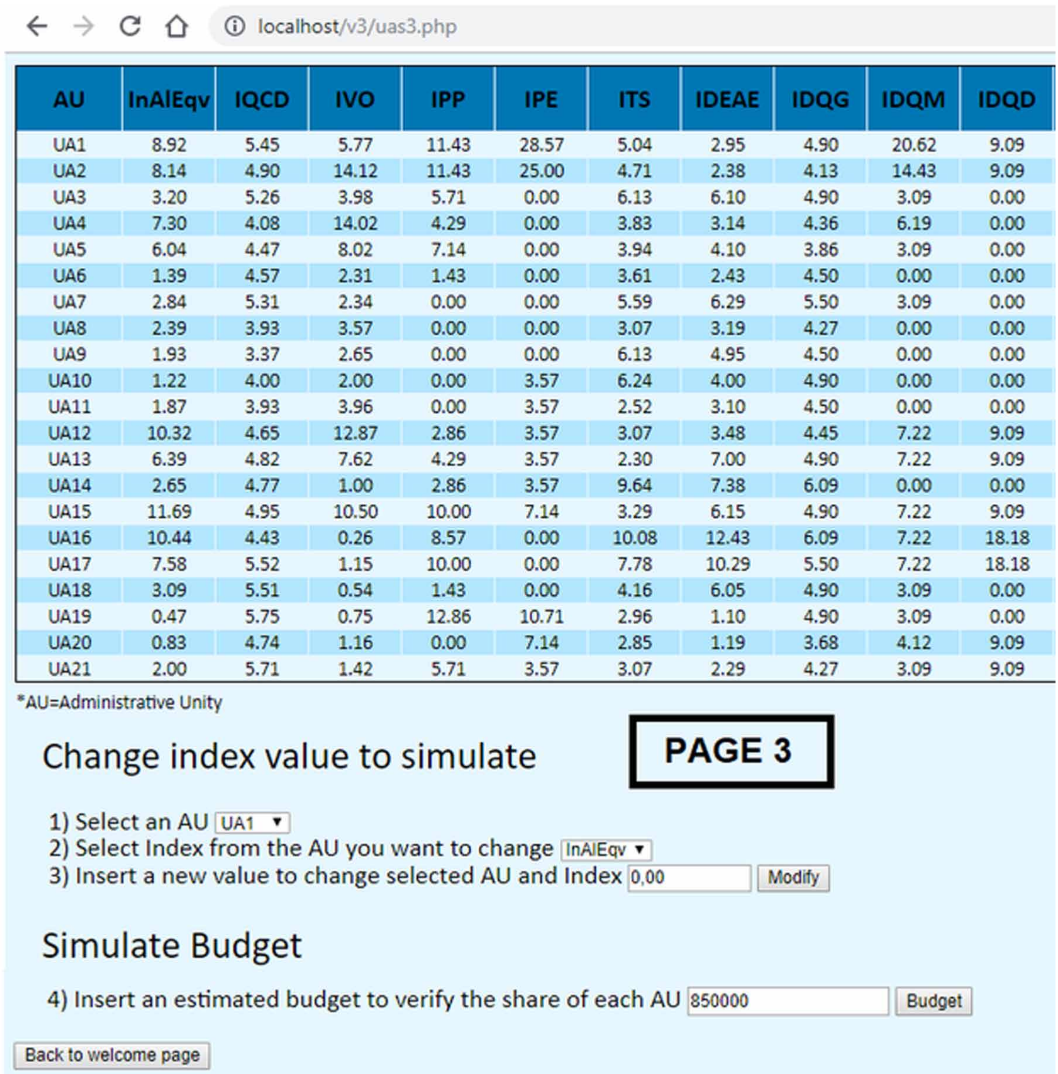
From pages 3 and 4 of the system, it is possible to determine the third and fourth components, that is the multicriteria model and the percentage of the budget related to every academic department, obtained from the MCDA model results. The third component uses a project portfolio selection model with a linear programming module, already described before. For this purpose, we used a Python link extension to solve the linear programming problem.

