Decision-making in the purchase of equipment in agricultural research laboratories: a multiple-criteria approach under partial information

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CHRONICLE	ABSTRACT
	Investments in the agricultural sector represented by innovations and new technologies strongly influence the economic growth in developing countries. In this context, purchasing decisions have become more relevant. Multiple-criteria decision-making techniques are well suited for decision-makers (DMs) who are considering the introduction of new technologies. In this paper, a multi-criteria model is built to help a Colombian agricultural research company make decisions on purchasing different laboratory equipment. A compensatory approach based on trade-offs is used to elicit the preferences of a group of DMs. The high number of answers and cognitive effort required from them during the elicitation process led to using an alternative approach based on partial information, called the FITradeoff (The Flexible and Interactive Tradeoff) method. It showed to be the best fit to solve the company's purchasing problem and allowed its managers to make decisions that consider criteria other than price, taking account of the DMs' conflicting viewpoints. The proposed model aimed at contributing to the articulation of the end-user knowledge in decision-making in order to ensure effective articulation of actors and strengthening of science, technology and innovation in agriculture.

1. Introduction

Investments in research and development related to the agricultural sector have led to the adoption of best practices and policies contributing to poverty reduction and increasing future food security (Andersen, 2015; Thornton et al., 2017). The outputs of such investments coupled with the timely adoption of new technologies that have contributed to major improvements made in agricultural productivity (FAO, 2017; Fuglie, 2018), thereby boosting agribusiness and economic growth in developing countries (Tan et al., 2006). Since agricultural productivity depends critically on investments that lead to innovation (Cai et al., 2017), several agricultural research firms have been seeking to upgrade their competitiveness by applying technologies that strengthen their supply chain management, improve the market and services, and reduce costs (Adenle et al., 2017). The success of such actions depends on the development and transfer of technologies (Elahi et al., 2018), requiring continuous capital investment over a long period (Kim et al., 2008). Investments in technical equipment, for example, involve the entire purchasing decision-making process, as this must consider global costs, input quality, innovation, flexibility, and the risk profile of the company (Kaufmann & Gaeckler, 2015). To illustrate how investments in equipment influence good agriculture practices, Adenle et al. (2017) refer to what happens in most African countries. The lack of laboratory equipment for testing and certification services and the precarious state of some equipment create barriers that hinder agricultural products from these countries entering the global supply chain.

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Although innovation combines different aspects, such as organizational, economic, and social factors (Lamprinopoulou et al., 2014), much of the literature focused on agribusiness involves methods based on budgeting and economic evaluations, financial analysis parameters, systems accounting, and costs (Dimova et al., 2006; Kuehne et al., 2012; Sohn et al., 2015). As a result, decision-making processes are mainly influenced by the initial purchase costs, which tend to increase rapidly due to the constant developments in technology (Kim et al., 2009). Hindering the adoption of more advanced technology, despite its potential benefits (Tan et al., 2006). In this context, the use of operations research techniques to assist decision-making problems has increased, as pointed out by Borodin et al. (2016) and Soto-Silva et al. (2016). Multi-Criteria Decision-Making/-Aiding (MCDM/A) techniques, in particular, provide a systematic framework with prescriptions and recommendations for DMs who consider the introduction of new technologies relevant (Hayashi, 1998), allowing several conflicting factors represented by a set of criteria to be analyzed (Aissaoui et al., 2007). MCDM/A methods can be classified as compensatory or non-compensatory, depending on the form of compensation that arises when the criteria are aggregated (de Almeida et al., 2015). In his survey on MCDM/A methods for agricultural resource management, Hayashi (2000) emphasizes that both classes of methods have been applied for selecting or ranking alternatives in a wide range of agricultural decisions. Compensatory methods are based on the concept of compensation between criteria, i.e., lower performance in one criterion can be compensated by a better performance in another criterion in the set, while non-compensatory methods are based on procedures derived from outranking relations in which there are no compensating trade-offs among different criteria (Fishburn, 1976; Hayashi, 2000). There are many agriculture-related situations in which non-compensatory methods may be appropriate, as illustrated by Mendas and Delali (2012), Macary et al. (2014), Silva et al. (2014), Silva et al. (2015), and Schmitt et al. (2017). Non-compensatory methods have also been applied to the context of purchasing, considering contracts for outsourcing (de Almeida, 2007) and contracts for supply selection (Almeida, 2005). Compensatory approaches have been found in many applications. For instance, when selecting the most suitable crops and uses of land for agrarian areas (Cardín-Pedrosa and Alvarez-López, 2012); sizing the location for new agri-food warehouses (García et al., 2014); and choosing the most suitable grape variety for establishing a new vineyard according to the preferences of a group of DMs (Dragincic et al., 2015). Wa Mbũgwa et al. (2015) and Goodridge et al. (2017) can find other applications in agriculture of compensatory MCDM /A methods in the studies.

