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Systeme d'Aide a la Decision Multicritere orienté Web pour la repartition des Ressources des Universites Publiques Bresiliennes

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UNIVERSIDADE FEDERAL DE PERNAMBUCO
PROGRAMA DE PÓS-GRADUAÇÃO EM ENGENHARIA DE PRODUÇÃO

Carolina Lino Martins

MULTICRITERIA WEB-BASED DECISION SUPPORT SYSTEM FOR RESOURCE ALLOCATION IN BRAZILIAN PUBLIC UNIVERSITIES

RECIFE
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PhD thesis submitted to UFPE to obtain the degree of doctor as part of the requirements of the Programa de Pós-Graduação em Engenharia de Produção (Research Area: Production Management).

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PhD EVALUATION COMMITEE REPORT ON THE THESIS PRESENTATION OF

CAROLINA LINO MARTINS

"MULTICRITERIA WEB-BASED DECISION SUPPORT SYSTEM FOR RESOURCE ALLOCATION IN BRAZILIAN PUBLIC UNIVERSITIES"

RESEARCH AREA: PRODUCTION MANAGEMENT

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RESUMÉ DE LA THÈSE EN FRANÇAIS

1 INTRODUCTION

En général et particulièrement au Brésil, où les universités publiques jouent un rôle important, l'utilisation efficace des ressources limitées est un problème crucial pour les universités. Le processus d'allocation des ressources internes dans les Universités Fédérales Brésiliennes (UF) entre les Unités Administratives (UA) est devenu de plus en plus difficile et dépend d'une diversité de paramètres juridiques, économiques, structurels et organisationnels. Par conséquent, l'utilisation d'un Système Interactif d'Aide à la Décision (SIAD) orienté Web , intégrant une approche d'Analyse Multicritère (MCDA / M) dans le processus d'aide à la décision, est un instrument important pour répondre à ce défi permanent.

Pareillement, les universités publiques au Brésil emploient l'argent de leurs contribuables pour fournir des services d'éducation. Mais il existe des contraintes budgétaires croissantes causées par la crise économique que connaît le pays, qui a commencé au début 2015 (BARUA, 2016) et continue en 2018, il y a donc un intérêt social énorme à répertorier la manière qu'un tel argent est affecté, où le coût d'un échec est vu comme quelque chose d'inacceptable (WILLIAMS, 2009).

Un des buts des universités fédérales est d'améliorer la fourniture de résultats salutaires pour l'intérêt de société, dans un environnement progressivement complexe et incertain. Dans ces contexte, Turban *et. al*. et Power (2011 ; 2016) affirment que les systèmes d'aide à la décision (SIAD) peuvent généralement améliorer la qualité des décisions et changer la structure et le fonctionnement des organismes.

Un système d'aide à la décision peut être défini comme un système informatisé d'information qui inclut des données et des modèles d'utilisation de décideurs pour résoudre des problèmes semi-structurés et non structurés. Il aide les décideurs à prendre de meilleures décisions et à répondre à des questions complexes (BIDGOLI, 1989 ; SPRAGUE & WATSON, 1989). Il existe différentes définitions pour un SIAD, qui partagent l'idée qu'un SIAD est essentiel pour soutenir le processus décisionnel (SPRAGUE & WATSON, 1989).

Toutes sortes de SIAD peuvent être mises en application utilisant des technologies de Web et sont alors appelés SIAD basé sur le WEB ou SIAD orienté Web. Les directeurs ont progressivement accès de Web aux entrepôts de données et aux outils analytiques (TAGHEZOUT *et al*., 2011). Un SIAD orienté Web apportent, ainsi, l'information à un directeur ou à un analyste d'affaires employant un web browser comme Internet Explorer qui accède à l'Internet globalement ou à un intranet d'entreprise. Son utilisation peut augmenter l'accès aux informations et son utilisation peut réduire l'encadrement et les frais de formation et permettre des capacités étendues aux utilisateurs (POWER, 2000).

En outre, dans ce contexte et, plus spécifiquement, il y a le concept de Système d'Aide à la Décision Multicritère (MCDSS), considéré comme un type « particulier » de système dans la large famille des SIAD (KORHONEN, 1991). Il s'agit de prendre en considération des critères multiples grâce à des méthodes de décision utilisant des techniques issues du domaine du MCDSS afin d'estimer les solutions selon les préférences d'un décideur, ceci grâce à de en nombreuses phases qui permettent une modélisation du problème à résoudre (KORHONEN, 1991).

L'aide à la décision multicritère (MCDM/A) permet d'aider les décideurs (DM) de façon efficace pour traiter les défis qui impliquent des problèmes d'attribution de ressources ou des problèmes budgétaires (MONTIBELLER, 2009).

Dans la littérature, il est possible de trouver des recherches qui présentent des méthodes d'aide à la décision multicritère pour l'allocation de ressources, telles que des modèles de processus d'attribution de ressources par l'intermédiaire du classement par ordre de priorité (PHILLIPS & BANA E COSTA, 2007), méthodes concentrées sur l'analyse d'efficacité, consistant en grande partie sur le Data Envelopment Analysis (COOK & GREEN, 2000; ABDOLLAH *et al.*, 2008; FANG & ZHANG, 2008; FANG, 2013) ou approches basées sur le processus de décision analytique/hiérarchique (AHP) qui fournissent des moyens efficaces de convertir un problème d'attribution de ressources en objectif simple équivalent (RAMANATHAN & GANESH, 1995) et des problèmes impliquant la considération des critères qualitatifs et quantitatifs (RAMANATHAN & GANESH, 1995).

D'ailleurs, les problèmes de sélection de portfolio de projet jouent un rôle important comme méthode de MCDM/A pour résoudre des problèmes d'attribution de ressources, basés sur les méthodes par exemple PROMETHEE (VETSCHERA & DE ALMEIDA, 2011 ; MAVROTAS *et al.*, 2006), goal programming (RAMANATHAN & GANESH, 1995; COLAPINTO *et al.*, 2017) ou fonctions de valeur additive (PHILLIPS & BANA E COSTA, 2007; ARCHER & GHASEMZADEH, 1999 ; KLEINMUNTZ, 2007 ; SALO *et al.*, 2011). Le cœur de cette étude sera centré sur les méthodes multicritères permettant d'aider à résoudre les problèmes de sélection de portfolio.

Pour calculer les fonctions de valeur ajoutée pour les problèmes de sélection de portefeuille de projets, il est nécessaire de faire une agrégation de scores d'éléments individuels en une valeur de portefeuille globale (DE ALMEIDA *et al.*, 2014). Le résultat du portefeuille est la somme des valeurs incluses dans le portefeuille (LIESIÖ & PUNKKA, 2014).

Lors de l'évaluation des fonctions de valeur additive, il est essentiel de noter que ces types de fonctions imposent des exigences spécifiques sur les échelles de mesure utilisées pour les articles d'un portfolio et qu'elles ne sont pas régulièrement prises en compte dans la littérature existante (DE ALMEIDA *et al.*, 2014), ce qui pourrait être un problème, une fois qu'ils auront un impact significatif sur les résultats (MARTINS *et al.*, 2016 ; MARTINS *et al.*, 2017). Par conséquent, cette recherche considère ces problèmes d'échelle pour l'analyse multicritère.

Vu le contexte d'une université, l'utilisation d'une méthode d'aide à la décision multicritère intégrée avec un système d'aide à la décision orienté WEB pour répartir au mieux le budget limité, permettrait une meilleure répartition du budget, afin de distribuer toutes les ressources disponibles de manière efficace Un outil orienté Web permet d'améliorer la communication, la collaboration, de faire progresser la productivité des membres de groupe et d'améliorer la gestion des données (TAGHEZOUT *et al.*, 2011).

Par conséquent, ce travail vise à présenter des Systèmes d'Aide à la Décision Multicritère orienté WEB pour l'attribution de ressources aux universités publiques brésiliennes. Il n'existe actuellement aucune étude de ce genre pour un tel problème, et ceci peut contribuer à améliorer la question de décision pour l'affectation du budget interne, leur permettant de prendre des décisions plus sûres et fiables, tout en cherchant à réduire les incertitudes et à maximiser leurs résultats.

1.1 Motivation de Thèse

L'étude de cas menée dans ce travail prend en compte les résultats d'études antérieures sur les questions d'échelle pour la sélection de portefeuille dans un contexte de MCDM (DE ALMEIDA & VETSHERA, 2012 ; DE ALMEIDA *et al.*, 2014 ; VETSCHERA & DE ALMEIDA, 2012 ; MARTINS *et al.* 2016, MARTINS *et al.,* 2017). L'intention est maintenant de continuer à analyser si le même problème d'échelle se produit dans un scénario différent.

Ainsi, une université fédérale brésilienne a été choisie comme étalon afin d'avoir une application numérique du modèle multicritère développé. La disponibilité des données et la similitude avec un modèle général au Brésil nous a influencés pour ce choix. L'université analysée dans cette recherche à 21 unités administratives sectorielles (UAS) qui sont divisées par domaines, tels que les sciences humaines, les sciences biologiques, l'ingénierie, la faculté de médecine, etc., et chacune d'entre elles a des besoins budgétaires annuels. L'objectif est que l'application d'un modèle correct pour répartir le budget local entre ces unités puisse contribuer à la stratégie permanente de l'Université en matière d'allocation efficace et équitable des ressources.

Actuellement, il n'y a pas de DSS général pour un tel problème. Toutes les données pour l'application du modèle sont recueillies manuellement et gérées par chaque département de l'Université étudiée. L'idée est que le système multicritère pourrait soutenir les décideurs, les parties prenantes qui participent au processus de décision et décentraliser la réalisation des tâches, puisque les SIAD orientés Web offrent des outils de recherche intelligents qui pourraient leur permettre de trouver et de gérer l'information rapidement et à peu de frais (TURBAN *et al*., 2011).

L'objectif principal de cette recherche est comment améliorer le processus d'allocation des ressources et le décideur considéré est le directeur représentatif de l'unité de gestion de l'Université Fédérale de Mato Grosso do Sul (UFMS).

En outre, il est important de souligner que le modèle présenté ici pourrait être étendu et utilisé par d'autres universités fédérales au Brésil ou dans d'autres pays, en adaptant les alternatives et les critères pour chaque cas spécifique. La principale préoccupation est de démontrer l'utilisation d'un DSS Web multicritères pour ce problème particulier.

1.2 Objectifs de Recherche

1.2.1 Objectif Principal

L'objectif principal de cette étude est de proposer un système d'aide à la décision multicritères orienté Web pour l'allocation interne des ressources dans les universités publiques brésiliennes afin de démontrer comment l'utilisation d'une méthode de décision multi-attributs appropriée pourrait améliorer la distribution d'un budget limité en utilisant une fonction de valeur additive combiné avec un système pour décentraliser la réalisation des tâches, afin d'augmenter la productivité des membres du groupe et pour améliorer la gestion des données en utilisant le Web.

1.2.2 Objectifs Spécifiques

Les objectifs spécifiques de cette recherche sont :

- Identifier le modèle d'allocation générale brésilien pour les universités publiques et les modèles internes d'allocation de chaque université fédérale, trouver des similitudes entre eux et diviser les modèles en catégories, en fonction de leurs similitudes ;
- Proposer un modèle multicritère de répartition interne des ressources pour une université publique brésilienne, en appliquant une fonction de valeur additive et en comparant les résultats possibles en considérant différentes échelles (échelle d'intervalle et de rapport) ;
- Concevoir et proposer un prototype de système d'aide à la décision multicritères basé sur le Web pour le problème considéré ;
- Effectuer une analyse de sensibilité pour analyser la robustesse du modèle proposé et évaluer les impacts possibles du système sur le processus de prise de décision.

2 CONTEXTE THEORIQUE ET REVUE DE LA LITTÉRATURE

2.1 Problèmes d'Allocation de Ressources

Les décideurs de toutes les organisations sont confrontés en permanence à la difficile tâche d'équilibrer les avantages par rapport aux coûts et les risques lorsqu'ils affectent des ressources limitées (PHILLIPS & BANA E COSTA, 2007). Kleinmuntz (2007) déclare que les décisions d'allocation des ressources sont un dilemme auquel sont confrontées des organisations de toute taille, de tout type, de tout but et que la ressource limite est souvent financière car la capacité d'une organisation à emprunter des fonds ou à lever des fonds propres est limitée.

D'une manière générale, l'allocation des ressources se réfère à la détermination des niveaux de ressources limitées à répartir entre un certain nombre d'activités concurrentes et des noms spécifiques sont donnés tels que la budgétisation lorsqu'il s'agit de l'allocation financière (MUSTAFA & GOH, 1996). Selon Xavier (2002), la budgétisation est importante dans l'allocation des ressources car elle permet à l'organisation d'établir des priorités en vue d'atteindre les objectifs et d'identifier les priorités les plus élevées à atteindre avec les fonds disponibles. Dixon (2003) souligne que la budgétisation est un outil utile pour la planification et l'efficacité dans toutes les organisations. L'un des avantages de la planification budgétaire est qu'un décideur peut planifier systématiquement la proportion du budget à allouer aux activités budgétaires identifiées en fonction des objectifs et des plans stratégiques du département ou de l'organisation concerné (AZIZ, 2013).

Si l'on considère le contexte d'une université fédérale, par exemple, les maigres ressources peuvent être utilisées de manière optimale si le DM peut allouer efficacement son budget. Puisque les ressources et les fonds distribués pour les activités des universités ne sont pas appliqués de manière efficace, cela entraînera une incohérence avec les objectifs souhaités du gouvernement et de la population (AZIZ, 2013). Par conséquent, les modèles qui utilisent des systèmes d'aide à la décision sont essentiels pour parvenir à une allocation efficace des ressources dans les organisations d'enseignement supérieur.

Un SIAD pourrait être un moyen efficace d'aider les décideurs à relever les défis liés aux problèmes d'allocation des ressources ou de budgétisation (MONTIBELLER, 2009), et c'est pourquoi son application est démontrée dans cette recherche. L'utilisation d'un SIAD combiné avec des modèles d'aide à la décision multicritère (MARTINS *et al.*, 2017) sont largement utilisés dans des problèmes de décision financière tels que la sélection de portefeuilles de projets (VETSCHERA & DE ALMEIDA, 2012) octroi de prêts, choix entre projets alternatifs ou opportunités d'investissement, évaluation de la crédibilité de l'entreprise ou du risque d'échec, etc. (MAVROTAS, 2006).

Avec un processus et une procédure, une gamme d'outils et de techniques a été développée pour aider les décideurs à évaluer les décisions d'allocation des ressources de manière cohérente et constituer la base d'un SIAD (BHAYAT, 2015), cela sera discuté ensuite.

2.2 Systèmes d'Aide à la Décision et Systèmes Orienté Web

Selon Sprague et Carlson (1982), un système d'aide à la décision comprend une classe de système d'information qui s'appuie sur les systèmes de traitement des transactions et interagit avec l'autre partie du système d'information global pour soutenir les activités de prise de décision. Les DSS ont été développés pour soutenir les décideurs dans leurs tâches semi-structurées et sont apparus vers la fin des années 60 (ACKOFF, 1967).

Power (2000) affirme qu'un SIAD est un système ou sous-système interactif informatisé qui aide les gens à utiliser des communications, des données, des documents, des connaissances et des modèles informatiques pour identifier et résoudre des problèmes, effectuer des tâches décisionnelles et prendre des décisions. Comme mentionné précédemment, un DSS aide les décideurs à utiliser des données et des modèles pour résoudre des problèmes semi-structurés et non structurés. Il aide les décideurs à prendre de meilleures décisions et à répondre à des questions complexes (BIDGOLI, 1989 ; SPRAGUE & WATSON, 1989). Considérant différentes définitions pour un SIAD, on peut dire que, en général, un SIAD est essentiel pour soutenir le processus de prise de décision (SPRAGUE & WATSON, 1989).

Ainsi, il est possible d'affirmer qu'un système d'aide à la décision est une expression pour toute application informatique qui améliore la capacité d'une personne ou d'un groupe à prendre des décisions. En général, les DSS sont une classe de systèmes d'information informatisés qui soutiennent les activités de prise de décision (POWER, 2016).

Power (2009) a définit les types de systèmes d'aide à la décision comme suit :

1. Communication orienté ; le SIAD comprend la communication et la collaboration soutenues par des technologies telles que les e-mails, les tableaux d'affichage, les systèmes de chat et les vidéos interactives.

2. Données orienté : le SIAD donne accès à des outils pour manipuler de grands ensembles de données.

3. Document orienté : le SIAD peut être utilisé pour récupérer et analyser des documents, tels que des produits spécifications, procès-verbaux des réunions, politiques et procédures.

4. Connaissances orienté : le SIAD suggère des actions dans un domaine spécifique.

5. Modèle orienté : le SIAD donne accès à un modèle quantitatif.

Cette étude se concentre sur un SIAD modèle orienté, puisque le composant dominant est un modèle quantitatif, plus précisément un modèle d'optimisation.

Déjà dans le cas de Systèmes Orienté Web (OW-SIAD), ils sont définis comme des systèmes d'aide à la décision qui sont accessibles sur le Web (ZAHEDI, SONG & JARUPATHIRUN, 2008). Ils ont les mêmes limites larges que celles des SIAD classique. Néanmoins, OW-SIAD peut être identifié par certaines caractéristiques (ZAHEDI, SONG & JARUPATHIRUN, 2008) :

• Accessible sur le Web ;

• Soutenir les individus / clients / employés / gestionnaires / groupes dans leur processus de prise de décision indépendamment de leurs emplacements physiques ou de l'heure de accès ;

• Avoir des résultats spécifiques à un contexte prédéterminé qui est soit unique à l'environnement Web ou en tant qu'interface pour le bureau SIAD ;

• Traiter des processus de décision semi-structurés ou non structurés à différentes étapes du processus de décision, dont certaines pourraient prendre placer sur le Web ;

• Utilisation de données, base de connaissances, document, modèle et heuristique, faire appel à un groupe d'utilisateurs variés et culturellement variés ;

• Être un outil optionnel pour les internautes dans leurs processus de décision.

Un SIAD Orienté Web apporte, ainsi, l'information d'aide à la décision ou les outils d'aide à la décision à un directeur ou à un analyste d'affaires employant un web browser de « client léger », comme Internet Explorer qui accède à l'Internet global ou à un intranet d'entreprise. Son application peut augmenter l'accès et l'utilisation, réduire l'appui et les frais de formation et permettre des capacités étendues aux utilisateurs (POWER, 2000).

2.3 Problème de Sélection de Portefeuille de Projet

Les problèmes de portefeuille ont généralement pour but de choisir, à partir d'un ensemble d'alternatives, un sous-ensemble limité par les contraintes données par le problème et le but considéré (BELTON & STEWART, 2002). La sélection du portefeuille de projets implique le choix d'un sous-ensemble de projets visant à optimiser les bénéfices obtenus, soumis régulièrement à une contrainte budgétaire (VETSCHERA & DE ALMEIDA, 2012). Le but principal de la sélection d'un sous-ensemble d'items est d'optimiser les bénéfices obtenus, en améliorant le processus de prise de décision en utilisant des modèles mathématiques dans l'élaboration de recommandations de décisions (Salo, et al., 2011).

Pour illustrer le concept adopté dans ce texte, considérons un problème dans lequel sont disponibles *n* projets et A_i ($i = 1, \dots n$) représente l'ensemble des alternatives pour construire un portefeuille. Le décideur peut sélectionner différents projets, en tenant compte de quelques contraintes de ressources ou d'autres contraintes qui déterminent si un portefeuille est faisable ou non (DE ALMEIDA *et al.*, 2014).

Dans un modèle d'optimisation, l'objectif principal est de maximiser la fonction objectif, compte tenu des contraintes données (KLEINMUNTZ, 2007), qui pourrait être une contrainte budgétaire, par exemple. Par conséquent, la fonction objectif (1) et les contraintes (2) peuvent s'écrire comme :

$$\sum_{i=1}^{n} z_i \, v(A_i) \tag{1}$$

Sujet à :

$$\sum_{i=1}^{n} z_i \, c_i \; \leq C \tag{2}$$

Où z_i est une variable binaire indiquant si l'élément A_i est inclus ou non dans le portefeuille, donc $z_i = 1$ s'il est inclus et $z_i = 0$ s'il ne l'est pas (CLEMEN & SMITH, 2009). $v(A_i)$ est la valeur de l'item A_i obtenue à partir de l'évaluation multi-attributs (DE ALMEIDA *et al.*, 2014). C et c_i sont liés aux contraintes, où C pourrait être le montant budgétisé disponible pour financer les coûts du projet et c_i le coût pour développer le projet i, par exemple (KLEINMUNTZ, 2007).

Quand on considère une université publique, aucune unité administrative ne peut rester sans recevoir une partie du budget en raison du montant minimum requis pour maintenir l'UAS, dans des services tels que la sécurité, par exemple. En analysant le modèle du point de vue de la sélection du portefeuille de projets, on pourrait alors en déduire que, pour ce modèle particulier proposé ici, tous les projets du problème seront financés (LOURENÇO, MORTON, BANA E COSTA, 2012) et alors il n'y aurait pas de décision à prendre, mais ce n'est pas le cas.

Le problème de la décision consiste ici à définir quelles sont les unités administratives qui recevront une partie du budget supérieure à la valeur minimale que chacune doit recevoir, c'est-à-dire : le budget total demandé par la UAS, compte tenu de ses performances pour l'ensemble de critères définis par le DM, ce qui constitue un problème de sélection du portefeuille de projets.

De plus, pour adapter le modèle à cette étude et en tenant compte de l'équation (1) et de l'inéquation (2), les variables du modèle peuvent également être décrites comme suit :

c_i = le budget demandé par l'unité administrative ou le budget supérieur à la limite minimale que chaque UAS souhaite recevoir;

$min \; c_i$ = pourcentage minimum du budget que chaque UAS devrait recevoir;

z_i = variable binaire égale à 1 lorsque l'UAS recevra le budget demandé ou égale à 0 sinon;

$z_i\ c_i$ = le budget alloué à l'UAS «*i*», qui est égal à c_i lorsque z_i est égal à 1;

B = budget total de l'université disponible à répartir ;

C = montant total du budget supérieur au pourcentage minimum du budget que chaque UAS devrait recevoir, à savoir :

$$B - \sum_{i=1}^{n} min\ c_i = C \quad (3)$$

Enfin, l'évaluation résulte d'une fonction de valeur additive de la forme (DE ALMEIDA *et al.*, 2014) :

$$v(A_i) = \sum_{j=1}^{m} k_j v_j(x_{ij}) \quad (4)$$

Où selon de Almeida et al. (2014):

x_{ij} est le résultat obtenu par l'élément Ai dans l'attribut j;

v_j est la fonction de valeur marginale de l'attribut j;

k_j est le poids (constante d'échelle) de l'attribut j, où sa somme doit être égale à 1.

Quand il est considéré des problèmes de portefeuille multi-attributs, de Almeida et al. (2014) ont discuté des effets de différentes échelles de valeur. Ils ont évalué trois effets : l'effet de la taille du portefeuille, la cohérence entre les différentes séquences d'agrégation et l'effet « *baseline* » (MARTINS *et al.*, 2016). Les mêmes auteurs (DE ALMEIDA *et al.*, 2014) ont proposé le concept de portefeuilles c-optimaux pour surmonter l'effet de la taille du portefeuille. Ils ont également montré que ces trois effets ont des causes similaires liées à l'utilisation d'une échelle de valeurs d'intervalle, ce qui permet la transformation additive des utilités (MARTINS *et al.*, 2016).

Lors de l'analyse des fonctions de valeur additive, il est important de noter qu'elles imposent certaines exigences aux échelles de mesure utilisées pour les éléments d'un portefeuille et, régulièrement, elles ne sont pas prises en compte dans la littérature existante (DE ALMEIDA *et al.,* 2014), ce qui pourrait être un problème, une fois qu'ils ont un impact significatif sur les résultats (MARTINS *et al.*, 2016) et c'est la raison pour laquelle ils sont pris en compte dans cette recherche.

Pour des informations plus complètes sur les transformations d'échelle ou d'autres sujets connexes, voir Almeida *et al.* (2014) ; Martins *et al.* (2016) ; et Martins *et al.* (2017).