The PHP system can run a Python script with a tool to export data in a text file, where Python will read this file, will interpret, will run the calculations, and will send it back to PHP by the same method. Python was used as an external link to execute the calculations of the MCDA / M model, once its language was more intuitive to use than other PHP extensions, such as PHP Simplex, PHP – LP_Solve, or other programming languages.

Regarding the Python code, a library called "PULP" was used, that has different tools to solve linear programming problems. The library reads and models the problem in the same way as a linear programming problem. The library reads the problem in the same way as an LP problem is modeled. Thus, in the code, lines 5, 78, 79, 82, 86,87,88, 90 from Figures 9 and 10 represent the problem modeling. Line 5 is the declaration of the problem. Lines 78 and 79 represent the decision variables and their limits. Line 82 represents the objective function and the constraints of the problem.

Between lines 34 and 51 of the code, a sensitivity analysis, using Monte Carlo Simulation, was developed for the model to be automatically calculated. Thus, when integrated into the PHP, the information regarding the criteria, the scaling constants, and the budget can be inserted by the user of the program to run different simulations (page 3 from the user's interface). For this demo version of the DSS, the parameters of the sensitivity analysis must be changed directly in the Python system

Figure 8. Web system page 3: user interface



AU	InAIEqv	IQCD	IVO	IPP	IPE	ITS	IDEAE	IDQG	IDQM	IDQD
UA1	8.92	5.45	5.77	11.43	28.57	5.04	2.95	4.90	20.62	9.09
UA2	8.14	4.90	14.12	11.43	25.00	4.71	2.38	4.13	14.43	9.09
UA3	3.20	5.26	3.98	5.71	0.00	6.13	6.10	4.90	3.09	0.00
UA4	7.30	4.08	14.02	4.29	0.00	3.83	3.14	4.36	6.19	0.00
UA5	6.04	4.47	8.02	7.14	0.00	3.94	4.10	3.86	3.09	0.00
UA6	1.39	4.57	2.31	1.43	0.00	3.61	2.43	4.50	0.00	0.00
UA7	2.84	5.31	2.34	0.00	0.00	5.59	6.29	5.50	3.09	0.00
UA8	2.39	3.93	3.57	0.00	0.00	3.07	3.19	4.27	0.00	0.00
UA9	1.93	3.37	2.65	0.00	0.00	6.13	4.95	4.50	0.00	0.00
UA10	1.22	4.00	2.00	0.00	3.57	6.24	4.00	4.90	0.00	0.00
UA11	1.87	3.93	3.96	0.00	3.57	2.52	3.10	4.50	0.00	0.00
UA12	10.32	4.65	12.87	2.86	3.57	3.07	3.48	4.45	7.22	9.09
UA13	6.39	4.82	7.62	4.29	3.57	2.30	7.00	4.90	7.22	9.09
UA14	2.65	4.77	1.00	2.86	3.57	9.64	7.38	6.09	0.00	0.00
UA15	11.69	4.95	10.50	10.00	7.14	3.29	6.15	4.90	7.22	9.09
UA16	10.44	4.43	0.26	8.57	0.00	10.08	12.43	6.09	7.22	18.18
UA17	7.58	5.52	1.15	10.00	0.00	7.78	10.29	5.50	7.22	18.18
UA18	3.09	5.51	0.54	1.43	0.00	4.16	6.05	4.90	3.09	0.00
UA19	0.47	5.75	0.75	12.86	10.71	2.96	1.10	4.90	3.09	0.00
UA20	0.83	4.74	1.16	0.00	7.14	2.85	1.19	3.68	4.12	9.09
UA21	2.00	5.71	1.42	5.71	3.57	3.07	2.29	4.27	3.09	9.09

command. The established standard variation was ± 20%. Figures 9 and 10 demonstrate the Python code developed for the model.

