Structuring Multicriteria Resource Allocation Models
A Framework to Assist Auditing Organizations

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Abstract: Multicriteria resource allocation models have been reported in the literature to support decision makers in selecting options/projects/programmes. These models are particularly important in public contexts in which resources are limited and there is an increasing demand for transparency and accountability in spending. Despite the potential of these models to promote an effective use of scarce resources, there is little organized and integrated research on how to structure them. In this paper we propose a framework with techniques and tools to support the structuring of multicriteria resource allocation models, so that these models have a potential to assist organizations in evaluating and selecting audit and control actions; and we provide illustrative examples on to apply these techniques and tools in the context of the Comptroller General of the Union, the Ministry of the Brazilian federal government responsible for helping the Brazilian president regarding the treasury, federal public assets application and the government's transparency policies.

1 INTRODUCTION

Brazil is a large country that has in place governmental programs that reach all its territory, and in which the public spending of federal funds is audited by the Ministry of Transparency, Supervision and Comptroller General of the Union (CGU). Similar to public auditing organizations in other countries, the activities of the CGU integrate actions of corruption prevention, fraud deterrence, public accounting, comptroller, ombudsman activities and increased transparency in management. In a time in which the country is going through a severe economic crisis, CGU has a key role in promoting transparency and accountability in public spending.

Since resources are scarce, CGU public managers must choose the set of projects to be executed with the available budget, considering costs and expected returns. This is a resource allocation situation well recognized in literature and, in this context, the use of multicriteria decision analysis concepts and tools can become useful and necessary.

Several multicriteria models for resource allocation have been reported in literature to support decision-makers in managing portfolios, taking into account of costs, benefits and risks (Liesiö et al., 2007; Phillips and Bana e Costa, 2007; Lourenço et al., 2012; Oliveira et al., 2012). However, there is little indication in the decision sciences and operational research literature on how to structure such type of problems in an integrated and organized manner (Montibeller et al., 2009). Proper structuring is required for building models that can effectively assist decision-makers.

This paper aims to fill this gap by proposing a framework to structure multicriteria resource allocation models (MRAM) in the context of auditing organizations. Specifically, the framework defines procedures and methods that can help to structure MRAM with a potential to improve the internal processes of organizations that have budget constraints and perform audit and inspection actions, such as in the CGU. The remainder of the paper is structured as follows. The next section outlines broadly the multicriteria resource allocation problem and key approaches set out in the literature to address those problems. Then we suggest a set of techniques and tools for the structuring MRAM and provide examples of its application for the auditing context. The paper ends with discussion of some relevant issues and directions for future research.

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2 THE (CLASSICAL) RESOURCE ALLOCATION PROBLEM

2.1 General Definition

The multicriteria resource allocation problem is characterized by the selection of attractive projects (portfolio) to be financed under the presence of a limited budget and of other relevant constraints. So, the prioritization and/or selection of options aims at generating portfolios of projects – which entail multiple benefits, costs and uncertainties – that offer the best overall value for a given budget. Clearly, the analyses of portfolios will depend on how the organization's decision-makers values distinct project benefits and risks, as well as on the costs required by those projects and by context constraints. As these benefits are usually multi-dimensional (e.g., losses recovery, strategic fit, social responsibility, safety etc.), this is a multicriteria problem.

The multicriteria resource allocation literature suggests two main modelling approaches that can inform the prioritization and/or the selection of projects and that can be used by the CGU: the **optimization** approach (Bana e Costa and Soares, 2004; Liesiö et al., 2007; Lourenço et al., 2012; Oliveira et al., 2012) and the **prioritization** approach (Bana e Costa et al., 2006; Phillips and Bana e Costa, 2007), which we now briefly describe.