2.4 Modèle d'allocation des Ressources pour les Universités Fédérales Brésiliennes

Pour expliquer le modèle d'allocation des ressources pour les universités fédérales (UF) au Brésil, il faut d'abord comprendre comment fonctionne le processus de budgétisation. Le budget adopté par les universités fédérales au Brésil est appelé « programme-budget », qui est régi par une loi fédérale numéro 4320, établie en 1964 (BRASIL, 1964) et par une loi complémentaire numéro 101, à partir de 2000 (BRASIL, 2000). Le "programme-budget" fait partie du budget général de l'Union. Par conséquent, il est discuté et approuvé par le Congrès national. Ce budget est constitué de ressources du Trésor national, de ressources provenant du financement direct des universités fédérales, appelées ressources propres, et de ressources provenant d'accords et de contrats célébrés avec des entités publiques ou privées (BRASIL, 2006).

Les ressources budgétaires destinées à maintenir les activités d'enseignement, de recherche et de vulgarisation à partir des UF sont appelées « autres coûts et capitaux (OCC) », ce qui représente leur budget total déduit des dépenses avec la masse salariale du personnel. Le transfert de ces ressources se fait sur la base d'un modèle mathématique appelé "matrice" (Matrice OCC) qui est fondé sur le nombre "d'étudiants équivalents", qui sera expliqué plus loin, et les indicateurs de production académique des UF. Ces concepts ont été adaptés du modèle anglais d'allocation des ressources pour les universités (HEFCE, 1998), développé par le Conseil supérieur de l'enseignement supérieur pour l'Angleterre - HEFCE.

La matrice d'allocation des ressources du OCC est constituée de deux types de budget : un budget de base appelé aussi « budget de maintenance » et un budget d'investissement. La détermination de ces deux budgets est faite par un processus divisé en trois étapes différentes : d'abord, le ministère brésilien de l'éducation (ministère de l'Éducation - MEC) fixe la limite des ressources nationale qui peuvent être dépensées par les FU. Deuxièmement, le budget global est alloué selon les règles de la matrice OCC, où les budgets individuels de chaque UF sont définis. Enfin, MEC consolide, valide et formalise la proposition de budget (BRASIL, 2006).

La matrice OCC a des critères équitables, qualitatifs, inducteurs, mesurables et vérifiables. Le modèle est commun à toutes les universités fédérales et la structure du budget est programmée l'année précédente (BRASIL, 2010). La base de la matrice, comme nous l'avons déjà dit, est le nombre d'étudiants (étudiants équivalents, dont le calcul peut être vu sur la Figure 1) de chaque université fédérale (MEC, 2013). Le modèle général de matrice OCC est décrit à la Figure 1.

PART = h1(PTAE) + h2(EQR)

PART = participation of the FU from the total OCC Matrix budget

h1= 0,9

h2= 0,1

h1 and h2 = weights

PTAE = TAE/∑TAE

PTAE = participation of the FU from the total of Equivalent Students of all the FU's

TAE = total of equivalent students

EQR = DEQ/∑DEQ

EQR = efficiency and scientific academic quality from the FU

DEQ = efficiency and scientific academic quality dimension from the FU

∑DEQ = efficiency and scientific academic quality dimension from the set of FU's

TAE= TAEG+TAERM+TAEM+TAED

TAEG= ∑ {[(NACG)(1+R)+N-NACG/4](PG)(DG)(BT)(BFS)}

TAEG = Total of Equivalent Students in Undergraduation

NACG = Total of students that finished Undergraduation Studies

N = Total of students that starts Undergraduation Studies

D = Duration of the undergraduation course

R = Standard "retention" factor of the undergraduation course

PG = weight of the undergraduation course

BT = bonus for having nightly undergraduation courses

BFS = bonus for having an undergraduation course outside the main campus

TAEG**= ∑(NMG)(PG)(BT)(BFS)

**= new undergraduation courses (less than 10 years)

NMG = Total of students enrolled in an undergraduation course

PG = weight of the undergraduation course

TAEG***= ∑ {[(NACG)(1+R)](PG)(DG)(BT)(BFS)}

***= New undergraduation course

DG = Standard duration of the undergraduation course

TAERM = ∑(NAMRM)(PRM)

TAERM = total of equivalent students from medical residency

NAMRM = total of students enrolled in a medical residency course

PRM = weight of the group from the medical residency course

TAEM = ∑(NACM)(DM)(PM)

TAEM = total of equivalent students in a master course

NACM = total of students that concluded the master course

DM = standard duration of the master course

PM = weight of the group from the master course

TAED = ∑(NACD)(DD)(PD)

TAED = total of equivalent students in a doctorate course

NACD = total of students that concluded the doctorate course

DD = standard duration of the doctorate course

PD = weight of the group from the doctorate course

DEQ = DEAE + DQG + DQM + DQD

DEAE = efficiency dimension of the teaching activities in the FU

DQG = quality dimension from the undergraduation courses

DQM = quality dimension from the master courses

DQD = quality dimension from the doctorate courses

DEAE = FRAP

FRAP = RAP / RAP

FRAP = relation factor between equivalent student and professor

RAP = relation between equivalent student and professor

RAP = average relation between equivalent student and professor

DQG = ∑FCG / NCG

FCG = (CSG / CSG)

FCG = quality factor from the undergraduation course

CSG = SINAES concept of the undergraduation course

CSG = SINAES average concept from the undegraduation course from the set of FU's

NCG = number of undergraduation courses evaluated at the FU

DQM = ∑FQM / NCM

FQM = (CCM / CCM)

FQM = quality factor from the master course

NCM = total number of master courses at the FU

CCM = CAPES concept of the master course

CCM = average CAPES concept from the set of FU's of the master courses that have the same area

DQD = ∑FQD / NCD

FQD = (CCD / CCD)

FQD = quality factor from the doctorate course

NCD = total number of doctorate courses at the FU

CCD = CAPES concept of the doctorate course

CCD = average CAPES concept from the set of FU's of the doctorate courses that have the same area

Figure 1 - Formules générales du modèle

La Figure 1 montre comment est calculée la participation générale de chaque UF au budget total de la matrice OCC (PART), basée principalement sur le total des équivalents étudiants (PTAE) et sur l'efficacité, la qualité scientifique et académique (EQR) du FU. La figure montre également comment sont calculés le facteur de relation entre étudiant et professeur équivalent (FRAP), le facteur de qualité du cours de premier cycle (FCG), le facteur de qualité du master (FQM) et le cours de qualité du doctorat. Enfin, la Figure 1 montre comment sont calculés les trois derniers indicateurs du modèle : total des étudiants équivalents en résidence médicale (TAERM), total des étudiants équivalents en master (TAEM) et total des étudiants équivalents en doctorat (TAED).

La matrice OCC est divisée en deux indicateurs principaux : les indicateurs quantitatifs et qualitatifs. L'indicateur quantitatif a un poids de 0,9 (figure 1) et l'indicateur principal est le TAE (total des étudiants équivalents), où son calcul est basé sur le nombre total d'étudiants de premier cycle, de résidence médicale, de master et de doctorat.

En revanche, l'indicateur qualitatif, pondéré à 0,1, repose sur des indicateurs globaux tels que l'évaluation des cours de premier cycle, master et doctorat, les numéros de production scientifique et la relation entre le nombre d'étudiants et de professeurs pour chaque cours.

Il y a 55 universités fédérales au Brésil qui reçoivent des ressources de la matrice OCC, et chacune d'entre elles a son propre modèle interne d'allocation des ressources. Il est important de souligner que le modèle d'allocation des ressources du MCDM proposé dans cette étude est axé sur le processus où le budget individuel défini par MEC est alloué selon le modèle interne défini par chaque FU. Plus précisément, le modèle MCDM sera appliqué à l'Université fédérale du Mato Grosso do Sul (UFMS), en raison de la disponibilité des données et de la similitude avec le modèle général.

3 MODÈLE MULTICRITÈRE D'ALLOCATION DES RESSOURCES POUR UNE UNIVERSITÉ FÉDÉRALE BRÉSILIENNE

L'un des objectifs de cette recherche est d'appliquer un modèle d'allocation de ressources MCDM pour une université publique brésilienne, plus précisément, l'Université Fédérale du Mato Grosso do Sul (UFMS). L'étude fera une demande pour évaluer comment le budget de la matrice OCC est réparti entre les 21 unités administratives sectorielles, appelées «UAS», de UFMS, et compare les résultats possibles en considérant différents scénarios. L'idée est que le modèle puisse indiquer le montant total du budget que chaque UAS devrait recevoir.

UFMS a déjà un modèle pour l'allocation interne des ressources et il est très similaire au modèle général adopté par le Ministère de l'Education au Brésil, à l'exception du fait que le modèle UFMS considère les mêmes poids pour les indicateurs quantitatifs et qualitatifs. Comme nous l'avons déjà dit, l'Université étudiée compte 21 unités administratives sectorielles divisées en domaines tels que les sciences humaines, les sciences biologiques, l'ingénierie, la faculté de médecine et autres, considérés comme des alternatives, des projets ou des unités budgétaires du modèle MCDM.

Chaque année, le département du budget et de la planification de l'UFMS (PROPLAN) établit les critères d'allocation des crédits budgétaires de la Matrice OCC du ministère de l'éducation (Autres coûts et capitaux - OCC), applicable à toutes les unités administratives sectorielles et les activités d'investissement. Chaque UAS fournit des données et des informations, basées sur les paramètres décrits ci-dessous, à l'unité de budgétisation. PROPLAN rassemble les informations et fixe ensuite le pourcentage du budget qui sera distribué à chaque UAS, sur la base du modèle d'allocation des ressources. La répartition des crédits budgétaires est fondée sur des variables quantitatives et qualitatives, décrites comme suit :

• Variable quantitative (IVQuan) : basée sur le nombre d'étudiants équivalents de chaque UAS (InAlEqv), calculée à partir des indicateurs relatifs au nombre d'étudiants entrant, inscrits et diplômés du premier cycle (TAEG), aux cours postuniversitaires (TAEM et TAED), et résidences médicales (TAERM). L'indicateur considère également des informations sur le sujet du cours, par exemple, un cours de médecine est plus cher qu'un cours d'histoire en raison du nombre de laboratoires nécessaires, donc, le cours a un facteur de pondération, et prend en compte la durée totale du cours aussi ;

• Variables qualitatives (IVQual): sur la base de critères mesurant l'efficience / l'efficacité de l'Unité, en termes de qualification du personnel académique (IQCD), de nombre de postes vacants (IVO), seul critère à minimiser, projets de recherche avec soutien (IPP), projets d'extension avec soutien financier externe (IPE), taux de réussite de l'obtention du diplôme (ITS), efficacité de l'enseignement (IDEAE), mesuré par la relation entre le nombre total d'étudiants et de professeurs, (IDQM), et des cours de doctorat (IDQD), sur la base des évaluations de l'Institut national d'études et de recherche en éducation Anísio Teixeira - INEP et la Coordination pour l'amélioration du personnel de l'enseignement supérieur - CAPES.

Ainsi, les formules du modèle sont calculées comme suit et des informations détaillées peuvent être vues dans UFMS (2017) et dans la Figure 1 puisque les modèles sont similaires :

$$\text{InPP UAS} = \text{IVQuan} + \text{IVQual}$$

Où :

$$\text{IVQual UAS} = \sum \text{IQCD} + \text{IVO} + \text{IPP} + \text{IPE} + \text{ITS} + \text{IDEAE} + \text{IDQG} + \text{IDQM} + \text{IDQD}$$

$$\text{IVQuan} = \text{InAlEqv} = \sum \text{TAEG} + \text{TAEM} + \text{TAED} + \text{TAERM}$$

Les alternatives et les critères définis pour cette application étaient les mêmes considérés par le modèle existant appliqué à l'université. Les poids ont été définis par le DM, qui était considéré comme le directeur du département du budget et de la planification (PROPLAN / UFMS). Le Tableau 1 montre la matrice de décision avec leurs valeurs et poids respectifs. Les scores ont été normalisés en utilisant une échelle d'intervalle et une échelle de rapport pour vérifier les impacts des problèmes d'échelle. De plus, une analyse de sensibilité a été effectuée pour tester la robustesse du modèle et ses résultats seront présentés à la Section 3.1.

Le budget total envisagé pour le problème était de 850 000 R $, une valeur qui représente 85% du budget total de 2017 pour la Matrice OCC, une fois que c'était le montant publié par le Ministère de l'Education en 2017, en raison des réductions budgétaires gouvernementales (UFMS, 2017). La valeur minimale a considéré que chaque unité administrative doit recevoir 70% du dernier budget, puisque c'est le montant minimum requis et considéré pour maintenir le UAS, une valeur à utiliser dans des services comme la sécurité, par exemple. Ensuite, les résultats du modèle sont présentés dans le Tableau 1 et la Figure 2.

Alternatives	**Critères**									
	InAlEqv	**IQCD**	**IVO**	**IPP**	**IPE**	**ITS**	**IDEAE**	**IDGQ**	**IDQM**	**IDQD**
UAS1	8.92	5.45	-5.77	11.43	28.57	5.04	2.95	4.9	20.62	9.09
UAS2	8.14	4.79	-14.12	11.43	25,00	4.71	2.38	4.13	14.43	9.09
UAS3	3.2	5.26	-3.98	5.71	0,00	6.13	6.1	4.9	3.09	0,00
UAS4	7.3	4.08	-14.02	4.29	0,00	3.83	3.14	4.36	6.19	0,00
UAS5	6.04	4.47	-8.02	7.14	0,00	3.94	4.1	3.86	3.09	0,00
UAS6	1.39	4.57	-2.31	1.43	0,00	3.61	2.43	4.5	0,00	0,00
UAS7	2.84	5.31	-2.34	0,00	0,00	5.59	6.29	5.5	3.09	0,00
UAS8	2.39	3.93	-3.57	0,00	0,00	3.07	3.19	4.27	0,00	0,00
UAS9	1.93	3.37	-2.65	0,00	0,00	6.13	4.95	4.5	0,00	0,00
UAS10	1.22	4,00	-2,00	0,00	3.57	6.24	4,00	4.9	0,00	0,00
UAS11	1.87	3.93	-3.96	0,00	3.57	2.52	3.1	4.5	0,00	0,00
UAS12	10.32	4.65	-12.87	2.86	3.57	3.07	3.48	4.45	7.22	9.09
UAS13	6.39	4.82	-7.62	4.29	3.57	2.3	7,00	4.9	7.22	9.09
UAS14	2.65	4.77	-1,00	2.86	3.57	9.64	7.38	6.09	0,00	0,00
UAS15	11.69	4.95	-10.5	10,00	7.14	3.29	6.15	4.9	7.22	9.09
UAS16	10.44	4.43	-0.26	8.57	0,00	10.08	12.43	6.09	7.22	18.18
UAS17	7.58	5.52	-1.15	10,00	0,00	7.78	10.29	5.5	7.22	18.18
UAS18	3.09	5.51	-0.54	1.43	0,00	4.16	6.05	4.9	3.09	0,00
UAS19	0.47	5.75	-0.75	12.86	10.71	2.96	1.1	4.9	3.09	0,00
UAS20	0.83	4.74	-1.16	0,00	7.14	2.85	1.19	3.68	4.12	9.09
UAS21	1.3	5.71	-1.42	5.71	3.57	3.07	2.29	4.27	3.09	9.09
Importance	**0,1917**	**0,1778**	**-0,029**	**0,1242**	**0,1086**	**0,113 3**	**0,0858**	**0,1279**	**0,0368**	**0,0368**

Tableau 1 – Matrice de decision

Alternatives	V_i (A_i) – Interval Scale	V_i (A_i) – Ratio Scale	*Go?*	P_i %
UAS1	0,6065	0,6682	0	12,16%
UAS2	0,5235	0,5981	0	9,98%
UAS3	0,2743	0,3880	1	2,92%
UAS4	0,2673	0,3821	1	3,71%
UAS5	0,2652	0,3804	1	3,58%
UAS6	0,1133	0,2523	1	1,41%
UAS7	0,2200	0,3422	1	2,55%
UAS8	0,0931	0,2352	1	1,62%
UAS9	0,1461	0,2799	1	1,75%
UAS10	0,1674	0,2979	1	1,72%
UAS11	0,0892	0,2319	1	1,57%
UAS12	0,3576	0,4583	0	5,86%
UAS13	0,2938	0,4044	0	4,72%
UAS14	0,3578	0,4584	1	4,36%
UAS15	0,4997	0,5781	0	10,43%
UAS16	0,7570	0,7950	0	11,75%
UAS17	0,5488	0,6195	1	9,78%
UAS18	0,2581	0,3744	1	2,72%
UAS19	0,3008	0,4103	1	2,58%
UAS20	0,1330	0,2689	1	2,20%
UAS21	0,2101	0,3339	1	2,62%
Total Value – Interval Scale	**3,6670**			
Total Value – Ratio Scale	**5,2551**			

Tableau 2 – Résultats du modèle d'allocation des ressources

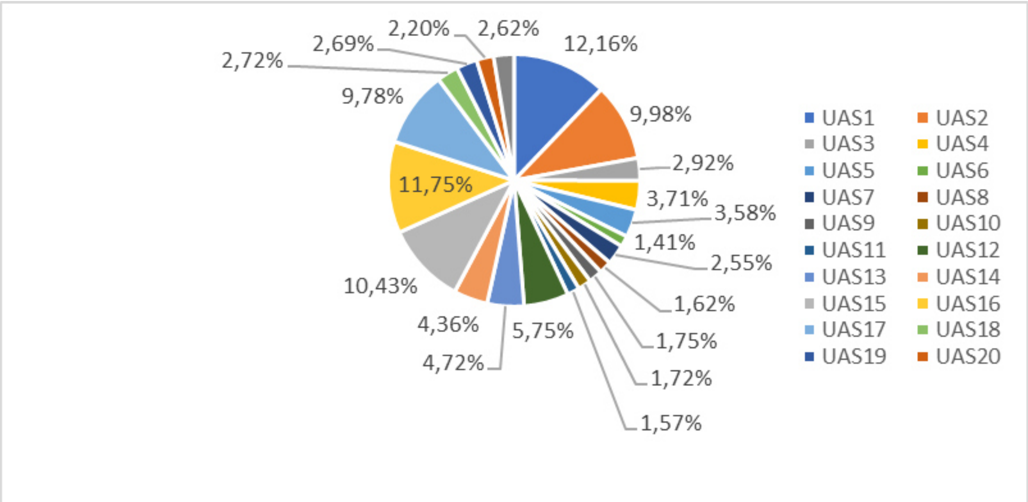

Figure 2 -% du budget

Le Tableau 2 montre les alternatives, leur valeur respective du modèle additif (V_i) en utilisant une échelle d'intervalle et une échelle de rapport, le pourcentage (Z_i%) du budget total que chaque unité administrative devrait recevoir et la valeur totale qui représente l'objectif fonction du modèle. La Figure 2 montre le pourcentage du budget total que chaque unité administrative devrait recevoir.

Les différences trouvées dans l'application lors de l'examen des différentes échelles étaient dans la fonction de valeur du modèle additif (V_i) pour chaque UAS, causée par différents poids et échelles dans le processus d'agrégation. La valeur totale, qui représente la fonction objectif du modèle diffère pour la même raison. Dans un contexte d'échelle de rapport, la performance de chaque alternative (UAS) est meilleure que celle d'un contexte d'échelle d'intervalle, et la même analyse pourrait être déduite de la valeur globale.

À partir de l'utilisation du modèle additif, les résultats indiquent un portefeuille de 11 projets, pour l'échelle intervalles et tenant compte du contexte d'une échelle de rapport, avec la transformation appropriée des pondérations, les résultats indiquent un portefeuille de 15 projets. En termes de valeur budgétaire, la solution avec une échelle d'intervalle utilise un total de R$ 148 512,71 et la solution avec une échelle de rapport consomme R$ 148 831,30 du budget disponible (R$ 150 000).

Comme indiqué précédemment, les problèmes de mise à l'échelle ne se produisent pas pour tous les cas, et ils dépendront de la combinaison des valeurs et des contraintes considérées par le problème analysé (MARTINS *et al.*, 2016). De plus, il est toujours important d'examiner l'existence du problème d'échelle et, si cela se produit, alors il faut apporter les changements nécessaires à l'adéquation du cas (MARTINS *et al.*, 2016). Cette application a montré un véritable cas de problème de budgétisation, notamment dans le domaine de l'éducation.

Les implications de ces résultats pour la pratique sont que lorsqu'une transformation d'échelle adéquate est considérée dans une analyse de portefeuille multicritère additive, cela peut contribuer à mieux répartir le budget limité, cela pourrait signifier atteindre des résultats optimaux, en appliquant toutes les ressources disponibles avec efficacité.

En analysant profondément les résultats, on peut en déduire que l'UAS 1 était l'alternative qui devrait recevoir la plus grande partie du budget (12,16%), suivie par l'UAS 16 (11,75%), l'UAS 15 (10,43%), UAS 2 (10%) et UAS 17 (9,78%). Ensemble, ces unités représentent plus de 50% du budget de l'université. Les résultats pourraient s'expliquer par la performance de ces alternatives dans les critères considérés. En outre, il est important de dire que les unités représentent le cours de médecine, la médecine vétérinaire, les cours de zootechnie, les cours dans le domaine biologique, tels que la biologie, la pharmacie et la nutrition. Tous sont considérés comme des cours ayant des besoins d'allocation de ressources supplémentaires, en raison de l'infrastructure nécessaire pour les gérer. Ou encore, les résultats pourraient être expliqués en raison du nombre d'étudiants. Par exemple, UAS 2 représente des cours dans le domaine des sciences humaines, tels que le droit, la gestion d'entreprise, qui sont traditionnellement des cours avec un grand nombre d'étudiants à UFMS.

Les alternatives avec la plus petite partie du budget représentent les petits collèges de l'université, composés principalement de cours qui n'ont pas besoin d'une grande infrastructure, comme l'histoire et la pédagogie, par exemple.

Le Tableau 3 fait une comparaison entre les pourcentages alloués avant (le modèle déjà utilisé par UFMS) et après la méthode d'allocation de ressources MCDM proposée ici.

Alternatives	**% du budget avant le modèle**	**% of the budget after the model**
UAS1	10,34%	12,16%
UAS2	8,49%	9,98%
UAS3	3,55%	2,92%
UAS4	4,50%	3,71%
UAS5	4,35%	3,58%
UAS6	1,71%	1,41%
UAS7	3,10%	2,55%
UAS8	1,98%	1,62%
UAS9	2,13%	1,75%
UAS10	2,09%	1,72%
UAS11	1,91%	1,57%
UAS12	6,99%	5,75%
UAS13	5,74%	4,72%
UAS14	3,71%	4,36%
UAS15	8,86%	10,43%
UAS16	9,99%	11,75%
UAS17	8,32%	9,78%
UAS18	3,31%	2,72%
UAS19	3,14%	2,69%
UAS20	2,68%	2,20%
UAS21	3,18%	2,62%

Tableau 3 - Comparaison entre les pourcentages alloués

La comparaison montre que les pourcentages alloués étaient différents du modèle UFMS, indiquant que certaines unités administratives sectorielles devraient recevoir un pourcentage différent du budget qu'elles reçoivent réellement. Cette différence se produit en raison de la valeur de chaque alternative (A_i) obtenue à partir de l'évaluation multi-attributs.

En cas de variation du budget total considéré par le modèle, en augmentant, par exemple, les pourcentages différeront de celui trouvé par le modèle étudié ici de la façon suivante : le pourcentage augmente dans le cas où l'UAS devrait recevoir le budget maximum demandé, réglé par la contrainte budgétaire maximale dans le modèle, et diminuera lorsque l'UAS devrait recevoir moins que le maximum. Cette situation se produit en raison de la performance des alternatives dans la fonction de valeur, et en tenant compte de cela, les ressources pourraient être mieux réparties en considérant une fonction de valeur additive.

De plus, bien que le modèle présenté ici ne pose pas de problèmes de mise à l'échelle, pour définir le pourcentage que chaque unité recevra, le DM doit toujours choisir un modèle qui reflète l'évaluation réelle que chaque critère implique par rapport à ses préférences. Lorsque vous effectuez une évaluation dans le contexte de fonctions de valeur ajoutée et, plus précisément, de sélection de portefeuille de projets, vous devez procéder, chaque fois que cela est possible, à une échelle de ratio, car elle assure la cohérence entre différents types d'agrégation.

Du point de vue de l'unité administrative sectorielle, la meilleure situation pour recevoir de meilleurs budgets serait de rechercher un équilibre entre tous les résultats des critères, avec une valeur moyenne pour chaque critère, et, peut-être, le modèle adopté par l'Université pourrait poids pour les critères, dans le but d'encourager tous les UAS à atteindre de meilleurs résultats et de démontrer une plus grande efficacité du modèle d'allocation des ressources utilisé.