Finally, the fourth component of the system takes care of the percentage of the budget related to every academic department, obtained from the MCDA model results. This component first calculates the value function of each alternative using the retrieved data and the MCDA model procedure outputs. Page 4 of the web system (Figure 11) presents the fourth component of the system.

Page 4 (Figure 9) has two main tables. The first one displays the budget in financial and percentage terms and the possibility of simulating the results with a different budget. These values represent the minimum budget considered that each academic department must receive. The last column (Budget) of the first table is the multiplication of the participation percentage of each alternative with the total budget available.

The second table represents the MCDA model results evidencing the alternatives that will receive a part of the budget above the minimum established by the university. Also, there is a histogram to show the results visually.

Figure 9. Python code – part 1

```
# Importa bibliteca de Porgramaçao linear
from pulp import *

# Inicia o problema de PL
prob = LpProblem("v01", LpMaximize)

# Indices da tabela normal
ua1 = [0.763, 0.947, 0.045, 0.888, 1.000, 0.500, 0.237, 0.804, 1.000, 0.500]
ua2 = [0.696, 0.833, 0.018, 0.888, 0.875, 0.467, 0.191, 0.678, 0.699, 0.500]
ua3 = [0.273, 0.914, 0.065, 0.444, 0.000, 0.608, 0.490, 0.804, 0.149, 0.000]
ua4 = [0.624, 0.709, 0.018, 0.333, 0.000, 0.379, 0.252, 0.715, 0.300, 0.000]
ua5 = [0.516, 0.777, 0.032, 0.555, 0.000, 0.390, 0.329, 0.633, 0.149, 0.000]
ua6 = [0.118, 0.794, 0.112, 0.111, 0.000, 0.358, 0.195, 0.738, 0.000, 0.000]
ua7 = [0.242, 0.923, 0.111, 0.000, 0.000, 0.554, 0.506, 0.903, 0.149, 0.000]
ua8 = [0.204, 0.683, 0.072, 0.000, 0.000, 0.304, 0.256, 0.701, 0.000, 0.000]
ua9 = [0.165, 0.586, 0.098, 0.000, 0.000, 0.608, 0.398, 0.738, 0.000, 0.000]
ua10 = [0.104, 0.696, 0.130, 0.000, 0.124, 0.619, 0.321, 0.804, 0.000, 0.000]
ua11 = [0.159, 0.683, 0.065, 0.000, 0.124, 0.250, 0.249, 0.738, 0.000, 0.000]
ua12 = [0.882, 0.808, 0.020, 0.222, 0.124, 0.304, 0.279, 0.730, 0.350, 0.500]
ua13 = [0.546, 0.838, 0.034, 0.333, 0.124, 0.228, 0.563, 0.804, 0.350, 0.500]
ua14 = [0.226, 0.829, 0.260, 0.222, 0.124, 0.956, 0.593, 1.000, 0.000, 0.000]
ua15 = [1.000, 0.860, 0.024, 0.777, 0.249, 0.326, 0.494, 0.804, 0.350, 0.500]
ua16 = [0.893, 0.770, 1.000, 0.666, 0.000, 1.000, 1.000, 1.000, 0.350, 1.000]
ua17 = [0.648, 0.960, 0.226, 0.777, 0.000, 0.771, 0.827, 0.903, 0.350, 1.000]
ua18 = [0.264, 0.958, 0.481, 0.111, 0.000, 0.412, 0.486, 0.804, 0.149, 0.000]
ua19 = [0.040, 1.000, 0.346, 1.000, 0.374, 0.293, 0.088, 0.804, 0.149, 0.000]
ua20 = [0.071, 0.824, 0.224, 0.000, 0.249, 0.282, 0.095, 0.604, 0.199, 0.500]
ua21 = [0.111, 0.993, 0.183, 0.444, 0.124, 0.304, 0.184, 0.701, 0.149, 0.500]

# Pesos
w =    [0.191734285737023, 0.177839817761702, -0.0029343179417247, 0.124226906569633, 0.108578875277171,
        0.113253770700481, 0.085804146265317, 0.127882485804701OO, 0.0368068951201453, 0.036807134705551]

# Analise de sensibildiade, perugunta qual indice quer alterar de 0 a 9
indicee = input("Qual indice? ")
indicee = int(indicee)

# Analise de sensibildiade, em quanto pretende altear. Sendo 1 sem alteração 1,5 50% para mais 0,5 50% para menos
valor = input("Qual Valor pretende variar? ")
valor = float(valor)

# calculos para analise de senbilidade
w_old = 1- w[indicee]
w_new = 1- w[indicee]*valor
r=w_new/w_old

for i in range(len(w)):
    if i != indicee:
        w[i] = round(w[i]*r, 4)
    else:
        w[i] = round(w[i]*valor, 4)
```