2.2 The OPTIMIZATION Approach

Following Oliveira et al. (2012), the performance x_{ij} of each project j in the benefit criterion i can be measured by a level in the respective descriptor, with partial value $v_i(x_{ij})$. Under an additive structure (which requires the respect for mutual independence conditions), the value of the overall benefit v_j of the project j, with k_i represent the weight assigned to criterion i, can be determined as:

$$v_j(x_{1j}, \dots, x_{nj}) = \sum_{i=1}^{n} k_i . v_i(x_{ij})$$
$$\sum_{i=1}^{n} k_i = 1 \text{ and } k_i > 0 \ \ (i = 1, \dots, n) \quad (1)$$

Considering each project j has $v_j > 0$ and cost c_j, B is the total of available resources, and as $l_j = 1$, if the project j is included in the best portfolio and $zero$ otherwise, we have:

$$maximize: \sum_{j=1}^{m} v_j l_j \quad (2)$$

$$subject\ to: \sum_{j=1}^{m} c_j l_j \leq B,$$
$$l_j \in \{0,1\}, \quad j = 1, \dots, m. \quad (3)$$

The best project portfolio will be found by solving this optimization problem. Additional constraints can be considered.

2.3 The PRIORITIZATION Approach

Following Bana e Costa et al. (2006), the prioritization approach can be applied in six steps, in which the first three steps are similar to the optimization approach but also necessary: 1. List the projects; 2. Use a multicriteria value model, as Equation (1), for instance, to determine the added expected benefit v_j, if the project j is financed; 3. Define the cost c_j of each project, equal to the amount of financial support funding; 4. Calculate the benefit-to-cost ratio ($r_j = v_j / c_j$) of each project; 5. Rank the projects from the highest to the lowest benefit-to-cost ratio; and 6. Go down the list, choosing projects until the available budget is depleted.

A variant of this prioritization approach is found in Phillips and Bana e Costa (2007), that use the Equity, a software for portfolio analysis, which enables a classification of projects within an organizational structure logic. Specifically, the funds can be spent on different levels in various organizational units or functions, called areas. In each of the areas K, the options are evaluated based on criteria of benefits and risks J, resulting in $K \times J$ scales. For a given criteria j is assigned a within criteria weight w_{jk}. The total value of each option i and the benefit-cost ratios are:

$$V_i = c \frac{\sum_j w_j \, . \, w_{jk(i)} . \, v_{ij}}{\sum_j \sum_k w_j \, . \, w_{jk}} \quad (4)$$

$$r_i = \frac{V_i}{C_i} \quad (5)$$

The options are ranked from highest to lowest ratio r_i. The Equity structure can also be used within an optimization approach, although requiring a more sophisticated optimization model.

Several decision support tools assist the implementation of both approaches, being that the case of PROBE - Portfolio Robustness Evaluation (Lourenço et al., 2012), RPM - Robust Portfolio Modelling (Liesiö et al., 2007, 2008; Vilkkumaa et al., 2014) and the resource allocation module of M-MACBETH (Bana e Costa et al., 2012; Hummel et al., 2017).

2.4 Auditing Context

Both the prioritization and optimization modelling approaches can be useful for assisting decision-making processes of auditing organizations, as directly or indirectly shown by distinct studies: Bradbury and Rouse (2002) point out that the audit risk assessment is an essential part of the audit planning process. As the authors explain, numerical risk scores for each audit unit, together with materiality, can be used as the basis for the audit resource allocation. In turn, some studies have presented models to allocate internal auditing time and others auditing resources to projects (Krüger and Hattingh, 2006; Mohamed, 2015), using the optimization approach.

Prior to the use of these models, one needs to structure the multicriteria resource allocation model. I.e., to build such a model it is necessary to get all the information pertaining on models, which means defining the organizational areas, audit units, project options, costs, measurement criteria of benefits, risks, synergies and interdependencies between projects and other necessary factors (Friend and Hickling, 2005; Keeney, 1992; Montibeller et al., 2009), as well as to understand who should participate in model construction and whom the model is expected to assist. Such structuring will show whether an optimization or a prioritization approaches should be used, and whether these approaches need further development (note this is not the focus of this article).

3 STRUCTURING RESOURCE ALLOCATION DECISION MODELS

We herein propose a framework with techniques and tools to help defining and structuring MRAM to assist auditing organizations. Departing from the work presented by Belton and Stewart (2002), the proposed framework, shown in Figure 1, is able to generate background information to build MRAM. Note that applying the propose framework will require the use of technical tools and concepts, as well to involve decision-makers into participatory processes (for instance, to build a multicriteria value model), i.e., the adoption of a socio-technical process (Phillips and Bana e Costa, 2007). In this article, we focus on the techniques, rather than on the social process.