3.1 Résultats de l'Analyse de Sensibilité

Après une analyse préliminaire des données, une analyse de sensibilité a été réalisée à l'aide d'une simulation de Monte Carlo. La procédure de simulation de Monte Carlo répète le modèle N fois, en faisant varier les paramètres dans une plage de valeurs sélectionnée et en établissant une distribution de probabilités. Ensuite, on obtient N solutions pour le cas. À cette fin, N devrait être un grand nombre et de nombreuses solutions N pourraient être identiques.

Pour la première analyse, les poids de chaque critère ont été augmentés de 10% séparément et l'ajustement des poids pour les autres critères a été effectué pour une distribution uniforme. La solution standard a été considérée comme la meilleure en l'absence de toute autre recommandation et le portefeuille standard est resté le même.

Dans la seconde analyse, les poids de chaque critère ont été augmentés de 20% avec l'ajustement correspondant pour les autres poids. Dans ce cas, la solution standard s'est avérée être la meilleure et il n'y a que 5,1% des cas dans lesquels une nouvelle solution a été recommandée, ce qui signifie qu'un portefeuille non standard a été recommandé. Dans ce cas, UAS 17 est remplacé par UAS 2.

À la lumière des résultats obtenus, l'analyse de sensibilité a montré un résultat robuste pour le cas. Toutefois, il y a eu quelques changements et le décideur peut analyser les portefeuilles, en évaluant uniquement les alternatives qui ont changé.

Il est important de souligner que lors de l'analyse de sensibilité, la somme de la fonction objective, c'est-à-dire de la valeur globale du modèle, est presque restée inchangée pour chaque simulation. Il y avait de petits changements variant de 0,0001 à 0,035 dans la valeur totale. Le critère qui augmente le plus la fonction objective quand ils augmentent est la qualité des cours de premier cycle (IDGQ).

Il serait intéressant que des variations simultanées des poids soient prises en compte par le DM, en plus des variations individuelles déjà prises en compte dans les résultats de l'analyse de sensibilité. Pour cette situation, le DM devrait revoir le modèle et se considérer capable de distinguer la signification de chaque poids dans le modèle UFMS.

Néanmoins, il est possible de souligner la robustesse du modèle, puisque même lorsque les poids changent pour chaque critère, le pourcentage du budget total pour les unités administratives reste à peu près le même que l'application originale du modèle.

4 PROTOTYPE DU SYSTEME d'AIDE A LA DECISION MULTICRITÈRE ORIENTE WEB POUR LA REPARTITION DES RESSOURCES

L'étude de cas DSS proposée ici se concentre sur un DSS basé sur un modèle et, selon le cadre DSS de Power (2001), peut être classé comme suit: le composant DSS dominant est un modèle d'optimisation basé sur une procédure d'allocation de ressources; les utilisateurs cibles sont le personnel administratif de l'unité de budgétisation de UFMS et les décideurs de chaque UAS, puisqu'ils sont affectés par la procédure d'allocation; le but est de contribuer à la question de la décision sur la façon d'améliorer le processus d'allocation des ressources correctement et de l'optimiser; et la technologie habilitante utilisée était Excel, le modèle d'allocation des ressources, la création de la base pour construire un DSS basé sur le Web, un modèle de base de données et un DSS basé sur le Web.

La création du DSS est justifiée par le fait que toutes les données pour l'application du modèle sont collectées manuellement et gérées avec des feuilles de calcul Excel par un seul département de l'Université étudié, à partir des données fournies par chaque UAS. L'idée est que le système pourrait soutenir les décideurs, les parties prenantes, améliorer la gestion des données, la communication, la collaboration, augmenter la productivité, décentraliser la réalisation des tâches, accéder aux informations à tout moment et de n'importe où, analyser et interpréter (TURBAN, SHARDA & DELEN, 2011).

Le prototype DSS du modèle trouvé par cette étude est présenté dans la Figure 2, où l'information peut être visualisée comme suit: les entrées sont des données du modèle (fourni par le UAS, rempli et stocké à la base de données), tels que le le nom de l'UAS et les indicateurs ou paramètres pris en compte par le modèle; le traitement est le traitement interactif des données et des modèles, le calcul des formules définies par les modèles, la simulation, l'optimisation et l'analyse que peuvent fournir les modèles; enfin, les résultats sont la part finale du budget que chaque université, unité académique ou cours recevra, les données transformées à partir des modèles qui peuvent être utilisés pour prendre des décisions. Les étapes de traitement et de sortie sont effectuées dans le système Web. Les utilisateurs finaux sont le personnel administratif de l'unité de budgétisation de UFMS et DM de chaque UAS.

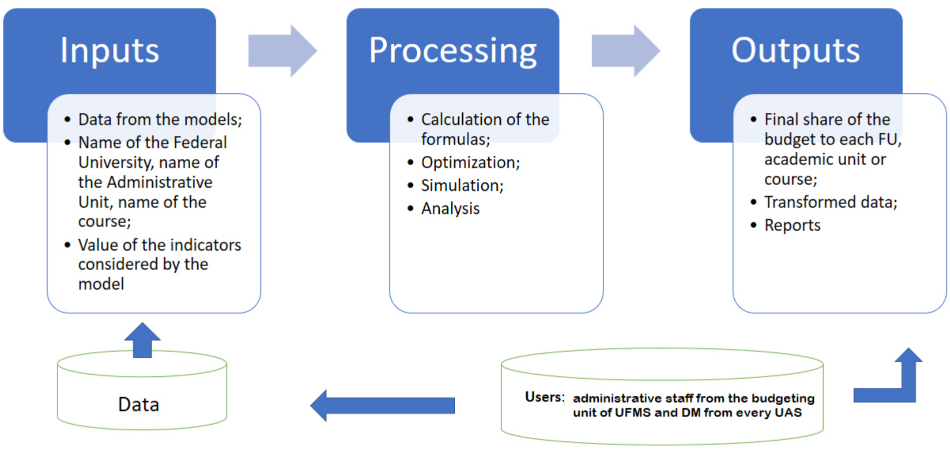

Figure 2: SIAD composants du prototype issus de cette recherche

Pour mettre en œuvre le DSS basé sur le Web, une application Web PHP a été développée côté serveur et un système de base de données MySQL a été appliqué pour stocker et récupérer des données en utilisant le langage SQL (Structured Query Language). Ensuite, la

Figure 3 montre le modèle de base de données et la Figure 4 montre les pages PHP de l'interaction de l'utilisateur.

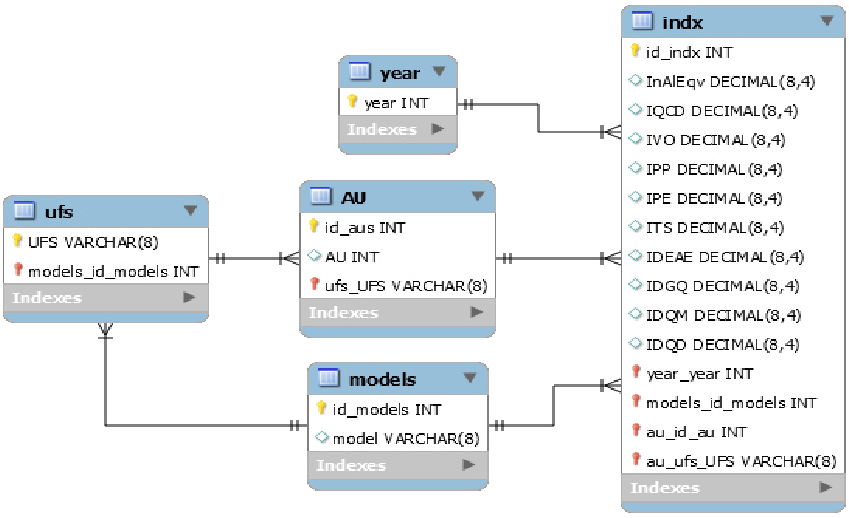

Figure 3: Modèle de base de données

La Figure 3 montre la structure du modèle de base de données dans laquelle les informations sont stockées et utilisées par le système Web. La table "indx" contient la plupart des clés étrangères, en fonction de l'année, du type de modèle, de l'unité administrative (au) et de l'université (UF'Ss). Avec l'association de tables AU, par exemple, le type de connexion est 1-to-n, ce qui signifie qu'un AU peut avoir n associé à indx, et la même règle est appliquée pour l'année, les modèles et les tables universitaires (AU) avec AU.

La Figure 4 montre l'interface utilisateur en fonction de son analyse détaillée des besoins. La page 1 est la page de sélection de l'année dans laquelle l'utilisateur peut sélectionner toutes les options de l'année dans la base de données (2015 / 2016). La page 2 est la page de sélection de l'université. Dans ce cas, il n'y a qu'une seule option de sélection : UFMS.

La page 3 montre toutes les informations de chaque unité administrative dans la matrice de décision, telles que leurs index, le pourcentage du budget et le nom de l'UA. En outre, l'utilisateur peut modifier les valeurs des index et le budget disponible pour simuler différents scénarios, puis procéder à une analyse multicritère. C'est la partie la plus importante du système, car elle permet aux utilisateurs d'estimer le budget qu'ils pourraient avoir en cas de modification de certains paramètres du modèle et de voir quelle variable est la plus sensible en cas de variation.

À partir de cette information, chaque unité peut établir un plan d'action afin d'améliorer ses indices et, par conséquent, augmenter son pourcentage de part du budget. Enfin, la page 4 montre également le pourcentage du budget en termes financiers, la possibilité de simuler les résultats avec un budget différent et un histogramme pour montrer les résultats de manière visuelle.

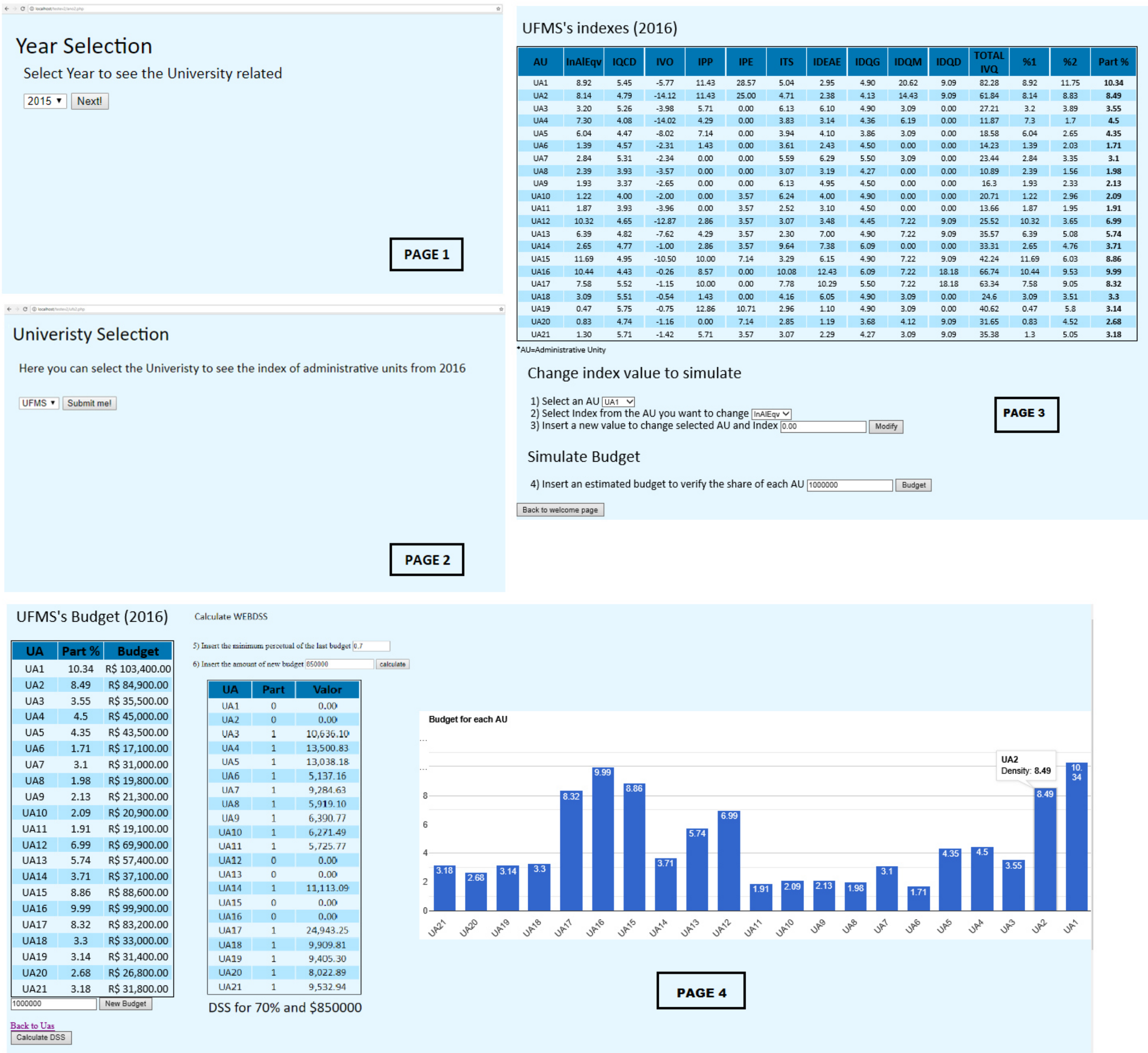

Figure 4 : pages du système Web - interface utilisateur

CONCLUSION ET PERSPECTIVES

Le but de cette étude était de présenter un système d'aide à la décision multicritère orienté pour l'allocation des ressources internes dans une université publique brésilienne. Actuellement, il n'y a pas un SIAD général pour ce problème. Toutes les données pour l'application du modèle sont recueillies manuellement et gérées par un département unique à l'Université étudiée (et cette situation se produit pour plusieurs autres universités fédérales au Brésil).

L'idée est que le système pourrait soutenir les décideurs, les parties prenantes du processus, décentraliser la réalisation des tâches, améliorer la communication, la collaboration, augmenter la productivité des membres du groupe (21 unités administratives sectorielles affectées par la procédure d'allocation)

Pour atteindre ces résultats, d'abord, un modèle multicritère basé sur une fonction de valeur additive a été proposé. Le modèle a été en mesure de définir un pourcentage du budget que chaque unité budgétaire de l'Université fédérale de Mato Grosso do Sul devrait recevoir. L'application numérique a pris en compte 21 variables, à savoir les unités administratives sectorielles de l'UFMS, et 10 critères, déjà définis par le modèle d'allocation des ressources de l'université, également pris en compte par le DM et ses préférences.

Avec les résultats générés par le modèle MCDM, une comparaison entre le pourcentage attribué par l'application du modèle MCDM et le modèle UFMS s'est révélée différente, indiquant que certaines unités administratives sectorielles devraient recevoir un pourcentage différent du budget qu'elles reçoivent.

Une analyse de sensibilité a été réalisée pour analyser la robustesse du modèle. Les résultats ont été satisfaisants, montrant la sensibilité de chaque critère et l'impact de leurs changements dans les résultats lorsqu'ils varient. En outre, l'analyse aide le DM à voir l'impact de chaque critère dans le modèle et l'UAS pour visualiser quels critères ils doivent améliorer pour atteindre de meilleurs résultats en termes de répartition du budget.

Après, l'étude a développé un modèle de base de données pour stocker et récupérer des données, a défini l'interface de l'utilisateur en fonction de son analyse détaillée des besoins et a utilisé une application Web pour transformer le prototype en un système basé sur le Web.

Le programme pourrait être testé par certains utilisateurs et une dernière version DSS sur le Web est prête à être mise en œuvre. Le système doit encore être amélioré pour être utile à tous les utilisateurs. L'idée est qu'un DSS basé sur le Web pour le problème présenté ici peut augmenter l'accès aux données, réduire les coûts de support et de formation et permettre des capacités étendues aux utilisateurs.

L'une des limitations du système proposé est qu'il n'est pas possible pour les utilisateurs d'entrer de nouveaux paramètres (tels que de nouveaux index) pour mettre à jour ou améliorer le modèle. Dans ce cas, il sera nécessaire de proposer un autre modèle.

D'autre part, en raison du système, un avantage supplémentaire fourni, mais non voulu, était que le système rendait plus transparent le processus de répartition des ressources internes de l'université pour tous ses utilisateurs et personnes impliquées.

En outre, à titre de suggestion, le concept présenté ici pourrait être étendu et appliqué par d'autres universités fédérales au Brésil ou dans d'autres pays, en adaptant les alternatives et les critères pour chaque modèle d'allocation interne spécifique.

Pour de plus amples recherches, il serait intéressant de comparer différentes méthodes d'allocation de ressources MCDM avec les résultats trouvés dans cette étude. Il est intéressant de noter que le prototype DSS n'a pas d'intention de production mais de traiter à titre expérimental uniquement à des fins de recherche.

Les perspectives sont de contribuer au problème de décision sur la façon d'améliorer le processus de ressources d'allocation correctement confrontées par les universités publiques brésiliennes, prendre des décisions plus sûres et fiables, en cherchant à réduire les incertitudes et à maximiser leurs résultats. En outre, il pourrait servir de base à la planification de l'allocation stratégique des ressources des universités fédérales.

ABSTRACT

The allocation of scarce resources is a complex problem, specially when it comes to budget constraints. Thus, 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, the research is divided into three steps: identify the Brazilian general allocation model and the models from each federal university; find similarities between the models; and, divide the models into categories, according to their similarities. Subsequently, a Brazilian federal university was chosen (the Federal University of Mato Grosso do Sul / UFMS) 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 special case of project portfolio selection problem because its approach is deemed to be appropriate for a resource allocation decision context. Also, the study analyzed the effects of possible scaling issues in additive value functions, when considering resource allocation problems and a sensitivity analysis was performed to analyze the robustness of the model. For the web-based DSS, the analysis was carried out by developing a DSS Database model to store and retrieve data, defining the user's interface based on his detailed requirement analysis and using a web platform to transform the prototype into a web-based system. The results were achieved. 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 to the government, enabling them to take safer and reliable decisions, seeking to reduce uncertainties and to maximize their results. The multicriteria web-based DSS presented here could be extended and applied by other federal universities in Brazil or other countries, adapting the alternatives and criteria for each specific internal allocation model and to the DM needs.

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

RESUMO

A alocação de recursos escassos é um problema complexo, especialmente quando se trata de restrições orçamentárias. Assim, este trabalho tem como objetivo propor um Sistema de Apoio à Decisão multicritério baseado na web para alocação de recursos no contexto de organizações do ensino superior, mais precisamente, universidades públicas que possuem restrições orçamentárias, como as Universidades Federais Brasileiras. Para tanto, a pesquisa foi dividida em três etapas: identificar o modelo geral brasileiro de alocação de recursos e os de cada universidade federal; encontrar semelhanças entre os modelos; e, separá-los categorias. Posteriormente, foi escolhida uma universidade federal brasileira (Universidade Federal de Mato Grosso do Sul / UFMS) como parâmetro para fazer uma aplicação numérica para validar o modelo proposto e, posteriormente, foi desenvolvido um SAD baseado na web. Para o modelo MCDM de alocação de recursos, considerou-se uma função valor aditiva para definir o percentual do orçamento total que cada alternativa deveria receber. O problema foi visto como um caso especial de problema de seleção de portfólio de projetos. Além disso, o estudo analisou os efeitos de possíveis problemas de escala em funções de valor aditivo e uma análise de sensibilidade foi realizada para analisar a robustez do modelo. Para o SAD baseado na Web, o estudo foi realizado desenvolvendo um modelo de banco de dados para armazenar e recuperar dados, definindo a interface do usuário com base em sua análise de requisitos e usando uma plataforma Web para transformar o protótipo em um sistema baseado na web. Os resultados foram alcançados. Em relação ao modelo, o percentual do orçamento que deveria ser alocado para cada alternativa permaneceu o mesmo quando os pesos do modelo foram alterados. Em relação ao SAD, o sistema forneceu uma visão clara de como funciona o procedimento de alocação de recursos, todo o processo tornou-se mais transparente para aqueles que são afetados por ele, para os tomadores de decisão e para o governo, permitindo-lhes decisões confiáveis, buscando reduzir as incertezas e maximizando seus resultados. O SAD multicritério baseado na Web aqui proposto poderia ser estendido e aplicado por outras universidades federais no Brasil ou em outros países, adaptando as alternativas e os critérios para cada modelo específico de alocação interna e para as necessidades do tomador de decisões.

Palavras-chave: Alocação de Recursos. Orçamentação. MCDM/A. Universidades. SAD baseado na web. SAD orientado a modelos.

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1 INTRODUCTION

The effective use of scarce resources is a crucial problem for universities in general and particularly in Brazil, where public universities perform an important role. The process of allocating internal resources in Brazilian federal universities (FU) among administrative units has become increasingly challenging and depends on a diversity of legal, economic, structural, and organizational parameters (MARTINS, *et al*. 2017). Therefore, the use of a suitable web-based Decision Support System (DSS) meant to integrate multiple criteria analysis (MCDA / M) into the decision aiding process it is an important tool to respond to this ongoing challenge.

Likewise, since public universities in Brazil use their taxpayers' money to provide education services and that there are growing budgetary constraints caused by an economic crisis faced by the country, which has started in early 2015 (BARUA, 2016) and continued into 2018, there is a tremendous societal interest (or at least should exist) in the way such money is allocated, where the cost of a failure is seen as something unacceptable (WILLIAMS, 2009).

One of the Federal Universities goals it is to improve the provision of beneficial results for the society interest, considering a progressively complex and uncertain environment. Within this context, Turban *et. al*. and Power (2011; 2016) affirm that circumstantial evidence suggests that Decision Support Systems (DSS), in general, can improve decision quality and change the structure and functioning of organizations.

A Decision Support System is a computer-based information system that supports decision makers use data and models to solve semi-structured and unstructured problems. It helps decision makers to make better decisions and to answer complex questions (BIDGOLI, 1989; SPRAGUE & WATSON, 1989). Considering different definitions for Decision Support Systems, they all share the idea that DSS are essential to support the decision-making process (SPRAGUE & WATSON, 1989).

All kinds of DSS can be implemented using Web technologies and can become web-based DSS. Managers progressively have web access to data warehouses (to store data) and analytical tools (TAGHEZOUT, BESSEDIK & ADLA, 2011). A web-based DSS, thus, bring decision support information or decision support tools to a manager or business analyst using a "thin - client" Web browser like Internet Explorer that is accessing the Global Internet or a corporate intranet. Its application can increase access and use, reduce support and training costs and allow extensive capabilities to the users (POWER, 2000).

Furthermore, within this context and, more specifically, there is the concept of Multiple Criteria Decision Support Systems (MCDSS), considered as a "particular" type of system within the broad family of DSS (KORHONEN, LEWANDOWSKI & WALLENIUS, 1991). 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 (KORHONEN, LEWANDOWSKI & WALLENIUS, 1991).

Multiple criteria decision making/aid (MCDM / A) area has been claimed as an effective way to assist decision makers (DM) to deal with the challenges that involve resource allocation problems or budgeting problems (MONTIBELLER, 2009).

In the literature, it is possible to find papers that address multi-attribute decision-making methods for resource allocation, such as models to approach the resource allocation process via prioritization (PHILLIPS & BANA E COSTA, 2007), methods focused on the efficiency analysis, consisting mostly on Data Envelopment Analysis (COOK & GREEN, 2000; ABDOLLAH *et al*., 2008; FANG & ZHANG, 2008; FANG, 2013) or approaches based on the Analytic Hierarchy Process (AHP) that provide effective means of converting a resource allocation problem into a single equivalent objective (RAMANATHAN & GANESH, 1995; KWAK & LEE, 1998) and problems involving consideration of both qualitative and quantitative criteria (RAMANATHAN & GANESH, 1995) can be found.

Moreover, project portfolio selection problems play an important role as an MCDM / A method to solve resource allocation problems, based on outranking methods for instance PROMETHEE (VETSCHERA & DE ALMEIDA, 2012; MAVROTAS *et al*., 2006), goal programming (RAMANATHAN & GANESH, 1995; COLAPINTO, JAYARAMAN, & MARSIGLIO, 2017) or additive value functions (PHILLIPS & BANA E COSTA, 2007; ARCHER & GHASEMZADEH, 1999; KLEINMUNTZ, 2007; SALO *et al*., 2011), that will be the emphasis of this study.