DISCUSSIONS

The multicriteria web-based DSS proposed by this study can be tested by the users, to evaluate better if there is any improvement to be made in order to be useful for all the users of the system. In anyhow, the system still has some limitations, like the fact that it is not possible to enter new parameters to the model, as a new criterion, for instance. In this case, another model will have to be developed and integrated with the web-DSS.

On the other hand, an advantage provided by the system is that the users can estimate the budget that they could have in case of changing the parameters (performance criteria and the budget) of the MCDA / M model. From this information, every academic department can establish an action plan, for instance, to improve their performance and, consequently, increase their budget share.

Thus, the DM can have a clear vision on how the resource allocation procedure works, and the entire process can become more transparent to the ones that are affected by it, to the decision-

Figure 10. Python code – part 2

```
# Vetor para UAS
V_uas = ["UA01", "UA02", "UA03", "UA04", "UA05", "UA06", "UA07", "UA08", "UA09", "UA10", "UA11", "UA12", "UA13", "UA14",
         "UA15", "UA16", "UA17", "UA18", "UA19", "UA20", "UA21"]

# Vetor com SomarProduto do total indice com o peso dele
V_tot = [sum(x * y for x, y in zip(ua1, w)), sum(x * y for x, y in zip(ua2, w)), sum(x * y for x, y in zip(ua3, w)),
         sum(x * y for x, y in zip(ua4, w)), sum(x * y for x, y in zip(ua5, w)), sum(x * y for x, y in zip(ua6, w)),
         sum(x * y for x, y in zip(ua7, w)), sum(x * y for x, y in zip(ua8, w)), sum(x * y for x, y in zip(ua9, w)),
         sum(x * y for x, y in zip(ua10, w)), sum(x * y for x, y in zip(ua11, w)), sum(x * y for x, y in zip(ua12, w)),
         sum(x * y for x, y in zip(ua13, w)), sum(x * y for x, y in zip(ua14, w)), sum(x * y for x, y in zip(ua15, w)),
         sum(x * y for x, y in zip(ua16, w)), sum(x * y for x, y in zip(ua17, w)), sum(x * y for x, y in zip(ua18, w)),
         sum(x * y for x, y in zip(ua19, w)), sum(x * y for x, y in zip(ua20, w)), sum(x * y for x, y in zip(ua21, w))]

# Percentual do minimo do budget
perc = 0.7

# Valor do Budget passado
bud = [103368.17, 84858.13, 35453.67, 45002.76, 43460.60, 17123.87, 30948.75, 19730.33, 21302.55, 20904.97, 19085.91,
       69836.10, 57333.04, 37043.62, 88621.29, 99878.95, 83144.15, 33032.70, 31351.01, 26742.98, 31776.45]

# Valor do budget atual
b_tot = 850000


# Declaração das variaveis e seu limites
for i in range(len(V_uas)):
    V_uas[i] = LpVariable(V_uas[i], 0, 1)

# Declaração da função objetivo
prob += sum(x * y for x, y in zip(V_uas, V_tot)), "obj"


# Restrições
for i in range(len(V_uas)):
    prob += V_uas[i] >= perc * bud[i] / b_tot
    prob += V_uas[i] <= bud[i] / b_tot

prob += sum(V_uas) <= 1

# Comandos para executar o "solver
prob.writeLP('test1.lp')
prob.solve()

# Informa que o problema foi resolvido
print("Status:", LpStatus[prob.status])

# Mostra os valores ótimos
for v in prob.variables():
    print(v.name, "=", round(v.varValue, 4))

# Mostra o valor da função objetivo
print("objective=", round(value(prob.objective), 4))
```