Each stage of the framework must generate relevant information to building the model in a structured way. The choice of which tools to use depends on the context of the problem being addressed, on which tools best fit the organizational culture, and on the user's familiarity with those tools.

Figure 1: Framework to assist the structuring resource allocation models.

3.1 Problem Identification

The first step is to identify the type of decision problem and understand the different perceptions of the actors relevant for the decision. Auditing organizations commonly need to choose the control actions to be performed by audit teams, taking into account the audit risks and available resources. Is this a prioritization problem? Is this a ranking problem? Is this about project selection with budget constraints? Or, moreover, does project selection involve possible conflicts of interest? The identification of the decision problem type is a key factor for MRAM.

In this step we suggest the use of structuring tools for problem definition, such as those cited by Franco and Montibeller (2011): cognitive mapping, dialog mapping, Soft Systems Methodology (SSM), group model building.

As explained by Eden (2004), a cognitive map is a graphical representation of thoughts in a network shape containing nodes and arrows whose direction implies causality. It is a powerful tool to capture different aspects of the problem to be addressed and is helpful to clarify people's ideas and perceptions.

Another tool is Dialog Mapping that seeks to build common understanding for wicked problems, which are ill structured and complex and can lead to different views and solutions depending on different stakeholders' perceptions. A diagram or map is shown in a shared display with use of a conversational grammar called IBIS, Issue Based Information System, that represents the moves in a conversation as questions, ideas (possible answers to the question), and arguments (pros and cons to the ideas) (Conklin, 2006).

Soft systems methodology (SSM) is an approach for dealing with problematical messy situations. Its

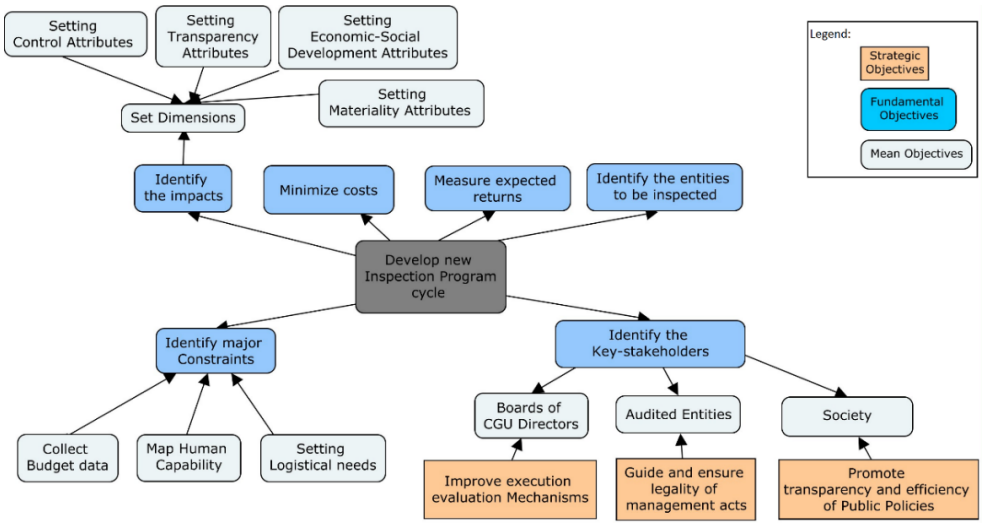

Figure 2: Mapping key concerns for developing an inspection program cycle with a means-ends objectives network.

use is recommended when divergent views on the problem definition exist. It is an action-oriented process of investigation in which users learn their way from finding out about the situation and what can be done to improve it (Checkland and Poulter, 2010).

In turn, a Group Model Building is a data analysis method from a group of decision makers. The dynamic patterns and relationships between key factors discussed by the group are portrayed to talk and analyse, resulting in new insights and possible new strategies or scenarios (Richardson and Andersen, 1995).