To calculate additive value functions for project portfolio selection problems, it is necessary to make an aggregation of scores of individual items to a global portfolio value (de Almeida et al., 2014), and the portfolio result is the summation of the projects' overall values that are included in the portfolio (LIESIÖ & PUNKKA, 2014).

When evaluating additive value functions, it is essential to note that these kinds of functions impose specific requirements on the measurement scales used for the items in a portfolio and, regularly, they are not considered in existing literature (DE ALMEIDA *et al.*, 2014), which could be a problem, once they have significant impact on the results (MARTINS *et al.*, 2016; MARTINS *et al.*, 2017). Thus, this research also considers these scale problems for the multicriteria analysis

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, it could mean to reach the best compromise solution, to apply all the available resources with efficiency. It could improve communication, collaboration, increase the productivity of group members and improve data management using the Web (TAGHEZOUT, BESSEDIK & ADLA, 2011).

According to Montibeller (2009), despite the growing attention to MCDA-based modelling approaches for resource allocation (GOLABI, KIRKWOOD & SICHERMAN, 1981; ARCHER & GHASEMZADEH, 1999; KLEINMUNTZ, 2007; LIESIÖ, MILD & SALO, 2007; PHILLIPS & BANA E COSTA, 2007), there is still little indication in the operational research and decision sciences literature on how to structure these models in practice.

Therefore, this work aims to fill this gap by proposing 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, such as Brazilian federal universities.

The study can contribute to the decision question of how to allocate universities internal budget properly, enabling decision makers to take safer and reliable decisions, seeking to reduce uncertainties and to maximize their results.

1.1 Motivation for the study

The study conducted in this work considers results of previous studies related to resource allocation problems in an MCDM situation (DE ALMEIDA & VETSHERA, 2012; DE ALMEIDA *et al.*, 2014; VETSCHERA & DE ALMEIDA, 2012; MARTINS *et al.*, 2016; MARTINS *et al.*, 2017). The intention now is to analyze how multicriteria methods can evaluate budgeting decisions in a different scenario.

Thus, a Brazilian federal university was chosen as a parameter to make a numerical application of a multicriteria model, because of the availability of data and the similarity with a general model used by the Ministry of Education in Brazil. The Brazilian federal university analyzed in this research has 21 sectoral administrative units (called UAS) that are divided by areas, such as human sciences, biological sciences, engineering, faculty of medicine, etc., and each one of them has an annual budgetary requirement. The aim is that the application of a correct model to distribute the local budget between these units can contribute to the University's permanent strategy of efficient and fair resource allocation.

Presently, there aren't any general DSS for such a problem. All data for the application of the model are gathered manually and managed with Excel spreadsheets by a single department at the studied University. The idea is that a multicriteria web-based DSS could support decision makers, stakeholders that are part of the process and decentralize tasks achievement, since they provide the availability of intelligent search tools that could enable users to find and manage the information they need quickly and inexpensively (TURBAN *et al.*, 2011).

The main decision of the model (not the problem situation of this study) it is how to improve the resource allocation process and the Decision Maker considered is the representative director of the budgeting unit from the Federal University of Mato Grosso do Sul (UFMS).

Also, it is important to emphasize that the multicriteria web-based DSS presented here could be extended and applied by other federal universities in Brazil or other countries, adapting the alternatives and criteria for each specific internal allocation model and to the Decision Makers (DM) needs. The main concern is to demonstrate the use of a multicriteria web-based DSS for this particular problem.

1.2 Objectives of this Research

1.2.1 Main Objective

The main objective of this study is to propose a multicriteria web-based decision support system for internal resource allocation in Brazilian public universities to demonstrate how the use of an appropriate multi-attribute decision method could improve the distribution of a limited budget by an additive value function for the model combined with a system to decentralize tasks achievement, increase productivity of group members and improve data management through the Web.

1.2.2 Specific Objectives

The specific objectives of this research are:

- Identify the Brazilian general resource allocation model for public universities and the internal resource allocation models of each federal university, find similarities between them and divide them into categories, according to their similarities;
- Propose a multicriteria model to distribute internal resources in a Brazilian public university as a parameter to other universities, by applying an additive value function and comparing the possible results when considering different scales for the case (interval scale and ratio);
- Conduct a sensitivity analysis to evaluate the robustness of the proposed model; and
- Design and propose a prototype of a multicriteria web-based decision support system for the problem and assess the potential impacts of the system on the decision-making process.

1.3 Methodology

To define the multicriteria web-based decision support system for this study, four phases of the decision-making process, usually attributed by Simon (1960), were considered (BIDGOLI, 1989; SPRAGUE & WATSON, 1989; TURBAN, ARONSON & LIANG, 2005): (1) intelligence, based on the identification, definition and understanding the problem; (2) design phase, that establishes the decision model to solve the problem. All interaction with the decision maker that is part of the preference modeling process was developed at this stage, as well as the choice of the MCDA method that was used; (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.

In the intelligence phase, it was necessary, first, to understand how the general resource allocation model from the Brazilian Ministry of Education works, the variables from the model, how they are calculated and how the budget is allocated among federal universities in Brazil. Second, data were collected to make a study of all universities that receive resources from this main model and, finally, a Brazilian public university was chosen as a parameter to propose the model for internal budget allocation.

The decision-making phases of design and choice were based on a procedure proposed by de Almeida *et al*. (2015) to model a multicriteria decision problem and it consists of three main phases, which are each divided into twelve steps. It applies to these phases and steps a successive refinements approach. Figure 1 represents this procedure.

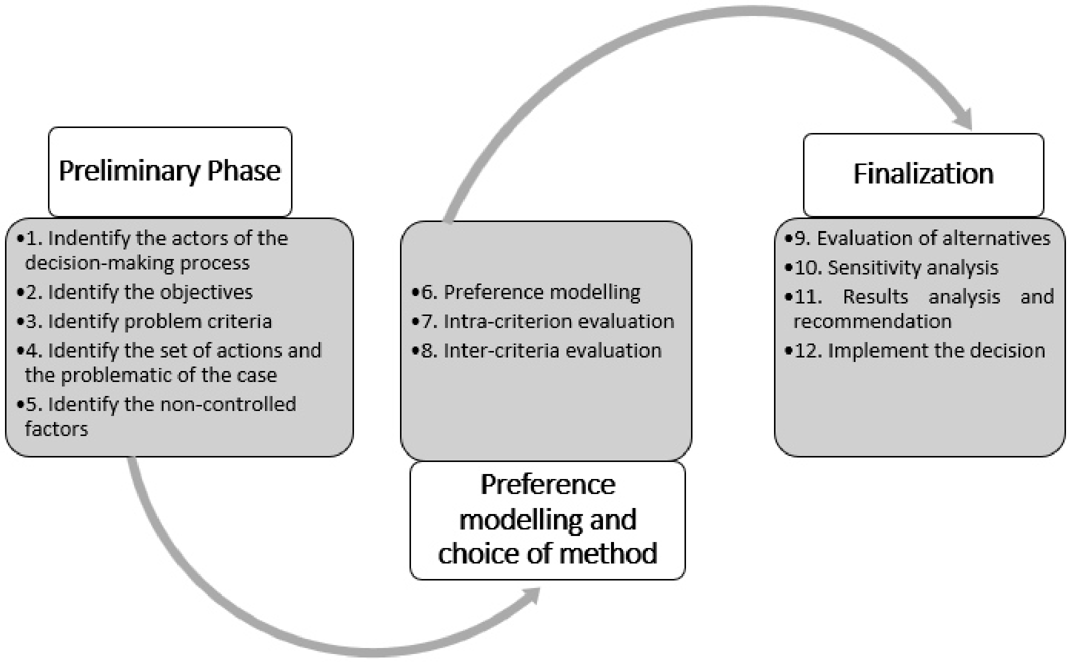


Figure 1. Procedure for solving a multicriteria decision problem (Adapted from de Almeida et al. (2015))

Preliminary and preference modelling phases correspond to the design stage and the finalization phase is related to the step of choice from the decision-making process (SIMON, 1960; DE ALMEIDA, 2015). Therefore, in the preliminary phase the actors of the decision problem are identified. The actors here could be the decision maker (DM), analyst, client, experts and stakeholder (DE ALMEIDA *et al*., 2015). Then, the objectives of the problem are identified.

In the third step, for each objective established there should be criteria or attributes that represent them in the modelling process. The last two steps of this phase involve establish 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 the second phase, the step of preference modelling (6) is developed in an integrated way with intra-criterion and inter-criteria evaluation steps, so that the results of them provide the most important elements for selecting the multicriteria method.

In the finalization phase, the model is already consolidated and the multicriteria method is applied. In the next step, a sensitivity analysis is performed to verify the robustness of the proposed model. The final steps are developed to analyze the results, develop a recommendation and to implement the recommended action. However, it should be remembered that at this stage one can still return to previous phases and make modifications or revisions in the decision model (DE ALMEIDA *et al*., 2015).

Besides the procedure proposed by de Almeida *et al*. (2015), the design phase of the web-based DSS consisted in analyzing possible courses of action for the case, identifying and exploring several solutions to the problem (ZARATÉ, 1991). Hence, a study of the resource allocation models from the Brazilians federal universities was made to separate them into "affinity groups", so that similar models were allocated to the same group. It was possible to establish three general groups of models according to the parameters considered by them.

Second, data was placed in Excel spreadsheets to flexibly analyze the models with the aim of enabling users to explore various options quickly and because the spreadsheets possess analytical tools for modelling data (POWER, 2000). Lastly, a prototype from the web-based DSS was made, with the help of a DM from the budgeting unit of the university taken as a parameter for the case, considered the end user of this research.

Still, the decision-making phases of choice, implementation and control (SIMON, 1960; TURBAN, ARONSON & LIANG, 2005) also consisted in developing a DSS Database model, using an appropriate language (SQL for the case), the user's interface was defined, and, finally, a prototype of the multicriteria web-based system was implemented, with a programming language (PHP combined with Python).

Figure 2 summarizes all the decision-making process mentioned before, emphasizing all the steps of this research.

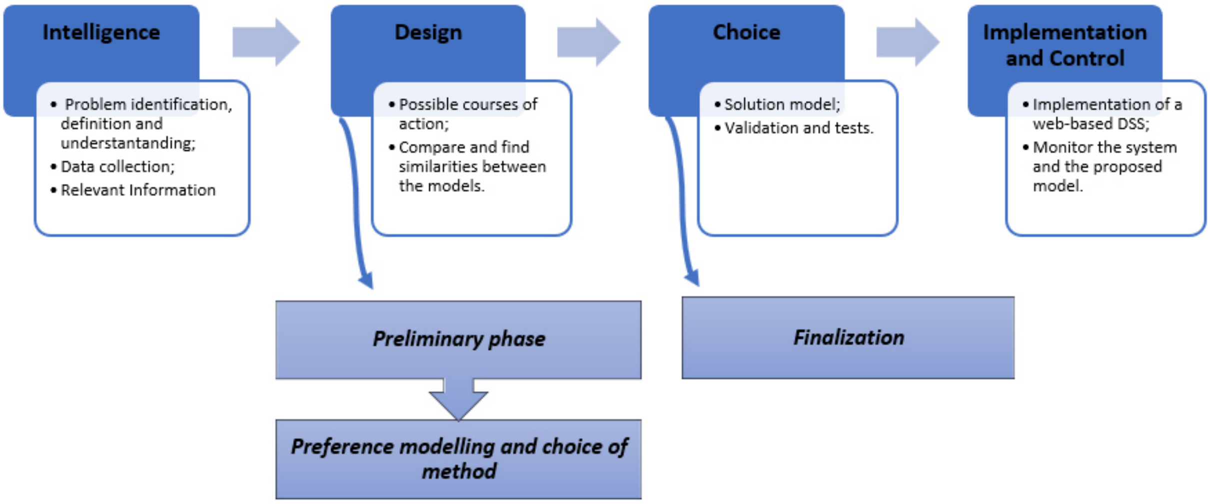


Figure 2. Steps of the research

1.4 Structure of the Thesis

Besides this introductory chapter, this thesis is structured into six chapters, as follows:

- **Chapter 2** contains the theoretical background of this study, underlying themes and concepts related to resource allocation problems, decision support systems, web-based decision support systems and multiple criteria decision making/aid (MCDM / A) methods for resource allocation.

- **Chapter 3** explains how the general budgeting process works in Brazilian federal universities and makes some considerations on the Brazilian general budgeting process.

- **Chapter 4** presents a multicriteria model for resource allocation in public universities and a numerical application with the proposed model in a Brazilian federal university.

- **Chapter 5** is related to the development of the multicriteria web-based DSS for resource allocation in a Brazilian public university, it indicates the method to design the system, the system architecture, the Database model and details the prototype of the web-based system.

- **Chapter 6** presents the impacts, the contributions and limitations of this research along with the perspectives and suggestions for future works.

2 THEORETICAL BACKGROUND AND LITERATURE REVIEW

This chapter presents the theoretical background used to propose the multicriteria web-based DSS for resource allocation that is presented in Chapters 3 and 4. The fundamental concepts related to resource allocation problems, multicriteria decision making/aid and decision support systems are provided.

2.1 Resource allocation problem

Decision makers in all organizations continually face the difficult task of balancing benefits against costs and the risks of recognizing the benefits when allocating scarce resources (PHILLIPS & BANA E COSTA, 2007). Kleinmuntz (2007) states that resource allocation decisions are a dilemma usually confronted by organizations of every size, type, purpose and that, often, the limiting resource is financial because an organization's capacity to borrow funds or raise equity capital has practical limits.

Phillips and Bana e Costa (2007) affirm that decision makers from both for-profit and not-for-profit organizations who must allocate resources are typically confronted with five problems: first, benefits are usually characterized by multiple objectives that frequently conflict; second, when decision makers are presented with a large number of opportunities they cannot know the details of each one well enough to make informed decisions; third, individually optimal decisions are rarely collectively optimal, giving rise to inefficient use of the total available resources; fourth, many people are usually involved; finally, implementation by those who disagree with the resource allocation can easily lead to the formation of small teams of people surreptitiously working on non-approved projects in which they are heavily invested personally.

In a general way, resource allocation refers to the determination of the levels of limited resources to be allocated among some competing activities and specific names are given such as budgeting when dealing with financial allocation (MUSTAFA, 1996). According to Xavier (2002), budgeting is important in resource allocation because it allows the organization to set priorities towards achieving goals and identifying highest priorities to be accomplished with the available funds. Dixon (2003) emphasizes that budgeting is a useful tool for planning and efficiency in all organizations. One of the advantages of budget planning is that a decision maker can systematically plan the proportion of the budget to be allocated for the identified budget activities to match with the objectives and strategic plans of the respective department or organization (AZIZ, 2013).

Another definition of resource allocation problem is given by Katoh, Shioura & Ibaraki (2013), which state that the problem seeks to find the best compromise solution of a fixed amount of resources to activities to minimize the cost incurred by the allocation. The simplest form of the problem is to minimize a separable convex function under a single constraint concerning the total amount of resources to be allocated. The number of resources to be allocated to each activity is treated as a continuous or integer variable, depending on the cases.

The authors define a generic form of the resource allocation problem as follows (KATOH, SHIOURA & IBARAKI, 2013):

RESOURCE : minimize $f(x_1, x_2, \dots, x_n)$ (2.1)

subject to $\sum_{j=1}^{n} x_j = N$ (2.2)

$X_j \geq 0, j = 1, 2, \dots, n.$ (2.3)

That is, given one type of resource whose total amount is equal to N, a person wants to allocate it to *n* activities so that the objective value $f(x_1, x_2, \dots, x_n)$ is minimized. The objective value may be interpreted as the cost or loss, or the profit or reward, incurred by the resulting allocation. In the case of profit or reward, it is natural to maximize *f*, and it should be considered maximization problems. The difference between maximization and minimization is not essential because maximizing *f* is equal to minimizing - *f* (KATOH & IBARAKI, 1998).

Besides, each variable x_j represents the amount of resource allocated to activity *j*. If the resource is divisible, x_j is a continuous variable that can take any nonnegative value. If it represents persons, processors or trucks, however, variable x_j becomes a discrete variable that takes nonnegative integer values (KATOH & IBARAKI, 1998).

Considering the case of a federal university, for example, the scarce resources can be applied in the most appropriate way if the DM 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, 2013). Therefore, methods that use optimization models are essential to achieving an efficient resource allocation in organizations of higher education.

MCDM is an approach that has been claimed as an effective way of assisting decision makers (DM) in dealing with the challenges that involve resource allocation problems or budgeting problems (MONTIBELLER, 2009). These methods are widely used in financial decision problems such as portfolio selection (Martins *et al*., 2017), loan granting, choice among alternative projects or investment opportunities, evaluation of the firm's credibility or failure risk, etc (MAVROTAS, 2006) and that's the reason its application will be considered for this study.

2.2 MCDA / M methods

Every decision a society or population takes involves the balancing of multiple aspects or criteria that are now and then clearly, but sometimes without conscious thought. Consequently, that in one sense everyone is well practiced in multicriteria decision making (BELTON & STEWART, 2002). Therefore, decisions are intrinsically related to a plurality of points of view, which can roughly be defined as criteria (FIGUEIRA, GRECO & EHRGOTT, 2005).

Within this context, according to Roy (2005), decision aiding is an activity of the person who, through the use of explicit but not necessarily completely formalized models, helps obtain elements of responses to the questions posed by a *stakeholder* in a decision process or a decision problem. These elements work towards clarifying the decision and usually towards recommending, or simply supporting, a behavior that will increase the consistency between the evolution of the process and this stakeholder's objectives and value system.

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. These objectives are associated with the consequences of choosing the alternative to be followed and they are associated with variables that represent them. These variables can be called criteria, attributes, or dimensions (DE ALMEIDA *et al*., 2015).

The International Society on Multiple Criteria Decision Making defines MCDA / M as the study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision process. The main objective is to provide decision makers (DM) with a tool in order to enable them to advance in solving a multiple criteria decision problem (ZARDARI *et. al*., 2015).

Belton and Stewart (2002) affirm that the expression MCDA is used as an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. Decisions matter when the level of conflict between criteria or between different *stakeholders* regarding what criteria are relevant and the importance of the different criteria, assumes such proportions that intuitive "*gut-feel*" decision-making is no longer satisfactory.

MCDA / M intuition is closely related to the way humans have always been making decisions. Consequently, despite the diversity of MCDA approaches, methods and techniques, the basic ingredients of MCDA are very simple: a finite or infinite set of actions (alternatives, solutions, courses of action), at least two criteria, and at least one decision maker. Given these basic elements, MCDA is an activity which helps to make decisions mainly regarding choosing, ranking or sorting the actions (FIGUEIRA, GRECO & EHRGOTT, 2005).

To state a clarification, the concept of alternative, defined by Roy (2005), corresponds to the case in which modeling is such that two distinct potential actions can in no way be conjointly put into operation. A set of alternatives denotes the set of potential actions considered at a given stage of the decision aiding process. Moreover, a criterion is a tool built for evaluating and comparing potential actions according to the point of view which must be well – defined (ROY, 2005).

One of the main goals of MCDA approaches is to help decision makers organize and synthesize information in a way that leads them to feel comfortable and confident about making a decision, minimizing the potential for post-decision regret by being satisfied that all criteria or factors have properly been taken into account (BELTON & STEWART, 2002).

Building models and the choice of multicriteria methods are straight associated with decision making actors, that directly or indirectly influences the decision by their value system (ROY, 1996). Besides the decision maker (the one who is responsible for taking the decision and expresses his preferences), other actors can be considered (DE ALMEIDA *et al.*, 2015): the analyst, whom provides methodological support to the decision making process; the client, an intermediary actor between the decision maker and the analyst, who plays the role of adviser of the DM; specialist or expert, which provides factual information about the problem.

Roy (1996) still considers the role of *stakeholders*, who are affected in somehow by the decision making process and their influence on the decision could result from an intentional action undertaken to affect the course of the process directly so that their preferences will prevail. Finally, a “third party”, that is also affected by the decision, but they play a passive role in the entire process.

Generally, there are four different reference problematics considered by the literature regarding the results aimed by the decision problem (ROY, 1996): (1) the choice problematic (P. α) presents the problem in terms of choosing one best action that indicates a decision that should be taken; the sorting problematic (P. β) presents the problem in terms of placing actions in categories that are defined in terms of the eventual fate of the actions; the ranking problematic (P. γ) presents the problem in terms of ranking the actions or alternatives; the description problematic (P. δ) presents the problem in terms of describing the actions/alternatives and their consequences.

Other authors also consider the portfolio problematic that purposes to choose a subset of alternatives from a larger set of possibilities, taking into account not only of the characteristics of the individual alternatives, but also of the manner in which they interact (BELTON & STEWART, 2002). A typical example for this problematic is project portfolio selection, that implicates the choice of a subset of projects that aims to optimize the benefits obtained, regularly subject to a budget constraint (VETSCHERA & DE ALMEIDA, 2012).

Still, there is the design problematic described by Keeney (1992) as “*value focused thinking*” (VFT) that aims to search for, identify or create new decision alternatives to meet the goals and aspirations revealed through the MCDA / M process (BELTON & STEWART, 2002).

Roy (2005) states that the problematics described above are not the only possible ones. Whatever the problematic chosen, the result arrived at by treating a given set of data through a single procedure is (except under unusual conditions) not enough for founding a prescription or a recommendation (ROY, 2005).

In terms of classifying MCDA/M methods, the most common approaches are: (1) based on a single synthesizing criterion, which aggregates criteria in a single criterion; (2) based on outranking methods, that makes pairwise comparisons so as to design a synthesizing preference relational system; and (3) based on interactive methods, associated with problems with discrete and continuous decision variables (ROY, 1996; ROY, 2005; DE ALMEIDA *et al.*, 2015).

Examples of single synthesizing criterion methods, which have a compensatory approach (i.e. a reduction in one deviation compensates for an increase in another) (BELTON & STEWART, 2002) include: Multi-attribute Value Theory (MAVT) (BELTON & STEWART, 2002); Multi-Attribute Utility Theory (MAUT) (KEENEY & RAIFFA, 1976); Simple Multi-Attribute Rating Technique with Swing (SMARTS) and Simple Multi-Attribute Rating Technique Exploiting Ranks (SMARTER) (EDWARDS & BARRON, 1994); Measuring Attractiveness by a Categorical Based Evaluation Technique (MACBETH) (BANA E COSTA; DE CORTE; VANSNICK, 2005); Analytic Hierarchy Process (AHP) (SAATY, 1980); Additive - veto model (DE ALMEIDA, 2013); and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS) (HWANG & YOON, 1981).

Outranking methods are non - compensatory and the possibility of the incomparability relation is one of the issues distinguished in this kind of method (DE ALMEIDA et al., 2015). The two most widely applied outranking methods are: Elimination et Choix Traduisant la Réalité (ELECTRE) (ROY & BOUYSSOU, 1993) and Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) (BRANS, VINCKE & MARESCHAL, 1986). The family of ELECTRE and PROMETHEE methods is: ELECTRE I, IS, II, III, IV and TRI; PROMETHEE I, II, III, IV, V and VI.

The last class of methods is the interactive methods. According to ROY (2005), this method leads to an *ad hoc* sequence of judgments formulated by the decision maker or other actors and a progression by trial and error. It is possible to cite as examples of these methods: Multi-objective Linear Programing (MOLP) (STEUER, 1986); UTilités Additive (UTA) (JACQUET-LAGREZE & SISKOS, 1982) and UTilités Additive DIScriminantes (UTADIS) (JACQUET-LAGREZE, 1995; ZOPOUNIDIS & DOUMPOS, 1997).

There are other approaches and concepts that may be seen either as specific methods or tools that can be applied in any method, such as fuzzy sets, rough sets, and disaggregation methods, which are based on holistic (or global) evaluation by the DM, followed by a subsequent step of inference of the parameters of an aggregation model (DE ALMEIDA *et al.*, 2015; BELTON & STEWART, 2002).

2.3 Multicriteria Methods for Resource Allocation

As mentioned in the Introduction of this study, the application of an appropriate method for resource allocation falls into the multiple criteria decision making (MCDM). There are plenty of multi-attribute decision making methods for resource allocation, such as models to approach the resource allocation process via prioritization (PHILLIPS & BANA E COSTA, 2007), methods focused on the efficiency analysis, consisting mostly on Data Envelopment Analysis (COOK & GREEN, 2000; ABDOLLAH *et al*., 2008; FANG & ZHANG, 2008; FANG, 2013) or approaches based on the Analytic Hierarchy Process (AHP) that provide effective means of converting a resource allocation problem into a single equivalent objective (RAMANATHAN & GANESH, 1995; KWAK & LEE, 1998) and problems involving consideration of both qualitative and quantitative criteria (RAMANATHAN & GANESH, 1995) can be found.