In this paper, an MCDM/A model is built in order to select the most appropriate supplier for three classes of equipment in a company dedicated to agricultural research. In a first step, the preferences of DMs from the company are introduced into the model by applying a compensatory approach based on trade-offs – the traditional trade-off procedure (Keeney and Raiffa, 1993). This approach requires complete information from DMs. However, this procedure is known to be difficult to implement in the real world because of the amount of cognitive effort required from the DMs (Hurson &Siskos, 2014; Danielson & Ekenberg, 2019). To overcome traditional trade-off procedure drawbacks, an alternative approach based on the FITradeoff method (de Almeida et al., 2016) is proposed. This method maintains the foundations of the traditional trade-off procedure while making use of partial information as a means to lower the cognitive effort required from the DMs, and overall, needing less information and saving time (Fossile et al, 2019). Even this method allows choosing the best alternative and even to rank all the rest of them, as applied in the food industry (Frej et al., 2019). The FITradeoff is applied in a purchasing case for laboratory equipment for agricultural research, due to the   technological updating importance in the research processes. Similarly, the MCDM and the DSS tools can optimize the processes for decision-making in other operations or purchasing processes in the company as a whole (Kechagias et al., 2020). Some studies have developed new methods to ease the DM process, focusing on simplicity, and user-friendliness mainly when the performance values in the alternatives are fuzzy (Abdulai & Turunen, 2021) Also combining different approaches, such as using partial information to estimate the criteria weight and to get the score function for the alternatives (Rani et al., 2021). However, the new MCDM methods developed need to be applied in real-life problems, mainly when the DMs consider that the process with traditional methods can be tedious, time–consuming, and possibly lead to an inconsistent result (Rodriguez et al., 2018) and to validate the method in different decision-making situations and under several points of view from different DM. In agricultural topics using Fitradeoff, Carrillo et al. (2018) analyze a problem for selection of technology packages in crop management, not considering the decisions process made internally by the organization to develop agricultural researches. The main contributions of the proposed model are:

i. Provide a reliable tool for decision-making, exemplified with a real case applied in management levels;
ii. Accommodate DMs' preferences based on a well-defined axiomatic structure while using a tool that is cognitively easier to understand and apply, thus contributing to the development of agricultural research processes.

The rest of this paper is organized as follows. Section 2 presents the study developed at a Colombian agricultural research company. The relevant aspects of the problem are analyzed in this Section, and the model is built. In Section 3, the model is applied by using an approach based on trade-offs to elicit preferences from the DMs. After that, an alternative approach based on partial information is put forward. In Section 4 the results obtained in the previous Section are discussed. Finally, some conclusions are drawn in Section 5.

2. Building the model

The study was conducted at the headquarters of the Colombian Corporation for Agricultural Research, located in the city of Mosquera, Cundinamarca, Colombia. The institution has more than 13 nationwide research centers dedicated to providing

technology solutions to local and regional agricultural problems. Nevertheless, they are constantly facing DM problems because of the need to optimize the limited public resources they manage and with the challenge to provide the researchers all necessary tools to develop the investigation processes successfully. The strengthening of institutional capacities is one of the strategies that have been proposed to improve the development and conduct of agricultural research activities. This is an opportune moment as the local government has made investments to stimulate agricultural production. This strategy is reflected in the infrastructure of the company's laboratories, which has been enhanced by replacing old equipment with one that is technologically up-to-date. Hence, it can generate innovation with respect to methodologies and knowledge. Even more in in pandemic times is necessary to optimize the purchasing process. In this context, the purchase of laboratory equipment has become a critical issue in the institution, since the outputs of this decision process directly influences the effective development of the company's agricultural research. In this regard, company's managers need to purchase three types of laboratory equipment, for which they will evaluate the most appropriate options according to different criteria and conflicting preferences of DMs. Thus, to assist the company managers, an MCDM/A model was built to evaluate different equipment in three cases (A, B and C). Thereby, to build the model dynamically, in which the problem structuring process is connected with the development and application of the model itself, the framework proposed by De Almeida et al. (2015) was applied together with the information provided by the company's specialists and the DMs' preferences. The main steps conducted to build the proposed MCDM/A model are presented below, ranging from the definition of DMs, objectives, criteria and potential suppliers to the mathematical basis on which relies the suggested multi-criteria evaluation.