makers and the government, enabling them to make safer and reliable decisions, seeking to reduce uncertainties and to maximize their results.

We reached the overall objective of the multicriteria web-based DSS proposed when there is an improvement of the rationality of a decision procedure, improving the quality of the decision process. Furthermore, the results reached are an effective generation of information on the decision problem from available data and ideas, effective generation of solutions (alternatives) to a decision problem, and to provide a good understanding of the structure and content of a decision problem (Janssen, 1992).

Therefore, decision support systems combined with multicriteria methods provide benefits when the combination of the system plus a decision-maker (or makers) is superior to the performance of software or humans alone. Often, the benefit is better decisions, a better decision-making process, or both. In some cases, neither the outcome nor the process is affected, but the model and the system serve to document the quality of the process in a way that may convince stakeholders of the correctness of a decision (Pick, 2008).

Figure 11. Web system page 4: user interface

PERSPECTIVES AND CONCLUSION

Resource allocation is one of the leading higher education organizations' decisions once it impacts their performance. Nevertheless, governments have decreased university funding, especially in countries where most of the higher education system is state-oriented.

In this context, it is necessary to have resource allocation models with a robust theoretical basis and capable of integrating different objectives into a single decision problem. Therefore, we propose a multiple criteria decision-making method as a correct approach to this problem. Our model consists of a particular case of a multicriteria project portfolio selection problem. An advantage of multicriteria project portfolio selection models is that they select the best combination of values to find an optimal solution instead of choosing the best partial alternatives.

We show that the method is valuable for managing the allocation of resources through a set of alternatives which are distributed rationally by explicit consideration of the real importance of the different criteria. The system we propose can support decision-makers, stakeholders that are part of the process, decentralize tasks achievement, besides improving communication, collaboration, increasing the productivity of group members and improve data management using the Web. Also, it can increase access and use, reduce support and training costs, and allow extensive capabilities to the users.

Another 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 a university when defining strategic resource allocation planning.

For future works, the MCDA project portfolio web-based DSS proposed could be tested by other universities, in different countries, in order to verify its applicability adapting the alternatives and criteria for each specific internal allocation model, and to the decision-makers needs with the same purpose of improving the decision-making process.

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Carolina Lino Martins is an assistant professor of management engineering at Federal University of Mato Grosso do Sul. She holds a PhD in Computer Science from Université Toulouse 1 Capitole and a PhD in Management Engineering from Universidade Federal de Pernambuco. Founding coordinator of the Institute of Information Systems ans Decision Aiding Methods (IISDAM) and member of the Modelling and alignment of portfolio and strategy (MAPS) research group. Her research interests include Multiple Criteria Decision Making/Aid and Decision Support Systems.