In addition, Friend and Hickling (2005) have presented the Strategic Choice Approach (SCA) that is useful to support the creation and definition of the problem in uncertain contexts.

Following Keeney's (1992) guidelines, one can also frame a decision situation by structuring the strategic, fundamental and mean objectives through means-ends relationships. Giving an example on auditing context, CGU performing an inspection program in states and municipalities, in order to assess the expenses incurred by these entities involving federal funds. The scope and entities to be inspected are chosen based on indicators divided into four dimensions: Control, Transparency, Economic and Social Development and Materiality.

Figure 2 illustrates the means-ends network for the CGU problem described. The main objective of an inspection cycle is to define the control actions (projects) that will be performed, within the available resources, which means defining auditing scope, auditees and measure expected returns/impacts. The map highlights key issues of the decision problem, namely the value system organized in a means-ends network. In fact, visual tools are useful to define and clarify the problem may be relevant in this step.

Once the problem is defined, as Franco and Montibeller (2011) well emphasized, it is necessary identify which aspects or particular decisional element of the decision problem will be evaluated in the model to be built. However, before that, we need to identify the key actors involved in the process.

3.2 Stakeholders Identification

The next step seeks to identify the key stakeholders and analyse their power and influence on the decision context. Bryson (2004) presents an array of techniques useful for stakeholders' identification and analysis and which grouped into four categories, which should be used in this step: organizing participation; creating ideas for strategic interventions; building a winning coalition around proposal development, review and adoption; and implementing, monitoring and evaluating strategic interventions. The author highlights five stakeholder identification and analysis techniques to helping organize participation: a process for choosing stakeholder analysis participants; the basic stakeholder analysis technique; power versus interest grids; stakeholder influence diagrams; and the participation planning matrix. He lists six additional techniques to creating ideas for strategic interventions: bases of power and directions of interest diagrams; finding the common good and the structure of a winning argument; tapping individual stakeholder interests to pursue the common good; stakeholder-issue interrelationship diagrams; problem-frame stakeholder maps; and ethical

analysis grids. The author also considers three techniques for proposal development review and adoption: stakeholder support versus opposition grids, stakeholder role plays and policy attractiveness versus stakeholder capability grids. And, finally, presents policy implementation strategy development grid for the last category.

From these techniques, we can highlight grouping the stakeholders in the matrix power/interest, proposed by Mendelow (1981), in which is possible to perceive how communication and relationships between stakeholders can affect the model structure and its implementation. Figure 3, for instance, helps to understand differences in power and influence of key stakeholders in the CGU inspection program.

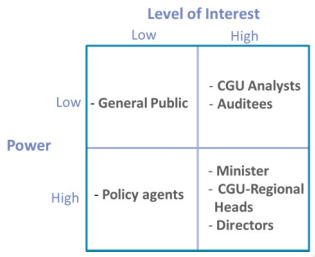

Figure 3: Power-interest matrix applied to an inspection action.

Ferretti (2016) shows that, under the existence of a plurality point of views, one needs to understand these differences, which requires the framework steps that follow.

3.3 Goals and Values Identification

Once the problem and the stakeholders are identified, one needs to have an understanding of the goals and values of the stakeholder(s). We can underline the concept of decision framing presented by Keeney (1992) which points out that values are used for evaluation and should reflect the decision-makers objectives. He highlights that there are two distinct types of objectives, the fundamental objectives and the mean objectives. While the former features an essential reason for the interest in the decision situation, the mean objectives are just a way to achieve them. As the author also emphasizes, structure objectives give the basis for any use of quantitative modelling and the fundamental objectives hierarchy can indicate the set of objectives over which attributes should be defined.

A structuring tool widely used in decision analysis is the value tree, which displays the family of key-concerns in a tree form and offers a useful visual overview of the main objectives in different levels of increasing specification (Bana e Costa, 2001; Bana e Costa et al., 2004). In Figure 4 we present a value tree with the fundamental objectives to be attained with an inspection action. For instance, the "Management Continual Improvement" objective is concerned with the assessment of the inspection program's objective component in terms of efficiency and technical quality as well as the agreement on the entities and the areas to be audited.