2.1 Characterizing the DM and Other Actors

The director of the research laboratories is the person in charge of deciding on equipment purchases. In his absence, other actors, such as logistics or metrology professionals, laboratory leaders, purchasing analysts, and other equipment users are accountable to make a group decision. The decision process may also include specialists or researchers who will also use the equipment. They will provide information and express their opinions on the needs of the research project. Other actors influencing the process are the stakeholders, who will verify that the investments of resources will be used to support research, and the analyst or facilitator, who will be in charge of stimulating thinking and capturing the concerns of the actors involved and will be aware of group process issues (Belton and Stewart, 2002). To examine different points of view, seven DMs were assigned to each case, i.e., to make decisions on each process for purchasing equipment, and designated as $D_{A1}, ..., D_{A7}$ for case A, $D_{B1}, ..., D_{B7}$ for case B and $D_{C1}, ..., D_{C7}$ for case C. For each case, the set of DMs consists of a professional from each of the departments of purchasing, metrology and logistics, and four laboratory managers, who are not necessarily the same for all cases. Only for case A, a user of the equipment replaced the representative of the metrology department. For each one, the preferences of each DM were obtained by interviewing them individually and were incorporated into the model.

2.2 Identifying Objectives and Criteria

It is a critical step as the objectives and criteria stated here will influence each of the following steps... The identification, structuring, analysis, and understanding of the relevant objectives were carried out based on the judgments of the company's laboratory and purchasing managers, guaranteeing the quality of the decision-making process. The main objectives established are to improve the effectiveness of research activities and to contribute to enhancing the management of the budget, since it is a public company managing public funds. From these two main objectives, others were derived, as shown in Fig. 1, resulting in the nine criteria that represent the objectives of the decision process (Keeney, 1996) (see Table 1).
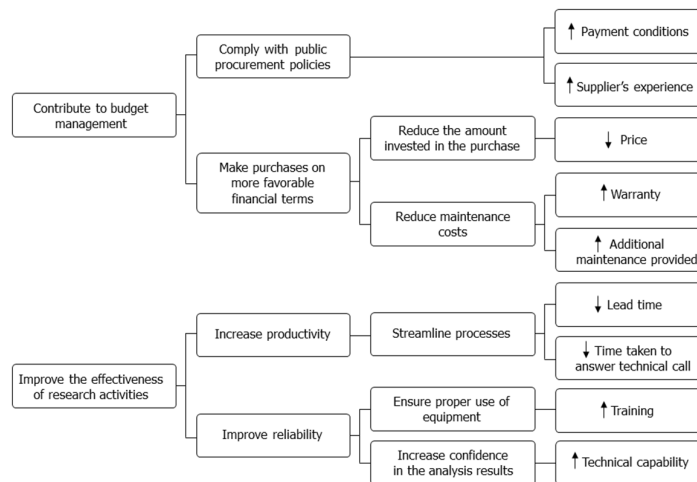

Fig. 1. Objectives and related criteria of the problem.

It is worth mentioning that not all the objectives and criteria in Fig. 1 were considered in every cases and by every DM. For example, the objective of ensuring the equipment's proper use and its corresponding criterion of training (C_8) was considered only in case B, because for case A the equipment was considered simple, and users found it easy to handle, particularly for case C. Even though the equipment was expensive, it is a standard system that does not require special training. Likewise, the objective of complying with public procurement policies and the related criteria of payment conditions and the supplier's experience (C_1 and C_2) were considered in case C but not in cases A and B. This can be justified by the fact that it is only the cost of the type of equipment that is considered in case C that exceeds the government's threshold price for purchases by public enterprises; consequently, this purchase process, in particular, requires additional documents and conditions to support the transaction.

Table 1

Set of criteria considered in the problem.

Criteria	Nomenclature	Explanation
Payment conditions	C_1	Evaluates the conditions offered by the supplier with regard to making payments.
Supplier's experience	C_2	Evaluates how the supplier conducts the service, and takes into consideration whether the supplier has previously had contracts and/or sales with the company, or can prove it has sold the same or similar equipment to other customers.
Price	C_3	Sale price of the equipment.
Warranty	C_4	The period during which the supplier is responsible for technical failures because of manufacturing or operating defects.
Additional maintenance provided	C_5	Number of preventive maintenance actions on the equipment provided by the supplier at no additional cost.
Lead time	C_6	Number of days between the purchase of the equipment and its installation in the laboratory.
Time taken to answer technical call	C_7	This refers to the maximum time the supplier takes to answer a technical call.
Training	C_8	Number of days offered by the supplier for user training on how to handle the equipment.
Technical capability	C_9	Evaluates the supplier's compliance with technical specifications. The set of technical specifications comprises the minimum characteristics, such as size, material, description of the electrical system, and quality norms.