Furthermore, project portfolio selection problems play an important role as an MCDM / A method to solve resource allocation problems, based on outranking methods, for instance PROMETHEE (VETSCHERA & DE ALMEIDA, 2012; MAVROTAS *et al*., 2006), goal programming (RAMANATHAN & GANESH, 1995; COLAPINTO, JAYARAMAN, & MARSIGLIO, 2017) or additive value functions (PHILLIPS & BANA E COSTA, 2007; ARCHER & GHASEMZADEH, 1999; KLEINMUNTZ, 2007; SALO *et al*., 2011), that will be the emphasis of this research.

In a deeper analysis, according to Phillips & Bana e Costa (2007), the three main perspectives on portfolio resource allocation decisions derive from corporate finance, operations research optimization methods, and decision analysis, emphasizing with different perspectives how benefits, costs and risks are handled.

In the corporate finance point of view, a project's worth is determined by calculating its net present value (NPV) and the project should be undertaken if the NPV is positive. In not – for - profit organizations, the benefit of a project may be determined by applying cost - benefit analysis, which is based on social welfare economics (PHILLIPS & BANA E COSTA, 2007)

In the optimization perspective the objective value is interpreted as a benefit and it is described by Kleinmuntz (2007):

$$\text{maximize} \sum_{i=1}^{m} b_i x_i \tag{2.4}$$

$$\text{subject to} \sum_{i=1}^{m} c_i x_i \leq C \tag{2.5}$$

$$x_i = (0 \text{ or } 1),\ i = 1, \ldots, m. \tag{2.6}$$

where c_i could be the cost to develop a project ($c_i > 0$ for $i = 1$ to m). b_i could denote the net present value of project benefits ($b_i > 0$ for $i = 1$ to m) and x_i represent a binary decision variable for each project ($x_i = 0$ or 1 for all i). Finally, C could be equal to the budgeted amount available to fund project costs. The objective is to maximize aggregate benefits while staying within the budget constraint. This model assumes that neither benefits nor costs of a project depend on which other projects are selected, with the implication that both benefits and costs are additive (KLEINMUNTZ, 2007).

Kleinmuntz (2007) also affirms that an appealing alternative to optimization is to rank projects using benefit-cost ratios (b_i / c_i) or the *closely related profitability index* ($(b_i - c_i) / c_i$). Projects are prioritized by selecting the highest - ratio projects until funds are exhausted.

The third perspective relies on multicriteria decision analysis. Golabi, Kirkwood and Sicherman (1981) propose a linear-additive multi-attribute value function that it is of the form (DE ALMEIDA *et al*., 2014):

$$v(A_i) = \sum_{j=1}^{m} k_j v_j(x_{ij}) \qquad (2.7)$$

Where according to de Almeida *et al*. (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).

Within this concept, currently, some authors have provided overviews on topics concerning project portfolio problems, such as baseline problems and scaling issues for portfolio selection in an MCDM context (DE ALMEIDA & VETSHERA, 2012; DE

ALMEIDA *et al.*, 2014; VETSCHERA & DE ALMEIDA, 2012; MARTINS *et al.*, 2016; MARTINS *et al.*, 2017).

For instance, Clemen and Smith (2009), when considering Equation (2.4), stated that the outcome of not doing a project has a utility of zero and this would mean it is identical to the worst possible outcome. In contrast, they alleged that the utility scale should be chosen in a way that zero utility is assigned to the outcome of not doing a project, rather than the worst possible outcome, which implies that some projects have negative marginal utility values indicating that the project worsens outcomes in some attributes (DE ALMEIDA *et al.*, 2014).

The settings of baselines from a theoretic measurement point of view were discussed by Morton (2015). The author argues that the value function of not doing a project can lead to a rank reversal and affirm that the benefits must be measured on at least a ratio scale. Also, Morton (2015) discusses how the solution proposed by Clemen and Smith (2009) addresses the problem and explore in what sense it may be open to similar contexts. The study concludes with lessons from practice that may be drawn from this analysis, focusing on settings where the Clemen and Smith proposal may not be the most natural way of modelling (MORTON, 2015).

Liesiö and Punkka (2014) developed a baseline value specification technique, based on ordinal comparisons of project portfolios and a computational tool to analyze how sensitive the decision recommendations given by the linear-additive portfolio value model are to the baseline value. The authors stated that their methods are applicable in situations where implementing a project with the least preferred performance level in each attribute is preferred to the alternative of not implementing it (LIESIÖ & PUNKKA, 2014).

When analyzing multi-attribute portfolio problems, de Almeida *et al*. (2014) discussed the effects of different value scales. They evaluated three effects: the portfolio size effect, consistency across different aggregation sequences and the baseline effect (Martins et al., 2016). The same authors (DE ALMEIDA *et al*., 2014) proposed the concept of c - optimal portfolios to overcome the portfolio size effect. They also showed that these three effects have similar causes related to the use of an interval value scale, which allows for the additive transformation of utilities (MARTINS *et al*., 2016).

Vetschera and de Almeida (2012) explored another formulation for project portfolio problems and developed different alternative approaches based on the concepts of boundary portfolios and c-optimal portfolios (MARTINS *et al*., 2016). It is worthy to say that the multicriteria method considered in their research is related to non-compensatory rationality (de Almeida et al., 2015), whereas the additive model uses compensatory rationality, and this should be checked with the DM's preference. A framework to deal with this evaluation is presented in de Almeida *et al*. (2015).

When analyzing additive value functions, it is important to note that they impose certain requirements on the measurement scales used for the items in a portfolio and, regularly, they are not considered in existing literature (DE ALMEIDA *et al*., 2014), which could be a problem, once they have significant impact on the results (MARTINS *et al*., 2016) and that's the reason why they are taken into account in this research.

2.4 Scaling Issues in Multicriteria Portfolio Selection

This research considers only linear marginal value functions, which are scaled in a way that a value of zero is assigned to the worst and a value of one is assigned to the best outcome (DE ALMEIDA *et al*., 2014). For a linear function, this implies that *v(.)* is defined as follows

$$v_j(x_{ij}) = (x_{ij} - \underline{x_j})/(\overline{x_j} - \underline{x_j}) \quad (2.8)$$

where $\underline{x_j}$ = $\min_i x_{ij}$ is the worst and $\overline{x_i}$ = $\max_i x_{ij}$ is the best outcome in attribute *j*. Equation (2.8) is a linear transformation of the form (DE ALMEIDA *et al*., 2014)

$$v_j\,(_{ij}) = a_j x_{ij} + b_j \quad (2.9)$$

and thus, will lead to the portfolio size effect.

According to de Almeida *et al*. (2014), for a ratio scale, an adequate transformation is

$$v_j(x_{ij}) = x_{ij} / \overline{x_j} \quad (2.10)$$

which avoids the constant term and the portfolio size effect.

de Almeida *et al*. (2014) affirm that the transformation (2.10) will map outcomes to a different value scale than (2.8), which means that weights that were elicited using (2.8) cannot directly be applied to a model using (2.10) (and vice versa), but must be adjusted to the different scale (DE ALMEIDA *et al*., 2014). Hence, the authors proposed the following transformation.

Denote by k_j the weights used in the original model using (2.8) and by q_j the weights to be used for (2.10). The weights must be rescaled to obtain similar evaluations of alternatives as

$$q_j = k_j \cdot (\overline{x_j} / \overline{x_j} - \underline{x_j}) \tag{2.11}$$

Alternatively, to maintain the scaling that weights sum up to one

$$q_j = \frac{kj \cdot \overline{x_j} / (\overline{x_j} - \underline{x_j})}{\sum_l k_l . \overline{x_l} / (\overline{x_l} - \underline{x_l})} \tag{2.12}$$

This change in weights could be avoided by using the transformation

$$v_j(x_{ij}) = x_{ij} / (\overline{x_j} - \underline{x_j}) \tag{2.13}$$

which transforms x_{ij} by the same factor as (2.9), but does not include a constant term (DE ALMEIDA *et al.*, 2014). In this scale, the best item might have a value larger than one, and the worst might have a negative value (DE ALMEIDA *et al.*, 2014).

For complete information on this scale transformation or additional related subjects, see de Almeida *et al*. (2014); Martins *et al*. (2016); and Martins *et al*. (2017).

2.5 Decision Support Systems

In the early 1970s, the concept of Decision Support Systems appears in the literature, signifying a new perception of the role that computer systems can play in decision making process. The interpretation of the term is not always the same. The different perspectives about the theme, from which researchers perceive and describe DSSs, led to the formulation of various definitions of the term DSS itself (MATSATSINIS & SISKOS, 2012).

One of the first definitions of DSS was provided by Keen and Scott-Morton (1978). The authors state that DSS couple the intellectual resources of individuals with the capabilities of the computer to improve the quality of decisions. It is a computer-based support system for management decision makers who deal with semistructured problems (KEEN & SCOTT-MORTON, 1978).

According to Sprague and Carlson (1982), a Decision Support System comprise a class of information system that draws on transaction processing systems and interacts with the other part of the overall information system to support the decision-making activities. DSS was developed to support decision makers in their semi - structured tasks and appeared towards the end of the 60s (ACKOFF, 1967).

For Turban, Sharda and Delen (2011), 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 completely supported by algorithms.

Moreover, Power (2000) affirms that a DSS is an interactive computer - based system or subsystem that helps people use computer communications, data, documents, knowledge and models to identify and solve problems, complete decision process tasks, and make decisions. As mentioned before, a DSS supports decision makers in the process of using data and models to solve semi-structured and unstructured problems. It helps decision makers to make better decisions and to answer complex questions (BIDGOLI, 1989; SPRAGUE & WATSON, 1989). Considering different definitions for DSS, they all share the idea that DSS are essential to support the decision - making process (SPRAGUE & WATSON, 1989).

Thus, it is possible to affirm that a Decision Support System is a term for any computer application that enhances a person or group's ability to make decisions. In general, DSS are a class of computerized information systems that support decision - making activities (POWER, 2016).

Power (2016) defines five DSS types: the initial DSS category is model-based or model-driven DSS, which emphasizes access to and manipulation of financial, optimization and/or simulation models; data-driven DSS, that emphasizes access to and manipulation of large data sets; knowledge-driven DSS, which suggests or recommend actions, they are person-computer systems; communications-driven DSS, that uses network and communications technologies to facilitate decision-relevant collaboration and communication; and, finally, document-driven DSS, which uses computer storage and processing technologies to provide document retrieval and analysis.

These DSS types can be seen in Table 1, provided by Power (2009).

Table 1: DSS types

DSS Type	Dominant DSS Component	Target Users (examples)	Purpose (examples)	Enabling technology (examples)
Communications-driven DSS	Communications	Internal teams; Supply chain partners	Conduct a meeting; Help users collaborate	Bulletin board; Videoconferencing
Data-driven DSS	Database	Managers and staff, new suppliers	Query a data warehouse	Relational databases; Multidimensional databases
Document-driven DSS	Document storage and management	Specialist and user group is expanding	Search web pages	Search engines, HTML
Knowledge-driven DSS	Knowledge base, AI	Internal users, new customers	Management advice	Expert Systems
Model-driven DSS	Quantitative models	Managers and staff, new customers	Scheduling; Forecasting	Linear programming, Excel

Source: Adapted from Power (2009)

This study focuses on a model-driven DSS, since the dominant DSS component is a quantitative model, more precisely, an optimization model.

Furthermore, and more specifically, there is the concept of Multiple Criteria Decision Support Systems (MCDSS), considered as a "particular" type of system within the broad family of DSS (KORHONEN, LEWANDOWSKI & WALLENIUS, 1991). 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 (KORHONEN, LEWANDOWSKI & WALLENIUS, 1991).

DSS based on multicriteria methods mainly go further and work with the subjective perspectives, judgments, beliefs and preferences of the DM. Besides, the increasing complexity of managerial contexts requires that the DSS work simultaneously with a multicriteria approach. MCDSS help and simplify the decision-making process and make it accessible to the end-users (BELAID & RAZMAK, 2013)

When considering resource allocation problems, DSS and MCDSS have been applied in different fields, such as healthcare management (AKTAŞ, ÜLENGIN & ŞAHIN, 2007); project management, location-allocation and mobilization planners in the army (GANTT & YOUNG, 1987; OLSEN, CYRUS & ARMSTRONG, 1989); disaster management (KONDAVETI & GANZ, 2009); water planning (ANDREU, CAPILLA & SANCHÍS, 1996); public services (ATHANASSOPOULOS, 1998); financial market (SUH, 2007); and education (MANSMANN & SCHOLL, 2007; HASANZADEH, MOGHADDAM & AKBARI, 2014).

As mentioned before and taking into account the characteristics of DSS applied to the case of a public university, for example, the use of a suitable multi-attribute decision method integrated with a web-based Decision Support System to better distribute the limited budget, it could mean to reach a compromise solution, that is, to apply all the available resources with efficiency. It could improve communication, collaboration, increase the productivity of group members and improve data management using the Web (TAGHEZOUT, BESSEDIK & ADLA, 2011).

2.6 Web-based Decision Support Systems

Since the development of the Internet, Web servers and tools, there have been expressive changes in how decision makers are supported, since the Web provides access to an ample body of data, information, and knowledge available around the world; a common, user - friendly graphical user interface (GUI) that is easy to learn, to use and readily available; the ability to effectively collaborate with remote people; and the availability of intelligent search tools that enable managers to find the information they need quickly and inexpensively (TURBAN, SHARDA & DELEN, 2011). Consequently, web-based technologies can be employed to improve the capacity of Decision Support Systems through decision models.

All kinds of DSS can be implemented using Web technologies and can become web-based DSS. Managers progressively have web access to data warehouses and analytical tools (TAGHEZOUT, BESSEDIK & ADLA, 2011). A web-based DSS bring decision support information or decision support tools to a manager or business analyst using a "thin-client" Web browser like Internet Explorer that is accessing the Global Internet or a corporate intranet. Its application can increase access and use, reduce support and training costs and allow extensive capabilities to the users (POWER, 2000).

Therefore, web-based decision support systems (WB-DSS) can be defined as decision support systems that are accessible on the Web and they can be identified by certain characteristics (ZAHEDI, SONG & JARUPATHIRUN, 2008):

- Accessible on the Web;

- Supporting individuals /customers /employees /managers /groups in their decision-making process regardless of their physical locations or time of access;
- Having outcomes that are specific to a predetermined context that is either unique to the Web environment or as the interface for desktop DSS;
- Dealing with decision processes that are semi-structured or unstructured at different stages of the decision process, some of which could take place on the Web;
- Utilizing data, knowledge base, document, model and heuristics, which appeal to a culturally varied and large user group
- Being an optional tool for Web users in their decision processes.

DSS access from the Web may have multiple motivations, like the fact that they reduce the cost of system maintenance, model updates, data updates, and other changes that may occur as the system evolves over time. Also, decision makers and users have increased access to the system because it is available from any computer at any time (ZAHEDI, SONG & JARUPATHIRUN, 2008).

3 PROBLEM STATEMENT AND THE CONTEXT OF RESEARCH

3.1 Problem Statement

To explain the resource allocation model for Federal Universities in Brazil, first it is necessary to understand how the general budgeting process works. The budget adopted by the Federal Universities in Brazil is called “program-budget”, which is regulated by a federal law number 4320, established in 1964 (BRASIL, 1964) and by a complementary law number 101, from 2000 (BRASIL, 2000). The “program-budget” is part of the general budget of the Union, therefore, it is discussed and approved by the National Congress. Resources from the National Treasury form this budget, resources derived from the Federal Universities direct funding, known as own resources, and from resources derived from agreements and contracts celebrated with public or private entities (BRASIL, 2006).

The budgetary resources destined to maintain activities of teaching, research and extension from the FU’s are called “Other Cost and Capital (OCC)”, that represents their total budget deducted from the expenditures with personnel payroll. The transfer of these resources occurs based on a mathematical model called “matrix” (Matrix OCC) that is based on the number of “equivalent students”, that will be explained later, and the indicators of academic production from the FU’s. These concepts were adapted from the English resource allocation model for universities (HEFCE, 1998), developed by the Higher Education Founding Council for England – HEFCE.

Two kinds of budget compose the OCC resource allocation Matrix: a basic budget, also called “maintenance budget”, and an investment budget. The determination of these two budgets is made by a process divided into three different steps: first, the Brazilian Ministry of Education (Department of Education - MEC) settles the limit of global resources that can be spent by the FU’s. Second, the global budget is allocated according to the OCC Matrix rules, where the individual budgets from each FU are defined. Finally, MEC consolidates, validates and formalizes the budget proposal (BRASIL, 2006).

The OCC Matrix has equitable, qualitative, inductors, measurable and auditable criteria. The model is common for all Federal Universities and the structure of the budget is programmed the year before (BRASIL, 2010). The basis of the matrix is the number of students (equivalent students) from each Federal University (MEC, 2013). The general OCC Matrix model is described from Formulas (3.1) to (3.19) below.

$$PART = h_1 (PTAE) + h_2 (EQR) \tag{3.1}$$

Where:

$h_1 = 0,9$

$h_2 = 0,1$

$$PTAE = \frac{TAE}{\sum TAE} \tag{3.2}$$

Where:

PTAE = participation of the FU from the total of Equivalent Students of all the FU's

TAE = total of equivalent students

$$EQR = \frac{DEQ}{\sum DEQ} \tag{3.3}$$

Where:

EQR = efficiency and scientific academic quality from the FU

DEQ = efficiency and scientific academic quality dimension from the FU

$\sum DEQ$ = efficiency and scientific academic quality dimension from the set of FU's

$$DEQ = DEAE + DQG + DQM + DQD \tag{3.4}$$

Where:

DEAE = efficiency dimension of the teaching activities in the FU

DQG = quality dimension from the undergraduation courses

DQM = quality dimension from the master courses

DQD = quality dimension from the doctorate courses

$$DEAE = FRAP \tag{3.5}$$

$$FRAP = \frac{RAP}{\sum ARAP} \tag{3.6}$$

Where:

FRAP = relation factor between equivalent student and professor

RAP = relation between equivalent student and professor

$\sum ARAP$ = average relation between equivalent student and professor

$$DQG = \frac{\sum FCG}{NCG} \tag{3.7}$$

$$FCG = \frac{CSG}{\sum ACSG} \tag{3.8}$$

Where:

FCG = quality factor from the undergraduation course

CSG = SINAES concept of the undergraduation course

$\sum ACSG$ = SINAES average concept from the set of FU's

NCG = number of undergraduation courses evaluated at the FU

$$DQM = \frac{\sum FQM}{NCM} \tag{3.9}$$

$$FQM = \frac{CCM}{\sum ACCM} \tag{3.10}$$

Where:

FQM = quality factor from the master course

NCM = total number of master courses at the FU

CCM = CAPES concept of the master course

$\sum ACCM$ = average CAPES concept from the set of FU's of the master courses that have the same area

$$DQD = \frac{\sum FQD}{NCD} \tag{3.11}$$

$$FQD = \frac{CCD}{\sum ACCD} \tag{3.12}$$

Where:

FQD = quality factor from the doctorate course

NCD = total number of doctorate courses at the FU

CCD = CAPES concept of the doctorare course

$\sum ACCD$ = average CAPES concept from the set of FU's of the doctorate courses that have the same area

$$TAE = TAEG + TAERM + TAEM + TAED \tag{3.13}$$

$$TAEG = \sum\left\{\left[\frac{(NACG).(1+R)+N-NACG}{4}\right].[(PG).(DG).(BT).(BFS)]\right\} \tag{3.14}$$

Where:

TAEG = Total of Equivalent Students in undergraduation

NACG = Total of students that finished undergraduation studies

N = Total of students that starts undergraduation studies

D = Duration of the undergraduation course

R = Standard "retention" factor of the undergraduation course

PG = weight of the undergraduation course

BT = bonus for having nightly undergraduation courses

BFS = bonus for having an undergraduation course outside the main campus

$$TAEG^{**} = \sum (NMG).(PG).(BT).(BFS) \tag{3.15}$$

Where:

** = new undergraduation courses (less than 10 years of existence)

NMG = Total of students enrolled in an undergraduation course

PG = weight of the undergraduation course

BT = bonus for having nightly undergraduation courses

BFS = bonus for having an undergraduation course outside the main campus

$$TAEG^{***} = \sum \{[(NACG).(1+R)].(PG).(DG).(BT).(BFS)\} \tag{3.16}$$

Where:

*** = New undergraduation course

DG = Standard duration of the undergraduation course

$$TAERM = \sum(NAMRM).(PRM) \tag{3.17}$$

Where:

TAERM = total of equivalent students from medical residency

NAMRM = total of students enrolled in a medical residency course

PRM = weight of the group from the medical residency course

$$TAEM = \sum(NACM).(DM).(PM) \tag{3.18}$$

Where:

TAEM = total of equivalent students in a master course

NACM = total of students that concluded the master course

DM = standard duration of the master course

PM = weight of the group from the master course

$$TAED = \sum(NACD).(DD).(PD) \tag{3.19}$$

Where:

TAED = total of equivalent students in a doctorate course

NACD = total of students that concluded the doctorate course

DD = standard duration of the doctorate course

PD = weight of the group from the doctorate course

The formulas show how the general participation of every Federal University from the total OCC Matrix budget is calculated (PART) (3.1), based mainly on the total of equivalent students (PTAE) (3.2) and on the efficiency and scientific academic quality (EQR) (3.3) from the FU.

The participation of the FU from the total of equivalent students of all the FU's (3.2) is based on the total of equivalent students in undergraduation (3.14), total of equivalent students from medical residency (TAERM) (3.17), total of equivalent students in a master course (TAEM) (3.18), and the total of equivalent students in a doctorate course (TAED) (3.19).

On the other hand, the efficiency and scientific academic quality (EQR) (3.3) is based on the efficiency dimension of the teaching activities in the FU (3.4), the relation factor between equivalent student and professor (FRAP) (3.6), the quality factor from the undergraduation course (FCG) (3.8), the quality factor from the master course (FQM) (3.9) and the quality course from the doctorate course (3.11).

Thus, the OCC Matrix is divided into two main indicators: quantitative and qualitative indicators. The quantitative indicator has a weight of 0.9 and the main indicator is the TAE (total of equivalent student). The qualitative indicator, with a weight of 0.1, is based on overall indicators such as the evaluation of undergraduate, master and doctorate courses, scientific production numbers and relation between the number of students and professors for each course.

3.2 Considerations on the Brazilian general budgeting process

When comparing the model from MEC with other countries, for example, higher education systems around the world differ substantially regarding research and education funding sources and to ways that resources are allocated. European universities receive most of their funding from public sources, but private funding plays a more important role in Anglo-American systems of higher education (LIEFNER, 2003).

Many governments use competitive elements in the process of allocating public funds to institutions of higher education, but when systems receive funding exclusively from their government they tend to conserve structures and be less innovative and less responsive to changes in demand (LIEFNER, 2003).

Besides, it is important to note that the model from the OCC Matrix and the internal resource allocation models from the federal universities do not allocate their budget based on cost estimation, based on what it is necessary in terms of the amount of budget to maintain and invest in a public university. The participation of every university or academic unit (when you consider the internal allocation in a specific university) in the budget is a percentage defined by the model that doesn't consider the total amount of budget available to make the allocation. These factors are essential to justify and support the need for resources.

Another consideration about the models studied here is that the total of equivalent students indicator (TAE), uses a standard "retention" factor (called R in 3.14 formula) and a weight of the course analysed, called PG, PRM, PM and PD in formulas 3.14, 3.17, 3.18 and 3.19, that are the number of students that have exceeded the time considered standard to conclude the undergraduation course and the weight of the course is based on the cost of every course, respectively (MEC, 2013). As both of them are a standard value to all FU, they do not take into account their reality and individuality.

Likewise, these indicators should be updated every year, since the data used in the models are not static. Finally, these parameters were established in 1980 (weights) and in the late 80's (retention factor), where the reality of the public universities in Brazil was very different from nowadays.

Although, some of these indicators of the models could be a measure of efficiency when they were created, they do not have a methodological background, since the English resource allocation model for universities (HEFCE, 1998) does not consider such indicators (MEC, 2013). These parameters interfere in the amount of budget that each FU will receive, making the resource allocation inaccurate.