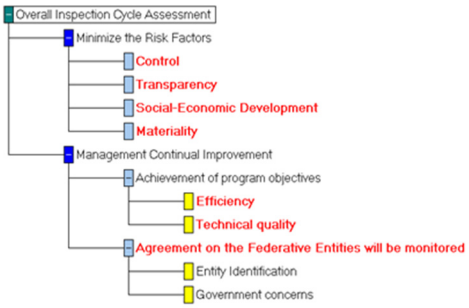

Figure 4: Value tree for an inspection action built with M-MACBETH.

At this stage, it is also important to look for the alternative's costs and identify the measurement criteria of alternative performances (expected benefits). One can make use of the framework for structuring options and areas and criteria presented in Montibeller et al. (2009). The authors propose two approaches to structuring criteria, based on Keeney's concepts: Alternative-focused thinking (AFT), which criteria are defined from the characteristics that distinguish options and Value-focused thinking (VFT), where the evaluation criteria should reflect the organization's values and strategic objectives.

3.4 Alternatives Identification

The identification of decision alternatives, which in auditing context means the identification of audit projects that will be evaluated, is an important step in the structuring process and can be performed through different techniques / tools.

In organizations segregated by pre-defined areas, where the initial set of project options is relatively stable, it can be used the AFT above described, in which, after problem definition, the projects are identified and, then, the values (criteria) to consider in the evaluation are specified. In turn, on the VFT, organizational values and goals are initially set. The options are then created thinking on how to achieve these goals (Keeney, 1992).

Another useful tool presented by Howard (1988) is the strategy-generation table. It shows how a total

strategy can be specified by combination of options under several dimensions, called strategy themes.

In turn, one may apply analysis of interconnected decision areas (AIDA) technique, present in Strategic Choice Approach (Friend and Hickling, 2005), that allows visualization of the compatibilities and incompatibilities of options within a problem focus.

One can still make use of cognitive map to explore/identify decision alternatives (Eden, 2004). Montibeller and Belton (2006) proposed the causal map, which can also be used to identify and agree to a set of potential strategic options. As the authors highlight, a causal map is a network of inter-linked concepts (ideas) which tries to represent the discourse of a person through means-ends structure, whereby decision options are means of achieving the decision-makers' goals.

In the CGU inspection case, since the projects to be evaluated depend on the definition of the federal state to be inspected and the audit scope, we can map the set of options surrounding the inspection program to gain a better understanding of the issues, their interrelations and perceived implications to the model to be built.

3.5 Uncertainties Identification

An analysis of which uncertainties are key for the evaluation of options and for the allocation of resources is required. To exemplify, uncertainties may be related with the budget, with the measurement of options performance and with the importance/weight of objectives.

Vilkkumaa et al. (2014) make a Bayesian modelling of uncertainties, to be considered in the selection of project portfolios. There is still another classification in Strategic Choice Approach to identify the uncertainties relating to the working environment, related to the guiding values and related to the choices in related agendas (Friend and Hickling, 2005). Thus, different uncertainty types may require different analysed with the prioritization and/or optimization modelling approaches.

In the auditing context, as highlighted by Krüger and Hattingh (2006, p.62), we can mention that "*risk is seen as a measure of uncertainty and is linked to the possible loss in an audit area — uncertainty in achievement of business objectives. The possible loss in an audit area will depend on specific characteristics and these characteristics are termed audit risk factors. Examples of well known and frequently used risk factors include complexity of operations, financial implications, recent changes, time since last audit, etc.*" – these issues should be discussed for each context and have naturally an impact on the MRAM to be developed.

In the CGU example, a relevant audit risk factor to be considered in the model may be related to the uncertainty in estimate the project (control actions) values to be included in the inspection program portfolio.

3.6 Constraints Identification

It is also necessary to identify constraints that may be relevant for the allocation of scarce resources to competing projects. For instance, there may be resources/budget restrictions, synergies between projects or interdependencies between projects.