Pascale Zaraté is a Professor at Toulouse 1 Capitole University. She conducts her researches at the IRIT laboratory (http://www.irit.fr). She holds a Ph.D. in Computer Sciences / Decision Support from the LAMSADE laboratory at the Paris Dauphine University, Paris (1991). She also holds a Master degree in Computer Science from the Paul Sabatier University, Toulouse, France (1986); as well as a Bachelors degree Toulouse, France (1982). Pascale Zaraté's current research interests include: Decision Support Systems; Group Decision Support Systems, Distributed and Asynchronous Decision Making Processes; Knowledge Modelling; Cooperative Knowledge Based Systems; Cooperative Decision Making. She published several studies and works : 3 books, edited 6 books, edited 18 special issues in several international journals, 11 proceedings of international conferences, 30 papers in several international journals, 2 papers in national journals, 7 chapters in collective books, 52 papers in international conferences. She belongs the Editorial Scientific Committee of five International Journals : Associate Editor of Group Decision and Negociation (Springer), European Jounal of Decision Process (Elsevier), Intelligent Decision Technologies (IOSPress), International Journal of Decision Support Systems (Inderscience), Journal of Decision System (Lavoisier). She was chairing the IFIP TC8/WG8.3 conference devoted to Collaborative Decision Making (https://www.irit.fr/CDM08) and the GDN 2014 conference (https://www.irit.fr/GDN). She was Awardee of the GDN section in 2018.

Adiel Teixeira de Almeida is Full Professor at Universidade Federal de Pernambuco, founding coordinator of the CDSID (Center for Decision Systems and Information Development) and coordinator of INCT-INSID. He holds a PhD in management engineering from The University of Birmingham, UK. He has a research fellowship Grantee for Productivity in Research from the Brazilian NRC (CNPq), since 1996. His main interests are in decision-making related to multiple objectives and group decision problems, which includes methodological issues and applications. Among his methodological contributions, there is the development of the multicriteria method FITradeoff, which has been widely used (www.fitradeoff.org), being awarded by the EURO (Association of European Operational Research Societies) as the best EJOR article in the Theory and Methodology category. He authored or co-author over 135 scientific papers in reviewed journals related to a variety of topics such as: Operational Research, Group Decision, Decision Systems, MCDM/A (Multicriteria Decision Making and Aid), and Risk. He serves on the editorial board of scholarly journals, such as: Group Decision and Negotiation (Management Science Departmental co-editor), Information Sciences, IMA Journal of Management Mathematics, International Journal of Decision Support System Technology, EURO Journal on Decision Processes, and Journal of Aerospace Technology and Management. He has been an active member of main societies related to his field and currently he serves the Executive Council of the GDN Section of INFORMS and the Executive Committee of the International Society on MCDM and he is an Associate Research Fellow of the Institute of Mathematics and its Applications (FIMA). He also received in 2017 the INFORMS GDN Section Award. Currently, he serves the Council of the Group Decision and Negotiation Section of INFORMS (as President). He has served in the Executive Committee of the International Society on Multiple Criteria Decision Making (2015-2019) and in the council of the MCDM Section of INFORMS (2017-2019).

Jônatas Araújo de Almeida is graduated in Civil Engineering from Escola Politécnica de Pernambuco - Universidade de Pernambuco (2008), Master in Production Engineering from Universidade Federal de Pernambuco (2010), PhD in Production Engineering from Universidade Federal de Pernambuco (2012). He is currently an associate professor at the Federal University of Pernambuco and Founding coordinator of Modelling and alignment of portfolio and strategy (MAPS) research group.

Danielle Costa Morais is an associate professor in the Management Engineering Department at Universidade Federal de Pernambuco (UFPE) since 2007, Director of Post-Graduate Program of Management Engineering at UFPE (2008-2010 and 2013-2021), Director of the research group on Decision and Negotiation for Water Management (DNW) and Vice-coordinator of INCT-INSID (National for Decision Systems and Information). She is Civil Engineering and received her Master and PhD degrees in Management Engineering from UFPE, Brazil. She has been awarded a grant of Productivity in Research by CNPq (Brazilian NRC). Her research interest includes MCDM/A, Group Decision and Negotiation, Operational Research and Water Resources Management. She co-authored over 40 scientific papers in reviewed journals. She serves on the editorial board a few scholarly journals, such as: Group Decision and Negotiation. She has been an active member of the main societies related to Operational Research, MCDM/A and Group Decision, and served the INFORMS MCDM section as a board member.