55 Federal Universities in Brazil receive resources from the OCC Matrix, and each one of them has their own internal resource allocation model.

Therefore, the global resource allocation process could be described by Figure 3.

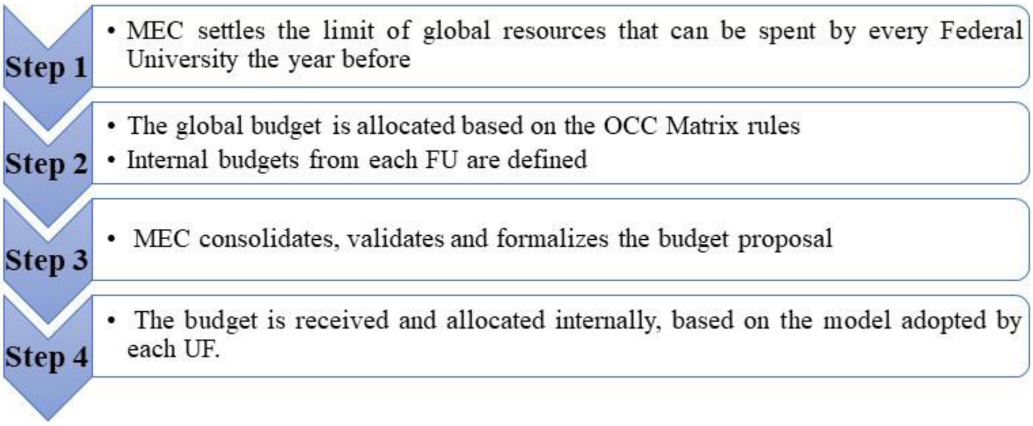


Figure 3 – Steps of MEC's resource allocation procedure

It is important to point out that the multicriteria web-based DSS for resource allocation proposed in this study is focused on the process described in Steps 2 and 4 (Figure 3), where the individual budget defined by MEC is allocated according to the internal model defined by each FU.

4 MCDM / A RESOURCE ALLOCATION MODEL

To propose a multicriteria resource allocation/budgeting model in the context of higher education organizations, a Brazilian federal university was chosen as a parameter to make a numerical application with real data and the model was defined by the procedure proposed by de Almeida *et al*. (2015), which consists of three main phases that are divided into twelve steps, as explained in Section 1.3. Thus, the steps of the research are shown next.

4.1 Numerical Application in a Brazilian Federal University

To present the MCDM resource allocation model proposed by this study, a Brazilian public university was chosen to validate the model, more exactly, the Federal University of Mato Grosso do Sul (UFMS), once, currently, there aren't any application for such a problem. Also, because of the availability of data and similarity to the general model presented in Section 3.1 that the university already uses. The research can contribute to the decision question of how to allocate universities internal budget properly.

Therefore, the study conducted an application to evaluate how the budget from the OCC Matrix should be allocated among the 21 sectoral administrative units from UFMS, called "UAS", and compared possible results when considering different scenarios, that will be explained later. The idea is that the MCDM model can indicate the total amount from the budget that each UAS should receive.

Since MCDM / A methods are clearly necessary when all the objectives from an organization cannot be represented by one single metric, they are capable of structuring an assessment of a complex problem, such as resource allocation or budgeting problem, associated with the facility with which a DM's preferences can be elicited, they can simplify internal processes, transparency and discussions about subjective elements, they can deal with incomplete and uncertain information (DE ALMEIDA, *et al.*, 2015; BELTON & STEWART, 2002), that is the reason its applicability was considered for this case.

The model resembles in parts with the general model adopted by the Ministry of Education in Brazil. The DM of the problem was the director of the budget and planning department (PROPLAN/UFMS) and the analyst was the author of this study. The University studied has 21 sectoral administrative units that are divided by areas, such as human sciences, biological sciences, engineering, faculty of medicine, etc, seen as the alternatives, projects or budgetary units of the MCDM model, as shown in Table 2.

Table 2: Alternatives of the MCDM model

Alternatives	Description
UAS 1	Faculty of Biological Sciences
UAS 2	Faculty of Human Sciences
UAS 3	School of Management and Business Studies
UAS 4	Pantanal Campus
UAS 5	Aquidauana Campus
UAS 6	Paranaíba Campus
UAS 7	Chapadão do Sul Campus
UAS 8	Coxim Campus
UAS 9	Nova Andradina Campus
UAS 10	Naviraí Campus
UAS 11	Ponta Porã Campus
UAS 12	Três Lagoas Campus
UAS 13	Computer Science College
UAS 14	Faculty of Law
UAS 15	Faculty of Engineering
UAS 16	Faculty of Medicine
UAS 17	Faculty of Veterinary Medicine and Animal Science
UAS 18	Faculty of Odontology
UAS 19	Institute of Physics
UAS 20	Institute of Mathematics
UAS 21	Institute of Chemistry

Source: This Research (2018)

Every year, the UFMS budget and planning department (PROPLAN) sets the criteria to allocate the budget credits from the Ministry of Education OCC Matrix (Other Cost and Capital – OCC), applicable to all sectoral administrative units, which should be strictly used for costing and investment activities. Each UAS provides data and information to the budgeting unit. PROPLAN gathers the information and then sets the percentage of the budget that will be distributed to each UAS. The distribution of the budget credits is founded on quantitative and qualitative variables. Considering this information, the DM was able to determine the criteria of the model, that are evidenced next.

- *InAlEqv*: general index of equivalent students for each UAS. Calculated from indicators related to the number of students entering, enrolled and graduated from undergraduate, postgraduate courses (master's and doctorate), and medical residences. Scale: unit. Criterion to be maximized;
- *IQCD*: faculty qualification criterion, that measures the academic staff qualification by the number of lecturers with Phd and master's degrees. Scale: unit. Criterion to be maximized;
- *IVO*: dropout rate criterion is defined by the summation of vacancies not filled in the regular admission process, plus vacancies arising from withdrawing,

dismissed students, transfer to another Higher Education Institution, and other transfer reasons. Scale: unit. Criterion to be minimized.

- *IPP*: total of research projects with external financial support. Scale: unit. Criterion to be maximized.
- *IPE*: total of extension projects with external financial support. Scale: unit. Criterion to be maximized.
- *ITS*: graduation success rate. It is a performance criterion indicator that measures the relationship between the number of graduates and the number of new entrants. Scale: unit. Criterion to be maximized.
- *IDEAE*: teaching efficiency. It is measured by the relation between the total of equivalent students and the total of equivalent professors. Scale: unit. Criterion to be maximized.
- *IDGQ*: quality of the undergraduate courses, which measures the evaluation of each one of them and it is based on the evaluations from the National Institute of Studies and Educational Research Anísio Teixeira – INEP / Brazil. Scale: unit. Criterion to be maximized.
- *IDQM*: quality of the master's degrees courses, based on the evaluation of the course calculated by the Coordination for the Improvement of Higher Education Personnel – CAPES / Brazil. Scale: unit. Criterion to be maximized.
- *IDQD*: quality of the doctorate degrees courses, based on the evaluation of the course calculated by the Coordination for the Improvement of Higher Education Personnel – CAPES / Brazil. Scale: unit. Criterion to be maximized.

The DM considered that the criteria had to be similar to the ones considered by the Ministry of Education in their general model, because quite different criteria, in his point of view, could lead to distortions in the internal resource allocation procedure.

Once the alternatives and criteria were defined, the next step was to establish the problematic to be applied. As explained by Belton & Stewart (2002), the problem considered here is a special case of portfolio problematic, seen as a resource allocation problem. The problematic may influence the kind of method, depending on the class of methods to be applied. Some methods may be applied in more than one problematic; the case of ranking problematic may include the solution for choice, for instance (DE ALMEIDA *et al.*, 2015). Likewise, the weights (scale constants) were defined by the DM, which was considered the director of the budget and planning department (PROPLAN/UFMS).

The weights elicitation procedure for the additive model aggregation used was the swing weighting method (VON WINTERFELDT & EDWARDS, 1986; EDWARDS & BARRON, 1994), in where the determination of the scale constants is based on direct information given by the DM, taking the range of the consequences into consideration (DE ALMEIDA *et al.*, 2015). A sensitivity analysis was conducted to test the robustness of the model, considering the weights of the model.

The scores from the decision matrix were normalized using an interval scale and a ratio scale to verify the impacts of scaling problems, since there are scaling issues when additive models are applied (DE ALMEIDA & VETSHERA, 2012; DE ALMEIDA *et al.*, 2014; VETSCHERA & DE ALMEIDA, 2012; MARTINS *et al.*, 2016; MARTINS *et al.*, 2017), as already mentioned in Section 2.4. Also, the weights that were elicited using an interval scale were adjusted to a ratio scale to obtain equivalent evaluations of alternatives (see Table 4).

According to De Almeida *et al.* (2014), for a portfolio problematic the scales of the value function $v_j(x)$ should be considered 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 is used by many of the elicitation procedures

Thereafter, the matrix of consequences can be presented in Table 3, with their respective values. In Table 3 it is possible to see the 21 alternatives of the problem, that represent the sectoral administrative units from UFMS, evidenced in Table 2. Table 3 also shows the 10 criteria of the problem, defined by the DM, based on his preferences and already explained before. The performance value of the alternatives in each criterion of the model is not normalized in Table 3. Since the value function $v_j(x)$ should use a ratio scale instead of an interval scale, Table 4 shows the decision matrix for a ratio scale and the new weights for the model.

Table 3: Decision matrix

Alternatives	Criteria									
	InAlEqv	IQCD	IVO	IPP	IPE	ITS	IDEAE	IDGQ	IDQM	IDQD
UAS1	8.92	5.45	5.77	11.43	28.57	5.04	2.95	4.9	20.62	9.09
UAS2	8.14	4.79	14.12	11.43	25,00	4.71	2.38	4.13	14.43	9.09
UAS3	3.2	5.26	3.98	5.71	0,00	6.13	6.1	4.9	3.09	0,00
UAS4	7.3	4.08	14.02	4.29	0,00	3.83	3.14	4.36	6.19	0,00
UAS5	6.04	4.47	8.02	7.14	0,00	3.94	4.1	3.86	3.09	0,00
UAS6	1.39	4.57	2.31	1.43	0,00	3.61	2.43	4.5	0,00	0,00
UAS7	2.84	5.31	2.34	0,00	0,00	5.59	6.29	5.5	3.09	0,00
UAS8	2.39	3.93	3.57	0,00	0,00	3.07	3.19	4.27	0,00	0,00
UAS9	1.93	3.37	2.65	0,00	0,00	6.13	4.95	4.5	0,00	0,00
UAS10	1.22	4,00	2,00	0,00	3.57	6.24	4,00	4.9	0,00	0,00
UAS11	1.87	3.93	3.96	0,00	3.57	2.52	3.1	4.5	0,00	0,00
UAS12	10.32	4.65	12.87	2.86	3.57	3.07	3.48	4.45	7.22	9.09
UAS13	6.39	4.82	7.62	4.29	3.57	2.3	7,00	4.9	7.22	9.09
UAS14	2.65	4.77	1,00	2.86	3.57	9.64	7.38	6.09	0,00	0,00
UAS15	11.69	4.95	10.5	10,00	7.14	3.29	6.15	4.9	7.22	9.09
UAS16	10.44	4.43	0.26	8.57	0,00	10.08	12.43	6.09	7.22	18.18
UAS17	7.58	5.52	1.15	10,00	0,00	7.78	10.29	5.5	7.22	18.18
UAS18	3.09	5.51	0.54	1.43	0,00	4.16	6.05	4.9	3.09	0,00
UAS19	0.47	5.75	0.75	12.86	10.71	2.96	1.1	4.9	3.09	0,00
UAS20	0.83	4.74	1.16	0,00	7.14	2.85	1.19	3.68	4.12	9.09
UAS21	1.3	5.71	1.42	5.71	3.57	3.07	2.29	4.27	3.09	9.09
Weights	0,2505	0,0405	0,145	0,124	0,124	0,150	0,038	0,044	0,042	0,042

Source: This Research (2018)

4.2 Description of the model

The model adopted was an additive aggregation procedure for portfolio problematic with a 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 is able to compare all consequences and order them (DE ALMEIDA *et al.*, 2015).

The primary goal of the model is to maximize the objective function, considering the given constraints (KLEINMUNTZ, 2007), that is a budget constraint. Therefore, the objective function (4.1) and the constraints (4.2) are written as:

$$\sum_{i=1}^{n} z_i\, v(A_i) \tag{4.1}$$

Subject to:

$$\sum_{i=1}^{n} z_i\, c_i \leq C \tag{4.2}$$

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 (Clemen and Smith, 2009). $v(A_i)$ is the value of item A_i obtained from the multi-attribute evaluation (DE ALMEIDA *et al.*, 2014).

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. Analyzing the model from a project portfolio selection point of view, then it could be inferred that, for this particular model proposed here, all projects of the problem will be funded (LOURENÇO, MORTON, BANA E COSTA, 2012) and then there would not be a decision to be made, but that is not the case.

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 defined by the DM, and that is a project portfolio selection problem.

Moreover, to adequate the model in this study and taking into account equation (4.1) and inequation (4.2), 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:

$$B - \sum_{i=1}^{n} min\ c_i = C \tag{4.3}$$

Finally, as already explained in Section 2.3, the evaluation results from an additive value function it is of the form (DE ALMEIDA *et al.*, 2014):

$$v(A_i) = \sum_{j=1}^{m} k_j v_j (x_{ij}) \tag{4.4}$$

The total budget available (*B*) considered for the problem was R$ 850,000.00, a value that represents 85% from 2017 total budget of the OCC Matrix, once that was the amount released by the Ministry of Education in 2017, due to government budget cuts (UFMS, 2017). 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 4, Table 5 and Figure 4.

Table 4: Decision matrix for a ratio scale and new weights

Alternatives	**Criteria**									
	InAlEqv	**IQCD**	**IVO**	**IPP**	**IPE**	**ITS**	**IDEAE**	**IDGQ**	**IDQM**	**IDQD**
UAS1	0,763	0,948	0,045	0,889	1,000	0,500	0,237	0,805	1,000	0,500
UAS2	0,696	0,833	0,018	0,889	0,875	0,467	0,191	0,678	0,700	0,500
UAS3	0,274	0,915	0,065	0,444	0,000	0,608	0,491	0,805	0,150	0,000
UAS4	0,624	0,710	0,019	0,334	0,000	0,380	0,253	0,716	0,300	0,000
UAS5	0,517	0,777	0,032	0,555	0,000	0,391	0,330	0,634	0,150	0,000
UAS6	0,119	0,795	0,113	0,111	0,000	0,358	0,195	0,739	0,000	0,000
UAS7	0,243	0,923	0,111	0,000	0,000	0,555	0,506	0,903	0,150	0,000
UAS8	0,204	0,683	0,073	0,000	0,000	0,305	0,257	0,701	0,000	0,000
UAS9	0,165	0,586	0,098	0,000	0,000	0,608	0,398	0,739	0,000	0,000
UAS10	0,104	0,696	0,130	0,000	0,125	0,619	0,322	0,805	0,000	0,000
UAS11	0,160	0,683	0,066	0,000	0,125	0,250	0,249	0,739	0,000	0,000
UAS12	0,883	0,809	0,020	0,222	0,125	0,305	0,280	0,731	0,350	0,500
UAS13	0,547	0,838	0,034	0,334	0,125	0,228	0,563	0,805	0,350	0,500
UAS14	0,227	0,830	0,260	0,222	0,125	0,956	0,594	1,000	0,000	0,000
UAS15	1,000	0,861	0,025	0,778	0,250	0,326	0,495	0,805	0,350	0,500
UAS16	0,893	0,770	1,000	0,666	0,000	1,000	1,000	1,000	0,350	1,000
UAS17	0,648	0,960	0,226	0,778	0,000	0,772	0,828	0,903	0,350	1,000
UAS18	0,264	0,958	0,481	0,111	0,000	0,413	0,487	0,805	0,150	0,000
UAS19	0,040	1,000	0,347	1,000	0,375	0,294	0,088	0,805	0,150	0,000
UAS20	0,071	0,824	0,224	0,000	0,250	0,283	0,096	0,604	0,200	0,500
UAS21	0,111	0,993	0,183	0,444	0,125	0,305	0,184	0,701	0,150	0,500
Weights	0,2201	0,0825	0,1246	0,1046	0,1046	0,1639	0,0352	0,0938	0,0354	0,0354

Source: This Research (2018)

Table 5: Resource allocation model results

Alternatives	$V_i\ (A_i)$ – Interval Scale	$V_i\ (A_i)$ – Ratio Scale	*Go?*	P_i %
UAS1	0,6065	0,6682	0	12,16%
UAS2	0,5235	0,5981	0	9,98%
UAS3	0,2743	0,3880	1	2,92%
UAS4	0,2673	0,3821	1	3,71%
UAS5	0,2652	0,3804	1	3,58%
UAS6	0,1133	0,2523	1	1,41%
UAS7	0,2200	0,3422	1	2,55%
UAS8	0,0931	0,2352	1	1,62%
UAS9	0,1461	0,2799	1	1,75%
UAS10	0,1674	0,2979	1	1,72%
UAS11	0,0892	0,2319	1	1,57%
UAS12	0,3576	0,4583	0	5,86%
UAS13	0,2938	0,4044	0	4,72%
UAS14	0,3578	0,4584	1	4,36%
UAS15	0,4997	0,5781	0	10,43%
UAS16	0,7570	0,7950	0	11,75%
UAS17	0,5488	0,6195	1	9,78%
UAS18	0,2581	0,3744	1	2,72%
UAS19	0,3008	0,4103	1	2,58%
UAS20	0,1330	0,2689	1	2,20%
UAS21	0,2101	0,3339	1	2,62%
Total Value – Interval Scale	**3,6670**			
Total Value – Ratio Scale	**5,2551**			

Source: This Research (2018)

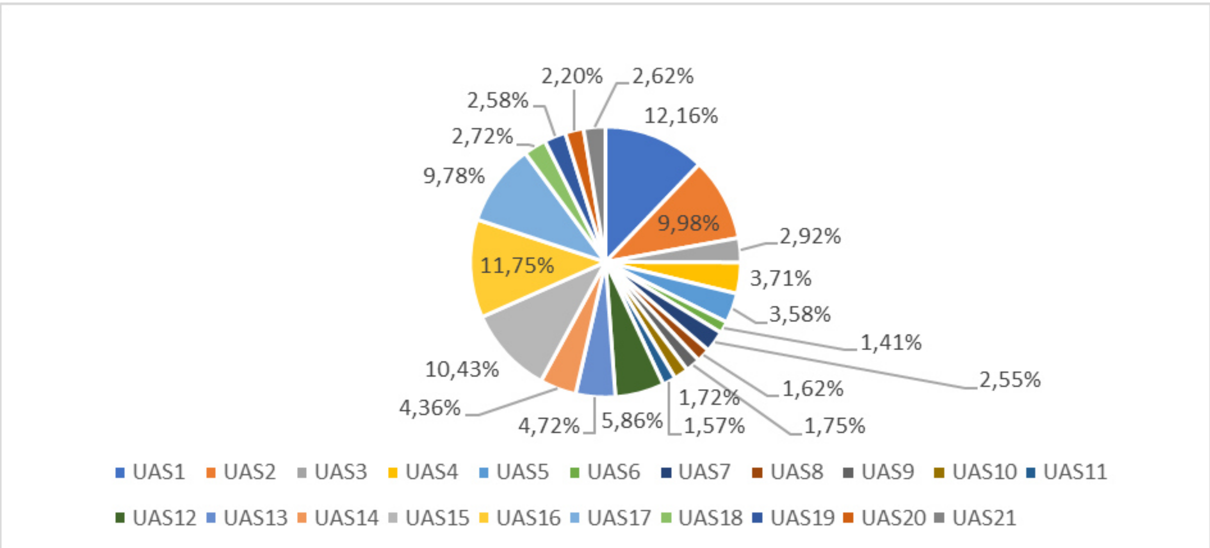


Figure 4 – % of the budget

Table 4 evidences the performance value of the alternatives, that is, the value function v_j (x), in each criterion for a ratio scale normalization procedure, considered as the appropriate procedure for this type of problem, also Table 4 shows the weights already normalized. Table 5 shows the alternatives, their respective value from the additive model (V_i) using an interval scale and a ratio scale, 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. Figure 4 shows the percentage of the total budget that each administrative unit should receive, showed in Table 5.

The differences found in the application when considering different scales were in the value function of the additive model (V_i) for every UAS, caused by different weights and scales in the aggregation process. The total value, that represents the objective function of the model differs because of the same reason. In a ratio scale context, the performance of each alternative (UAS) is better than an interval scale context, and the same analysis could be inferred from the global value.

From the use of the additive model, the results indicate a portfolio with 11 projects, for the interval scale and considering a ratio scale context, with the proper transformation of weights, the results indicate a portfolio with 15 projects. In terms of budget value, the solution with an interval scale uses a total of R$ 148,512.71 and the solution with a ratio scale consumes R$ 148,831.30 from the available budget (R$ 150,000.00).

As pointed out before, scaling problems do not happen for all the cases, and they will depend on the combination of values and constraints considered by the problem analyzed (MARTINS *et al*., 2017). Moreover, it is always important to examine the existence of the scale problem and, if it does happen, then one should make the necessary changes to adequate the case (MARTINS *et al*., 2017). This application has shown a real case of budgeting problem, particularly in the domain of the education sector.

The implications of these results for practice are that when an adequate scale transformation is considered in an additive multicriteria portfolio analysis, this can contribute to improve the limited budget distribution, it could mean to reach better results, applying all the available resources with efficiency.

When deeply analyzing the results, it can be inferred that UAS 1 was the alternative that should receive the biggest part of the budget (12,16%), followed by UAS 16 (11,75%), UAS 15 (10,43%), UAS 2 (10%) e UAS 17 (9,78%). Together, these units represent more than 50% of the university's budget. The results could be explained by the performance of this alternatives in the criteria considered. Also, it is important to say that the units represent the medical course, veterinary medicine, zootechny courses, courses in the biological area, such as biology, pharmacy, and nutrition. All of them, are considered courses with extra resource allocation needs, because of the infrastructure needed to manage them. Or yet, the results could be explained due to the number of students. For example, UAS 2 represents courses in the human sciences area, such as law, business management, which are traditionally courses with a large number of students at UFMS.

The alternatives with the smallest part of the budget represent small colleges from the university, composed mainly of courses that do not need a large infrastructure, such as history and pedagogy, for instance.

In case of varying the total budget considered by the model, increasing, for example, the percentages will differ from the one found by the model studied here in the following way: the percentage increases in the case where the UAS should receive the maximum budget requested, settled by the maximum budget constraint in the model, and will decrease when the UAS should receive less than the maximum. This situation occurs because of the performance of the alternatives in the value function, and taking this into account, the resources could be better distributed when considering an additive value function.

In addition, in terms of defining the percentage that each unit will receive, the DM must always choose a model that reflects the real evaluation that each criterion implies regarding to its preferences. When performing an evaluation in the context of additive value functions, and more specific, project portfolio selection, one should proceed, whenever is possible, with a ratio scale, since it provides consistency between different types of aggregation. Although portfolio problems and scaling issues in portfolio analysis represent more complex multicriteria problems, the resource allocation model proposed here has a simpler analysis, due to the reality presented by the context in question and the characteristics of the problem itself.

From the sectoral administrative unit point of view, the best situation to receive better budgets would be to look for a balance between all the criteria results, with an average value for each criterion, and, maybe, the model adopted by the University could consider different weights for the criteria, with the aim of encouraging all the UAS to reach better results and demonstrating a bigger efficiency of the resource allocation model used.

4.3 Sensitivity Analysis Results

After a preliminary analysis of the data, a sensitivity analyzes was performed, using Monte Carlo simulation. The Monte Carlo simulation procedure repeats the model *N* times, varying parameters within a selected range of values and a distribution of probabilities established. Then, there are obtained *N* solutions for the case. For this purpose, *N* should be a large number, and many of the *N* solutions may be identical.

For the first analysis, the weights of every criterion were increased by 10% separately, and the weights adjustment for the other criteria was performed for a uniform distribution. The standard solution was considered the best once there was no other recommendation, and the standard portfolio remained the same.

In the second analysis, the weights of every criterion were increased by 20% with the respective adjustment for the other weights. For this case, the standard solution was found to be the best one, and there was only 5.1 percent of the cases in where a new solution was recommended, which means that one non-standard portfolio was recommended. In this case, UAS 17 is replaced by UAS 2.