At this stage, in a brainstorm session/focus group, one can use VFT to elicit the main constraints involved in the decision problem by equations (Keeney, 1992). AIDA can also help with Option Bars that bring the incompatibilities that can be translated into equations to be added to the value model used (Friend and Hickling, 2005).

In the CGU case, it is important to consider the following constraints:

Budgetary. Identify financial cost of each control action and prioritize projects within the available budget, so as to be accounted for in equation (3).

Logistical. The distribution of teams available for each control action needs to be accounted for (e.g., equipment, vehicles, and special displacements). Whereas h_{kj} the amount of resources k consumed by the project j and H_k the total available resources k. It has been:

$$\sum_{j=1}^{n} h_{kj} l_j \leq H_k \tag{6}$$

Context. Projects of entities identified as vulnerable should be positively discriminated. Be the corresponding v project to the federal entity identified as vulnerable, one should have:

$$l_v = 1 \tag{7}$$

3.7 Interactions between the Stages

To complete the structuring process, one cannot apply the framework without considering the joint analysis of different framework stages, as these are key to select and/or develop MRAM. Table 1 summarises techniques and tools included in the proposed framework. The diagonal includes techniques and tools previously described, and the remainder cells provide tools that can assist more complex analyses.

Table 1: Selection of techniques and tools that can assist structuring (crossing framework stages).

	Stakeholders	Goals and Values	Alternatives	Uncertainties	Constraints
Stakeholders	Stakeholder Power-interest Grid Stakeholder Visualization Influence Map	Negotiation Analysis Drama Theory	Conflict Dissolution Drama Theory		
Goals and Values	Negotiation Analysis Drama Theory	Value Tree Decision framing Fundamental Objectives Hierarchy	Value Tree Causal Map and MCDA	DSS PROBE RPM	
Alternatives	Conflict Dissolution Drama Theory	Value Tree Causal Map and Multicriteria Decision Analysis (MCDA)	Cognitive Map SCA AFT, VFT Strategy Table		AIDA in SCA RPM
Uncertainties		DSS PROBE RPM		Bayesian modelling SCA Risk Factor Analysis	
Constraints			AIDA in SCA RPM		Brainstorm Focus group VFT AIDA in SCA

For instance, different stakeholders (single, multiple, group) can lead to different goals and values and can generate different sets of alternatives and criteria.

In this situation, it may be useful to apply conflicts dissolution modelling techniques to have an understanding for possible win-win solutions, which are often used for evaluation models but can be adapted to the structuring context. (Bana e Costa et al., 2001; Edwards et al., 2007)

As implications for resource allocation models, we can cite:

- **Multiply stakeholders:** Preparation of a cognitive map to every stakeholder, analysis of common and divergent characteristics. Conducting focus group/brainstorming sessions for the preparation of an aggregated map (Ferretti, 2016). The use of bargain negotiation/drama theory (Edwards et al., 2007; Rosenhead and Mingers, 2001) can be useful.
- **Group of stakeholders**: The necessity for using techniques conflict dissolution in brainstorming session/focus group (Bana e Costa, 2001; Bana e Costa et al., 2001; Salo, 1995).

Regarding uncertainties, it may be related to the objectives and values, since the weights of the criteria might influence the project consequences - in this case robustness analysis and impact measurement can be used.

Thus, the result to be presented will be determined by the whole process and possibly different MRAM may emerge. Therefore, the modelling approaches presented in Section 2 may need to be enhanced and developed for the context.

4 DISCUSSION

This paper combined decision making techniques and tools to support the structuring of multicriteria resource allocation models for the auditing context, in an attempt to aid stakeholders involved in the auditing decisions and which are pressured and charged for transparency and accountability in public spending.

The application of the framework requires thinking about which decision-makers and stakeholders should be directly involved in each framework stage, together with a facilitator/consultant, an analyst, an recorder and/or others necessary roles in the process (Richardson and Andersen, 1995). This is necessary so that decision-makers will have confidence in MRAM results.

For future research, it is relevant: to extend the concepts and techniques to be used in the distinct framework stages; to systematically apply the framework for well-defined decisions at CGU and in other real-world auditing contexts; and, to measure the added value of using the framework.

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