In light of the results presented above, the sensitivity analysis showed a robust result for the case. Even so, there were a few changes and the DM can analyze the portfolios, evaluating just the alternatives that have changed.

It is important to highlight that during the sensitivity analysis the sum of the objective function, that is, the global value of the model, almost remained unchanged for every simulation. There were small changes varying from 0.0001 to 0.035 in the total value. The criterion that increases more the objective function when they increase is the quality of the undergraduate courses (IDGQ).

It would be interesting if simultaneous variations of the weights were considered by the DM, in addition to individual variations already considered in the sensitivity analysis results here. For this situation, the DM would have to review the model and consider himself able to distinguish the meaning of every weight in the UFMS model.

Nevertheless, it is possible to emphasize the robustness of the model, since even when the weights change for every criterion, the standard solution remained roughly the same as the original application of the model.

5 MULTICRITERIA WEB-BASED DSS FOR RESOURCE ALLOCATION

In this Chapter, the steps to build the multicriteria web-based decision support system for resource allocation in public universities are presented. The MCDM model shown in Chapter 4 was integrated to the web-based DSS. As pointed out in the Introduction, the web-based DSS takes into account the four phases of the decision-making process: intelligence, design, choice and implementation phase (SIMON, 1960; TURBAN, ARONSON & LIANG, 2005). The DSS has the purpose of supporting the phases of the decision-making process.

Thus, in the intelligence phase, after understanding how the general resource allocation model from the Brazilian Ministry of Education works, already explained in Section 3.1, data were collected to make an investigation of all universities that receive resources from this main model. A total of 55 universities was found.

All relevant information that was available about the internal model of each federal university was examined through documents provided on the university's websites or, when this information was not available, a contact was made by e-mail with the administrative units responsible for providing such data. After searching for all 55 models, it was possible to obtain complete information about 30 internal resource allocation models. Figure 5 shows all the 55 universities researched. The names of the universities are abbreviated and those 30 in which the complete model was found are highlighted in blue color.

Universities										
UFRR	UFSJ	UNIRIO	UFERSA	UFLA	UFES	UFSCar	UFMT	UFF	UFAL	UFMS
UFT	UFABC	UFAC	UTFPR	UNIFESP	UFAM	UFC	UFSM	UNIVASF	UFRPE	FURG
UFMA	UNIPAMPA	UFPA	UFCG	UFPEL	UFG	UNB	UFBA	UFRRJ	UFMG	UNIFAL
UFRA	UFGD	UNIFAP	UFRB	UFSC	UFS	UFPB	UFPR	UFRJ	UFPE	UFPI
UNIFE	UFJF	UFVJM	UFCSPA	UFOP	UFRN	UFTM	UFU	UFV	UFRGS	UNIR

Figure 5 – Brazil's Federal Universities that receive the budget based on the Ministry of Education (MEC) methodology

In the design phase of the research, a study of the models was made to separate them into "affinity groups", so that similar models were allocated to the same group. It was possible to establish three general groups of models according to the parameters considered by them: Model 1, based on the general resource allocation model adopted by MEC; Model 2, based on some indicators suggested by the Brazilian audit office (TCU, 2012); and Model 3, based on some other indicators that has different aspects from each model. Finally, to validate the choice of the MCDM resource allocation model and also to validate the design of the web-based DSS, an application in a Brazilian public university was conducted.

The parameters of the models will be shown in Sections 5.1, 5.2 and 5.3.

5.1 Model 1

Model 1 is based on the general resource allocation model presented in Section 3.1, where the formulas were already described. Some universities vary or adapt a few parameters from this general model (as the distribution of weights, for instance). The criteria are based in the total of equivalent students, efficiency and academic-scientific quality of the federal university.

UFMS belongs to this first model and the university takes into account, in their existing resource allocation model, other criteria such as the quality of the academic staff and the graduation success rate.

5.2 Model 2

Model 2 is based mainly on indicators suggested by the Brazilian audit office (called Tribunal de Contas da União – TCU) to allocate internal resources from the OCC matrix. These indicators suggested are: costing; the total amount of hours from each undergraduation course; the number of students in every course; the number of professors and their workloads in teaching, research and extension activities; publications from every academic department; the number of laboratories and qualification of the academic staff. Figures 6 and 7 show the indicators considered.

PART cust =	0.2*(ADIS / ∑ADIS + CHDD / ∑CHDD) + ∑β * C		
cust =	costing		
C =	selected criteria		
β =	weights of the quality criteria C		
ADIS =	Number of students in every course * amount of hours of the course		
CHDD =	Number of professors * amount of hours taught by each one of them		
Prod =	total research production of every administrative unit		
Ext =	number of extension projects		
PART =	Total participation in costing resources from each Administrative Unit		
PART cap =	0.1* CHDD / ∑CHDD + 0.3* Nlab / ∑Nlab + 0.2*(RO / ∑RO + IQCD / ∑IQCD + IDCD /∑IDCD)		
cap =	capital	RO =	∑ ROman ; ROprod; ROext
Nlab =	number of laboratories	ROman =	budget resources for maintenance
RO =	inicial budget from the year before	ROprod =	budget resources for research
IQCD =	qualification indicator from the professors	ROext =	budget resources for extension
IDCD =	qualification indicator from the administrative staff		

Figure 6 – Indicators from model 2 – part 1

IQCD =	(5*D + 3*M + 2*E +1*G) / (D+M+E+G)
D =	total amount of professors with a PhD degree
M =	total amount of professors with a Master degree
E =	total amount of professors with a specialization degree
G =	total amount of professors with an undergraduation degree
IQCTA =	0.75*Tem + 0.5*Tef + 1*Tg + 2*Te + 3*Tm + 5*Td
Tem =	Total of administrative staff with primary education
Tef =	total of administrative staff with high school education
Tg =	total of administrative staff with undergraduation education
Te =	total of administrative staff with specialization education
Tm =	total of administrative staff with master education
Td =	total of administrative staff with doctorate education

Figure 7 – Indicators from model 2 – part 2

5.3 Model 3

Model 3 is based on other indicators that has different aspects from models 1 and 2 and it is based essentially on the following criteria: number of professors; the number of technical employees (technical staff); the number of students from each department; the total area from the laboratories; the total area from the departments; scientific production from the departments (in terms of research projects and scientific publications); extension activities and efficiency factor. These indicators can be seen in Figure 8.

PART =	(0.7*Neu + 0.1*Produ + 0.1*Extu + 0.1*AP) * (1+FE) / ∑ (0.7*Neu + 0.1*Produ + 0.1*Extu + 0.1*AP) * (1+FE)		
Neu =	total of equivalent students	**ROu =**	PART * (ROj - ∑ ROi)
Produ =	scientific production of the administrative unit		
Extu =	extension production of the administrative unit		
AP =	percentage area of the administrative unit		
FE =	efficiency factor		
PRODU =	∑wpi * ALCPu / NDu		
ALCPu =	number of papers published in journals, conference proceedings, softwares, research projects		
wpi =	weight of the publication		
Ndu =	total number of professors		
EXTU =	∑wei * PECu,i / NDu		
Ndu =	total number of professors		
PECu,i =	number of extension activities		
wei =	weights of the extension activies		
AP =	100 * ACon, u / ∑ ACon,u		
ACon,u =	area of the administrative unit		

Figure 8 – Indicators from model 3

Subsequently, data was placed in Excel spreadsheets to flexibly analyze the models with the aim of enabling users to explore various options quickly and because the spreadsheets possess analytical tools for modelling data (POWER, 2000). Lastly, a prototype from the DSS was made, with the help of a Decision Maker from the budgeting unit of the Federal University of Mato Grosso do Sul (UFMS), taken as the end user of this first prototype.

5.4 DSS Prototype

As specified before, the DSS proposed here focuses on a model-driven DSS, and according to Power's (2001) DSS framework, can be classified as it follows:

• Dominant DSS component: an optimization model based on a resource (budget) allocation procedure;

• Target users: administrative staff from the budgeting unit of every Brazilian Federal University (for the general DSS prototype);

• Purpose: to contribute to the decision question of how to allocate resources properly and to optimize this process;

• Enabling technology used: Excel, resource allocation model, creation of the basis to build a web-based DSS.

The DSS prototype from the main three models found by this study is presented next. According to Power (2000), a DSS prototype is an important step because, once approved, the prototype can be expanded in the development environment or used as a specification for a DSS developed in different programming languages. Also, prototyping seems to improve user-developer communication and it has rapid application development (POWER, 2000).

The DSS components of the prototype from this research can be seen in Figure 9, where the information can be visualized as it follows: the inputs are the data from the models, such as the name of the federal university, the name of the course and the values of the indicators or parameters considered by the model; the processing are the interactive processing of data and models, the calculation of the formulas defined by the models, the simulation, optimization and analysis that can be provided by the models; lastly, the outputs are the final share of the budget that each university, academic unit or course will receive, the transformed data from the models that can be used to take decisions. Also, the end user is the representative director of every budgeting unit from the Brazilians Federal Universities.

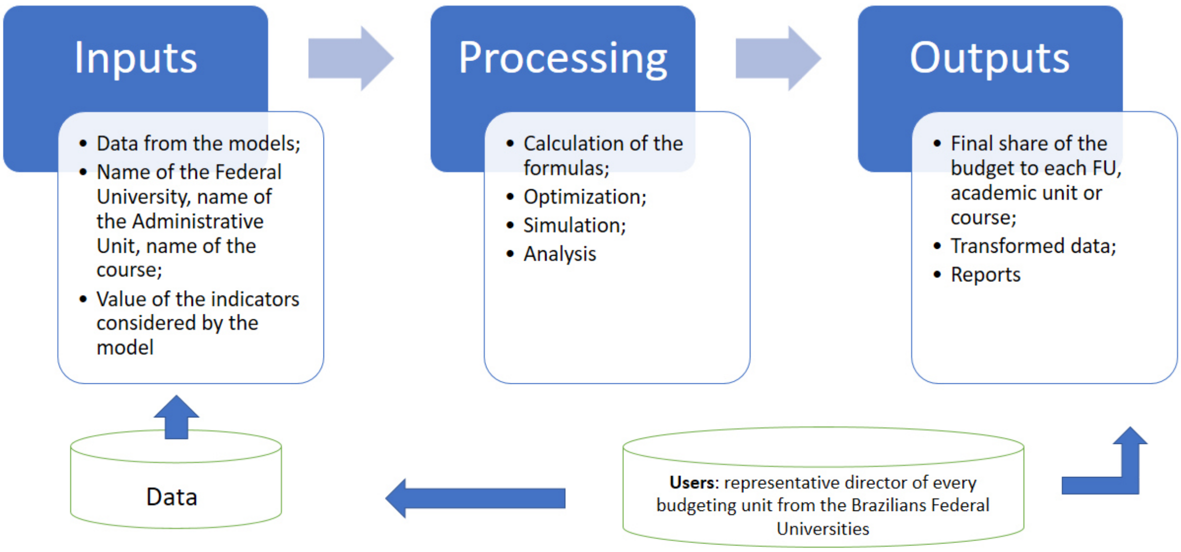


Figure 9 – DSS components of the prototype from this research

This initial prototype was designed in Microsoft Excel spreadsheets. According to Power (2000), models can be developed in a variety of software packages including spreadsheets and they are commonly used for desktop Model-Driven DSS, which is the case of this study.

Spreadsheets are a very popular end-user modeling tool and have many advantages, such as the modeling capability; users can write their own models and also conduct "What-If" analysis, scenario analyses and goal seeking. Also, reports can be consolidated, and data can be organized or sorted in alphabetical or numerical order. Other capabilities include setting up windows for viewing several parts of a spreadsheet simultaneously and executing mathematical manipulations.

These capabilities enable the spreadsheet to become an important tool for analysis, planning, and modeling (POWER, 2000). In addition, the current trend is to integrate spreadsheets with a software and web-based DSS, and that's the reason they were used for the initial prototype, that can be seen in Figures 10, 11 and 12.

Undergraduation

Course	N. of students entering the course	N. of students that finished the cour	Group	Weight	Area	Standard "retention" factor	Duration of the course	Duration of the course at the FU	Bonus Nightly Course	Equivalent Student - TAEG	
Civil Eng.	50	27	A2	2,0	ENG	0,0820	5	5,5	1	385	
Manag. Eng.	50	35	A2	2,0	ENG	0,0820	5	5,1	1	425	
Electrical Eng.	50	29	A2	2,0	ENG	0,0820	5	5,2	1	381	
Medicine	60	54	A1	4,5	CH2	0,0650	6	6	1	1.593	
Natural Science	40	33	A4	1,0	CS1	0,1000	4	4,5	1,15	197	
	250	**TOTAL**								**2.980**	**TOTAL**

Master Course

Course	NACM	DM	Weight	TAEM	
Civil Eng.	15	0,75	2	22,5	
Manag. Eng.	15	0,75	2	22,5	
Electrical Eng.	10	0,75	2	15	
Medicine	10	0,75	4,5	33,75	
Natural Science	18	0,75	1	13,5	
				107,25	**TOTAL**

Doctorate Program

Course	NACD	DD	Weight	TAED	
Civil Eng.	10	0,38	2	7,6	
Manag. Eng.	10	0,38	2	7,6	
Electrical Eng.	8	0,38	2	6,08	
Medicine	10	0,38	4,5	17,1	
Natural Science	15	0,38	1	5,7	
				44,08	**TOTAL**

Figure 10 – DSS Prototype from Model 1

Model 1 is based on the general MEC model (see Section 3.1). The formulas in MS Excel were developed to find the budget participation of an administrative unit, based in the summation of the AU in the total of equivalent students from undergraduation courses, master courses, doctorate programs and medical residency. The model also considers the efficiency and scientific academic quality from the FU.

Department	ADIS	CHDD	β	C	RO	N	PART cost	PART c	W	Total Part
Engineering	8000	7500	0,2	1,0	220000	22	0,2	0,2	0,2	0,316
Computer Sci.	6000	5500	0,2	1,0	140000,0	14	0,2	0,2	0,2	0,281
Human Sci.	5500	4800	0,2	1,0	210000,0	8	0,1	0,1	0,2	0,275
Mathematics	4000	3600	0,2	1,0	130000,0	10	0,1	0,1	0,2	10,265
Medical School	4500	4100	0,2	1,0	250000,0	28	0,4	0,4	0,2	18,619

Department	D	M	E	G	W	IQCD
Engineering	150	120	50	10	1	3,6969697
Computer Sci.	110	99	41	8	1	3,6317829
Human Sci.	160	150	46	4	1	3,7388889
Mathematics	85	90	32	11	1	3,5321101
Medical School	155	110	62	3	1	3,7333333

Department	ADM, EM	ADM, EF	ADM, G	ADM, E	ADM,M	ADM, D	IQCTA
Engineering	54	32	33	19	14	66	500
Computer Sci.	5	33	40	25	46	66	578
Human Sci.	70	45	23	79	51	48	649
Mathematics	12	50	11	64	29	14	330
Medical School	10	40	20	58	54	9	371

Figure 11 – DSS Prototype from Model 2

The formulas from Model 2 in MS Excel are based on costing (PART cost); the total amount of hours from each course and the number of students in every course (ADIS); the number of professors and their workloads in teaching (CHDD), qualification of the academic staff (IQCD) and qualification of the technical staff (IQCTA). The budget participation of an administrative unit is given by the "Total Part" indicator.

Depart.	Ne	Prod	Ext	AP	FE	PART
Engineering	2518,88	5,17	0,76	0,23	0,4	1,25
Computer Sci.	1799,4	10,33	1,53	0,16	0,4	0,89
Human Sci.	1092,9	4,84	0,72	0,21	0,6	0,62
Mathematics	1461,1	13,37	1,98	0,14	0,3	0,67
Medical School	2715,25	4,66	0,69	0,26	0,7	1,64

Depart.	We	PEC	ND	Ext
Engineering	0,6	12	220	0,76
Computer Sci.	0,4	8	110	1,53
Human Sci.	0,8	16	235	0,72
Mathematics	0,5	4	85	1,98
Medical School	0,6	18	244	0,69

Depart.	Wp	ALCP	ND	Prod
Engineering	0,6	80	220	5,17
Computer Sci.	0,4	45	110	10,33
Human Sci.	0,8	112	235	4,84
Mathematics	0,5	22	85	13,37
Medical School	0,6	133	244	4,66

Depart.	Aconu	Aconi	Apcon
Engineering	480	2130,0	23
Computer Sci.	350	2130,0	16
Human Sci.	450	2130,0	21
Mathematics	300	2130,0	14
Medical School	550	2130,0	26

Depart.	PART	Roj	Roi	RO
Engineering	1,25	183192,6	778375,61	744.077
Computer Sci.	0,89	214741,6	778375,61	503.673
Human Sci.	0,62	98820,1	778375,61	421.438
Mathematics	0,67	118901,1	778375,61	444.590
Medical School	1,64	162720,2	778375,61	1.007.408

Figure 12 – DSS Prototype from Model 3

The formulas from Model 3 are based on the number of professors (ND); the number of students from each department (Ne); the total area from the laboratories and the total area from the departments (AP); scientific production from the departments (in terms of research projects and scientific publications) (Prod); extension activities (Ext) and efficiency factor (FE).

After defining the general DSS prototype, the decision-making phases of choice, implementation and control (SIMON, 1960; TURBAN, ARONSON & LIANG, 2005) consisted in developing a DSS Database model, using an appropriate language (SQL for the case), the user's interface was defined, and, finally, a prototype of the multicriteria web-based system was implemented for a Brazilian public university chosen as a parameter (UFMS) to validate the system, with a programming language (PHP combined with Python). These steps of the study will be shown next.

5.5 Multicriteria Web-based DSS for Resource Allocation in a Brazilian Federal University (UFMS)

This section aims to present a multicriteria web-based Decision Support System (DSS) for internal resource allocation in a higher education organization. For this purpose, a Brazilian public university (UFMS) was selected as a parameter. Presently, there aren't any general DSS for such a problem in the organization or in Brazilian federal universities, for instance.

Consequently, the creation of a DSS in UFMS is justified by the fact that all data for the application of their internal resource allocation model is gathered manually and managed with Excel spreadsheets by a single department at the University studied, from data provided by each administrative unit.

The idea is that the system could support decision makers, stakeholders that are part of the process and decentralize tasks achievement, since web-based DSS provide the availability of intelligent search tools that could enable them to find and manage the information they need quickly and inexpensively (TURBAN, SHARDA & DELEN, 2011).

Moreover, the system could improve communication, collaboration, increase productivity of group members (there are 21 sectoral administrative units that are affected by the allocation procedure) and improve data management using the Web (TAGHEZOUT, BESSEDIK & ADLA, 2011).

As a suggestion, the general concept of the web-based DSS presented here could be extended and applied by other federal universities in Brazil or other countries, adapting the alternatives and criteria for each specific internal allocation model and to the Decision Makers (DM) needs with the same purpose of improving the decision-making process.

Also, to state a clarification, the main decision of the model (not the problem situation of this study) it is how to improve the resource allocation process and the Decision Maker considered is the representative director of the budgeting unit from the Federal University of Mato Grosso do Sul (UFMS), because of the availability of data and similarity to a general model in Brazil.

The Brazilian federal university considered (UFMS) has around 5287 employees (divided between academic, technical and administrative staff) and more than 15 thousand students (from undergraduation and graduation courses). The aim is that the application of a correct DSS combined with a multicriteria model to distribute the local budget between these units can contribute to the University's permanent strategy of efficient and fair resource allocation. Once, when a DSS is involved 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).

Power's (2001) DSS framework presented in Section 5.4 and in Figure 9 can be adapted for the special case of UFMs to define the system's architecture as it follows: the dominant DSS component is the multicriteria model based on an additive value function for the resource (budget) allocation procedure; the target users are the administrative staff from the budgeting unit of UFMS, DM participants from every UAS, since they are affected by the allocation procedure, facilitators, developers and administrators; the purpose is to contribute to the University's permanent strategy of efficient and fair resource allocation; and the enabling technology used was MS Excel, resource allocation model, multi-attribute decision-making methods, creation of the basis to build a web-based DSS, Database model and web-based DSS. The system's architecture can be seen in Figure 13.

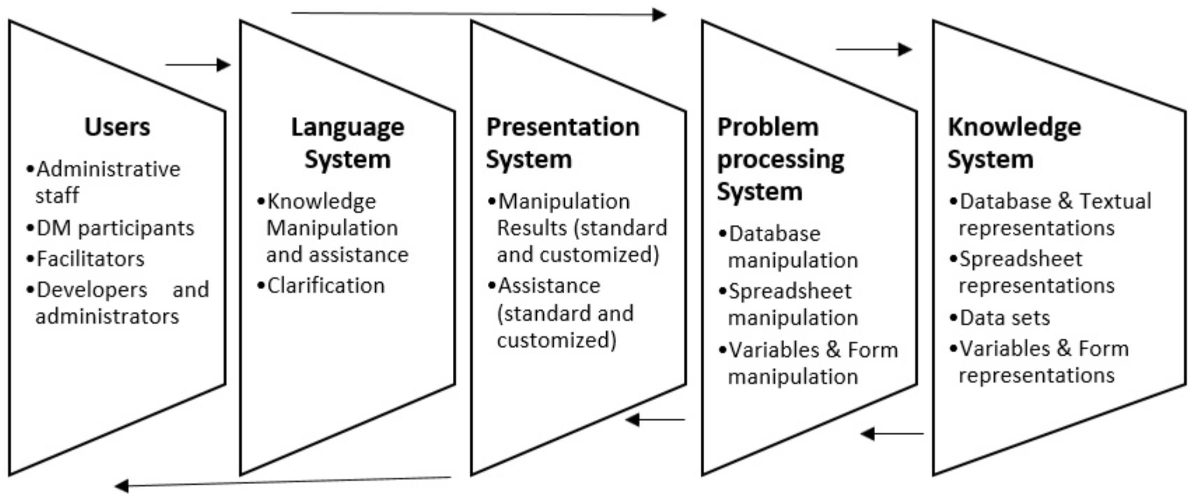


Figure 13 – DSS Architecture (Adapted from Holsapple (2008))

Analyzing Figure 13, and according to Holsapple (2008), 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 (HOLSAPPLE, 2008).

The knowledge system involves all knowledge the DSS has stored and retained. The knowledge system here is comprised of 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 important to clarify that the user does not need to know about database, rule set, or solver manipulations, for example. These activities happen beneath the customized DSS surface provided by the PPS (HOLSAPPLE, 2008).

Given this consideration on the problem, it was possible to implement the multicriteria web-based DSS. To do so, 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).

PHP is an open source scripting language commonly used to develop Web applications and can be simply integrated with HTML codes, for instance (POWER, 2001). The development of dynamic web systems brings the requirement to access some type of relational database and PHP is one of the languages with the greatest availability of database access, since it can access Oracle, SQL Server, PostgreSQL, FireBird, MySQL, SysBase, Informix, SQLite and several other databases (POWER, 2000). Among all these databases, the most used is MySQL, chosen for this research.

The name defined for the web system was: MDSSFRA (Multicriteria Decision Support System for Resource Allocation). The technological background of the system is illustrated in Figure 14.

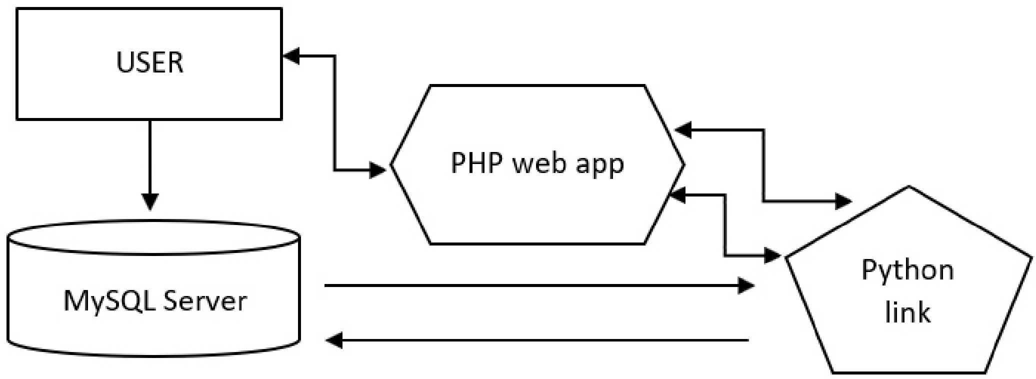


Figure 14 – DSS background

The technological background of the web-based DSS provided by Figure 14 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 MCDM model calculation, and return to PHP with the final result information.

The system has four major components. First one is a database component in which all federal university data is divided by year, criteria and budget information are stored. Before starting a new analysis, user can modify these parameters for updates. Figure 15 shows the Database Model.

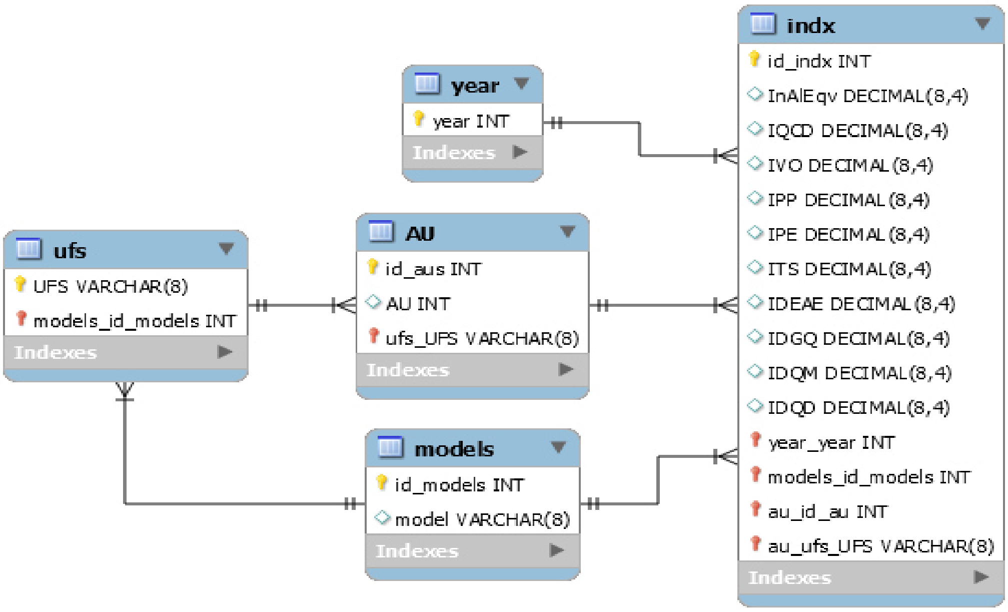


Figure 15 – Database model

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

The second component is a data processing component that allows the user to make a simulation by selecting an administrative unit, different criteria, insert criteria values and a total budget to be analyzed via web-based user interface. Here, data are retrieved from the Database model (MySQL). These features can be seen in the first, second and third pages of the MDSSFRA. The respective PHP pages from the system are shown in Figures 16, 17 and 18.

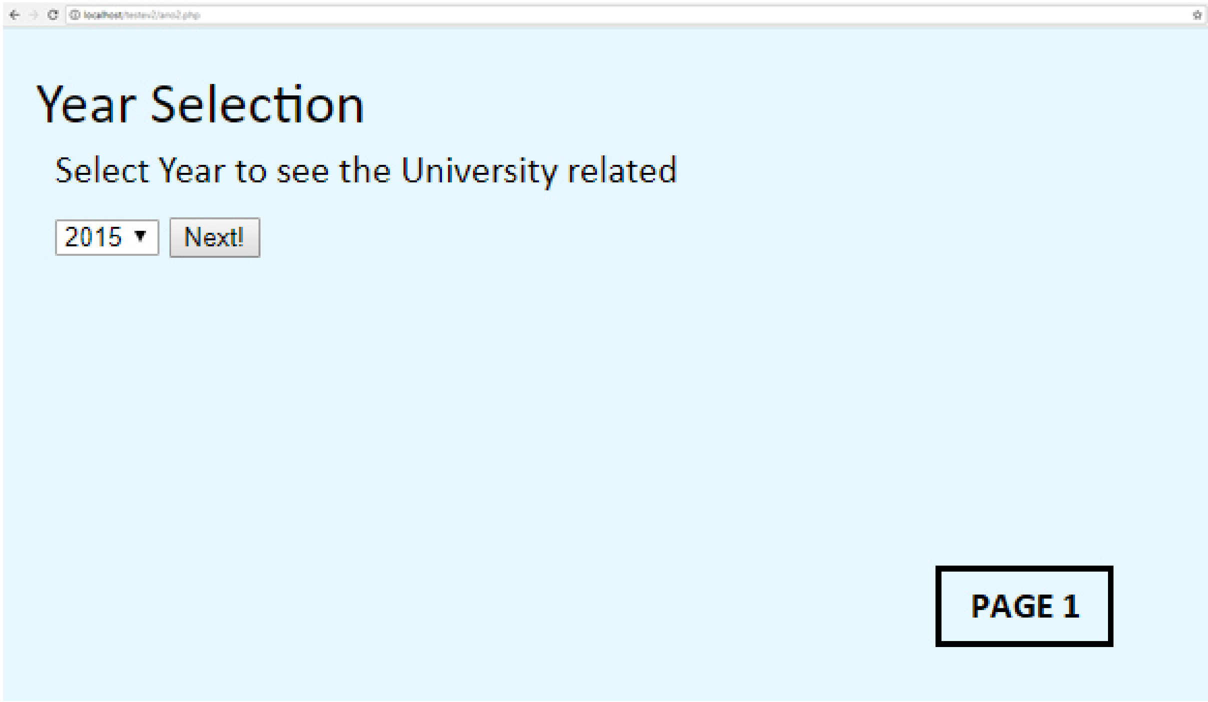


Figure 16 – Web system page 1 – user interface

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 2017. After selecting the year, the user is taken to page 2 for the next selection.

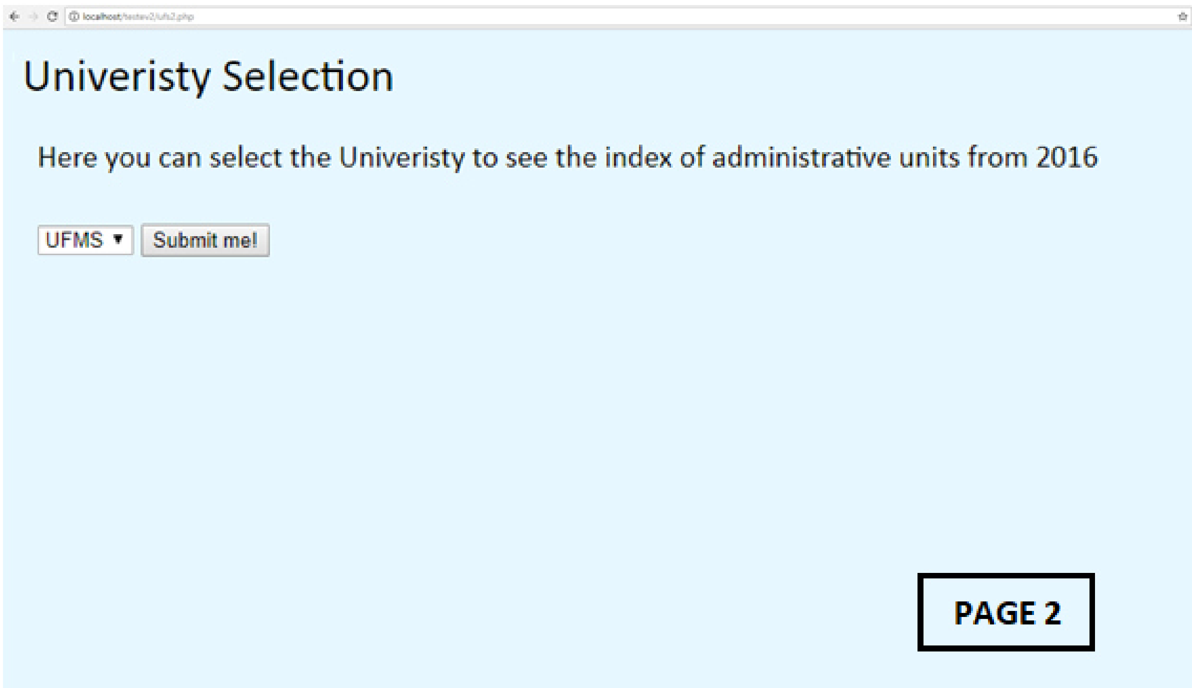
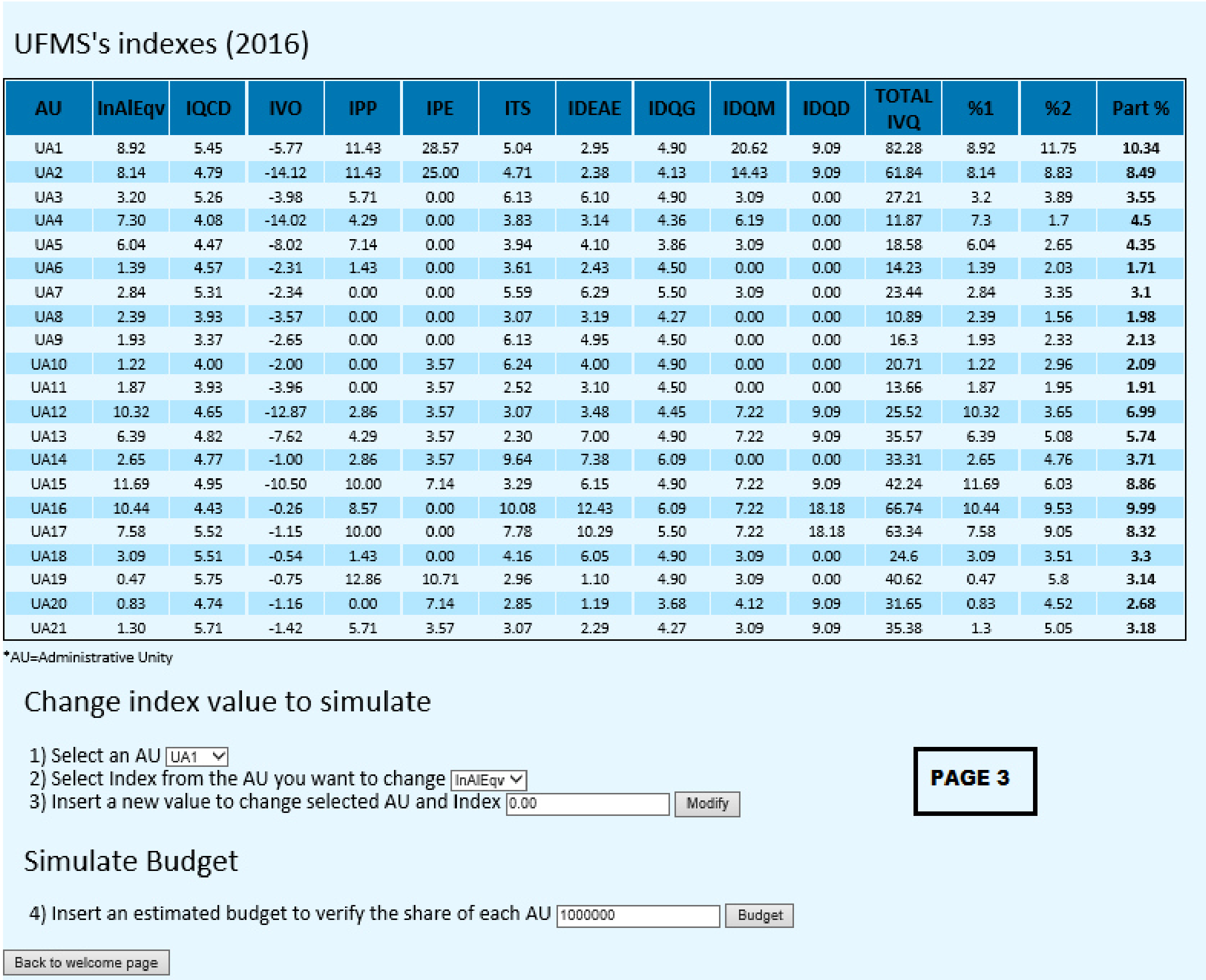


Figure 17 – Web system page 2 – user interface

Page 2 is the university selection page. Every university is associated with a different resource allocation model (explained in Sections 4.1, 4.2 and 4.3). Once the university is selected, the system takes the user to page 3, in where the data are shown. In this case, there is only one selection option: UFMS.


UFMS's indexes (2016)

AU	InAIEqv	IQCD	IVO	IPP	IPE	ITS	IDEAE	IDQG	IDQM	IDQD	TOTAL IVQ	%1	%2	Part %
UA1	8.92	5.45	-5.77	11.43	28.57	5.04	2.95	4.90	20.62	9.09	82.28	8.92	11.75	10.34
UA2	8.14	4.79	-14.12	11.43	25.00	4.71	2.38	4.13	14.43	9.09	61.84	8.14	8.83	8.49
UA3	3.20	5.26	-3.98	5.71	0.00	6.13	6.10	4.90	3.09	0.00	27.21	3.2	3.89	3.55
UA4	7.30	4.08	-14.02	4.29	0.00	3.83	3.14	4.36	6.19	0.00	11.87	7.3	1.7	4.5
UA5	6.04	4.47	-8.02	7.14	0.00	3.94	4.10	3.86	3.09	0.00	18.58	6.04	2.65	4.35
UA6	1.39	4.57	-2.31	1.43	0.00	3.61	2.43	4.50	0.00	0.00	14.23	1.39	2.03	1.71
UA7	2.84	5.31	-2.34	0.00	0.00	5.59	6.29	5.50	3.09	0.00	23.44	2.84	3.35	3.1
UA8	2.39	3.93	-3.57	0.00	0.00	3.07	3.19	4.27	0.00	0.00	10.89	2.39	1.56	1.98
UA9	1.93	3.37	-2.65	0.00	0.00	6.13	4.95	4.50	0.00	0.00	16.3	1.93	2.33	2.13
UA10	1.22	4.00	-2.00	0.00	3.57	6.24	4.00	4.90	0.00	0.00	20.71	1.22	2.96	2.09
UA11	1.87	3.93	-3.96	0.00	3.57	2.52	3.10	4.50	0.00	0.00	13.66	1.87	1.95	1.91
UA12	10.32	4.65	-12.87	2.86	3.57	3.07	3.48	4.45	7.22	9.09	25.52	10.32	3.65	6.99
UA13	6.39	4.82	-7.62	4.29	3.57	2.30	7.00	4.90	7.22	9.09	35.57	6.39	5.08	5.74
UA14	2.65	4.77	-1.00	2.86	3.57	9.64	7.38	6.09	0.00	0.00	33.31	2.65	4.76	3.71
UA15	11.69	4.95	-10.50	10.00	7.14	3.29	6.15	4.90	7.22	9.09	42.24	11.69	6.03	8.86
UA16	10.44	4.43	-0.26	8.57	0.00	10.08	12.43	6.09	7.22	18.18	66.74	10.44	9.53	9.99
UA17	7.58	5.52	-1.15	10.00	0.00	7.78	10.29	5.50	7.22	18.18	63.34	7.58	9.05	8.32
UA18	3.09	5.51	-0.54	1.43	0.00	4.16	6.05	4.90	3.09	0.00	24.6	3.09	3.51	3.3
UA19	0.47	5.75	-0.75	12.86	10.71	2.96	1.10	4.90	3.09	0.00	40.62	0.47	5.8	3.14
UA20	0.83	4.74	-1.16	0.00	7.14	2.85	1.19	3.68	4.12	9.09	31.65	0.83	4.52	2.68
UA21	1.30	5.71	-1.42	5.71	3.57	3.07	2.29	4.27	3.09	9.09	35.38	1.3	5.05	3.18

*AU=Administrative Unity

Figure 18 – Web system page 3 – user interface

Page 3 shows all the information from every administrative unit, such as their criteria or indexes, and the percentage of the budget associated with the AU. In order to develop a functional web-based DSS, the user has the option to change any index value from an administrative unit and the available budget to simulate different scenarios. That is the most important 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 unit can establish an action plan, for instance, to improve their indexes 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 are the multicriteria model and the percentage of the budget related to every administrative unit, obtained from the MCDM model results. The third component uses an additive value function with a linear programming module. For this purpose, it was used a Python link extension to solve the linear programming problem.

The PHP system can be integrated to Python with a tool to export data in text file, in where this file will be read by Python, will be interpreted, will make 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 MCDM / A 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 the problem by the same way as a LP problem is modeled. Thus, in the code, the lines 5, 78, 79, 82, 86,87,88, 90 from Figures 19 and 20 represent the problem modelling. Line 5 is the declaration of the problem, which is a LP maximization 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 was developed for the weights of the model to be automatically calculated. Thus, when integrated to the PHP, the information regarding the criteria, the weights and the budget can be insert by the user of the program to run different simulations (page 3 from user's interface). Figures 19 and 20 demonstrate the Python code developed for the model.

```python
# 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, 0.12788248580470100, 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)
```

Figure 19 – Python code – part 1

```python
# 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))
```

Figure 20 – Python code – part 2

Finally, the fourth component of the system takes care of the percentage of the budget related to every administrative unit, obtained from the MCDM model results. This component first calculates the value function of each AU using the retrieved data and the MCDM model procedure outputs. The fourth component is represented in page 4 of the web system

Page 4 (Figure 21) 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 AU 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. Also, there is a histogram to show the results in a visual way.

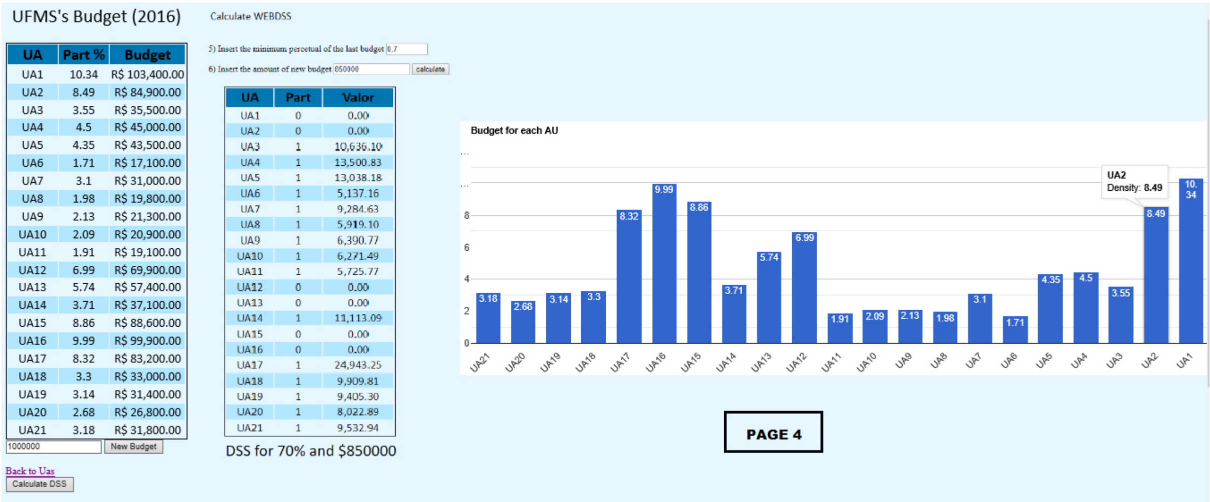


Figure 21 – Web system page 4 – user interface

5.6 Considerations on the system

The multicriteria web-based DSS proposed by this study can be tested by the users, to better evaluate if there is any improvement to be made in order to be useful for all the users of the system. In anyway, the system still has some limitations, as the fact that it is not possible to enter new parameters to the model, as a new criterion, for instance. For 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 when there is a clear vision on how the resource allocation procedure works, the entire process becomes more transparent to the ones that are affected by it, to the decision makers and to the government, enabling them to take safer and reliable decisions, seeking to reduce uncertainties and to maximize their results.

The overall objective of the multicriteria web-based DSS is reached when there is an improvement of the procedural rationality of a decision procedure in order to improve the quality of the decision process. Furthermore, the results reached are: 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 are 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).

6 FINAL REMARKS AND FUTURE WORKS

6.1 Contributions of the Study

This thesis 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, such as Brazilian federal universities, 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.

Thus, the study was divided into three steps: identify the Brazilian general allocation model and the models from each federal university; find similarities between the models; and, divide the models into categories, according to their similarities. Subsequently, a Brazilian federal university was chosen (Federal University of Mato Grosso do Sul / UFMS) as a parameter to make a numerical application to validate the multicriteria model for resource allocation proposed and, afterward, the web-based DSS was developed.

The MCDM / A model was able to define the percentage of the budget that every budgetary unity of the Federal University of Mato Grosso do Sul should receive. The numerical application considered 21 alternatives, which were the sectoral administrative units from UFMS, and 10 criteria were defined by the DM, which was the director of the budget and planning department (PROPLAN/UFMS).

With the results generated by the MCDM model, a comparison between the percentage attributed by the application of the MCDM model and the UFMS model demonstrated to be different, indicating that some sectoral administrative units should receive a different percentage amount from the budget. Consequently, the method proved to be valuable for managing the allocation of resources through a set of alternatives which were distributed rationally by clear consideration of the real importance of the different criteria.

Also, it has been demonstrated an analysis of the existence of scaling issues in the problem when comparing the results taking into account interval and ratio scales. When considering an interval scale context, a portfolio of 11 projects was found, contrasting with a portfolio containing 15 projects when considering a ratio scale context, with the proper transformation of weights. Thus, the implications of these results for practice are that the results can always be improved in the constant search to find the best possible solution to the problem. In addition, it is always important to examine the existence of scaling problems and, if it does happen, then one should make the necessary changes to adequate the case.

A sensitivity analysis was performed to analyze the robustness of the MCDM model. The results were achieved, they showed the sensitivity of each criterion and the impact of their changes in the results when varying the weights. Besides, the analysis helps the DM to see the impact of each criterion in the model and the administrative is able to visualize which criteria they need to improve to reach better results in terms of distribution of the budget as well.

On the web-based DSS side, a DSS prototype was established in MS Excel spreadsheets. Besides, a Database model was developed to store and retrieve data using Structured Query Language (SQL). To define the user's interface based on his detailed requirement analysis, a PHP web platform was developed on the server side integrated with Python to transform the prototype into a web-based system. The name attributed to the system was: MDSSFRA (Multicriteria Decision Support System for Resource Allocation).

Currently, there aren't any general MCDM model neither a web-based DSS for the problem. All data for the application of the model are gathered manually and managed by a single department at the University studied (and this situation happens for several others Federal Universities in Brazil).

The idea is that the system could support decision makers, stakeholders that are part of the process, decentralize tasks achievement, besides improving communication, collaboration, increasing productivity of group members (there are 21 sectoral administrative units affected by the allocation procedure) 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 on how the resource allocation procedure works, the entire process becomes more transparent to the ones that are affected by it, to the decision makers and to the government. In addition, the web-based DSS could be used to provide background for the Federal Universities strategic resource allocation planning.

The multicriteria web-based DSS proposed by this research can be tested by the users, to better evaluate if there is any improvement to be made in order to be useful for all the users of the system.

To conclude, it is worthwhile to note that the DSS developed has no production intention. The purpose is to deal with the problem as an experiment with only research purposes.

6.2 Limitations

Regarding the MCDM model proposed, there are some limitations. First, the resource allocation was built considering that the scale constants were to be elicited using swing weighting procedure. However, this is not the only elicitation procedure for scale constants in the additive model. Another available option it would be to use the tradeoff procedure, proposed by Keeney and Raiffa (1976).

The tradeoff procedure is classified as an indirect procedure (WEBER & BORCHERDING, 1993), since the determination of the scale constants is based on inference from information given by the DM. It is also classified as an algebraic procedure, since it calculates the *n* scale constants from a set of *n-1* judgments often using a simple system of equations, the trade-off method (DE ALMEIDA, *et al.*, 2015). Thus, it is necessary to verify the impacts on the results when considering another elicitation procedure for scale constants.

Regarding the web-based DSS, the system still has some limitations, as the fact that it is not possible to enter new parameters to the model, as a new criterion, for instance. For this case, another model will have to be developed and integrated with the web-DSS. Therefore, it would be interesting, and it could bring a broader vision to the problem if the system was adapted to insert new parameters to the model or the type of analysis that it is performed.

6.3 Future Works

For future works, the MCDM / A model proposed here should be tested in other types of environments in order to verify its applicability, such as in private higher education sectors or in another public organization. In addition, the model could be extended to group decision and negotiation context. Also, it would be interesting to compare different MCDM resource allocation methods with the results found in this study.

Still, the same multicriteria web-based DSS could be extended and applied by other federal universities in Brazil, by the Ministry of Education or other countries, 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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