2.3 Establishing the Set of Alternatives

In this step, an initial set of suppliers available in the national market was pre-selected in order to find those able to provide the laboratory equipment. Based on this pre-selection, for each case seven suppliers were considered as the potential solutions to the purchase problem: for case A, the set of potential suppliers $S_A = \{s_{A1}, s_{A2}, s_{A3}, s_{A4}, s_{A5}, s_{A6}, s_{A7}\}$; for case B, set $S_B = \{s_{B1}, s_{B2}, s_{B3}, s_{B4}, s_{B5}, s_{B6}, s_{B7}\}$, and finally $S_C = \{s_{C1}, s_{C2}, s_{C3}, s_{C4}, s_{C5}, s_{C6}, s_{C7}\}$ for case C. In this context, the decision problem refers to choosing the best supplier from the set of potential ones (Roy, 1996). The evaluations p_{ij} made of each supplier i concerning each criterion j are shown in the matrices of consequences in Tables 2, 3 and 4 for cases A, B and C respectively.

Table 2

Consequences matrix for case A

Suppliers	Criteria			
	C_3	C_4	C_6	C_9
s_{A1}	595.0	24	120	8
s_{A2}	440.8	12	30	6
s_{A3}	624.3	12	30	4
s_{A4}	396.7	18	60	8
s_{A5}	453.5	12	60	8
s_{A6}	379.3	12	45	6
s_{A7}	674.3	24	90	8
Unit	USD$	Months	Days	Units

Table 3

Consequences matrix for case B

Suppliers	Criteria					
	C_3	C_4	C_6	C_7	C_8	C_9
s_{B1}	8,426.0	24	90	24	1	10
s_{B2}	6,550.0	18	45	24	2	13
s_{B3}	6,425.0	12	60	24	3	12
s_{B4}	7,965.9	24	90	72	2	16
s_{B5}	6,694.0	12	60	72	1	16
s_{B6}	7,794.5	12	90	48	3	13
s_{B7}	7,645.7	12	90	72	1	12
Unit	USD$	Months	Days	Hours	Days	Units

Table 4
Consequences matrix for case C

Suppliers	Criteria							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_9
s_{C1}	3	2	121,333.3	1	1	120	24	49
s_{C2}	2	3	91,736.7	1	0	90	24	19
s_{C3}	3	2	117,610.0	3	0	90	48	37
s_{C4}	3	3	76,133.3	2	2	60	24	41
s_{C5}	2	2	70,000.0	1	0	90	72	32
s_{C6}	1	1	63,333.3	1	0	60	72	27
s_{C7}	1	1	61,716.7	2	2	60	72	33
Unit	Points	Points	USD$	Years	Units	Days	Hours	Units

2.4 Preference Modeling

This step belongs to the second phase of the procedure for building the MCDM/A model and is a relevant step for choosing the MCDM/A method that will be applied. To represent the DMs' preferences appropriately in the problem under study, strict preference (P) and indifference (I) binary relations should be assumed (Vincke, 1992), and the property of transitivity must be respected. Likewise, compensatory rationality is assumed in this problem, to the extent that the poor performance of a supplier in a particular criterion can be compensated by high performances in other criteria (de Boer et al., 1998). In accordance with the above-mentioned aspects, it was concluded that an MCDM/A method based on MAVT (Multi-Attribute Value Theory) would be convenient for this situation. In this theory, strict preference and indifference relations are admitted, since the overall scores v_{s_1} and v_{s_2} associated with each potential supplier s_1 and s_2 are such that $s_1 P s_2 \Leftrightarrow v_{s_1} > v_{s_2}$; $s_2 P s_1 \Leftrightarrow v_{s_2} > v_{s_1}$ and $s_1 I s_2 \Leftrightarrow v_{s_1} = v_{s_2}$, and the property of transitivity is also respected. Taking into account other characteristics of the decision, the DMs, and the time available for carrying out the process (Keeney and von Winterfeldt, 2007), the additive model was used to aggregate the criteria because it is relatively easy to implement, since it is based on weighted sums, and produces useful and reasonably reliable data (Kaliszewski & Podkopaev, 2016). Finally, an MCDM/A approach under both MAVT and the additive model was applied. For this approach, the trade-off procedure was used to elicit criteria weights (Keeney and Raiffa, 1993). Afterwards, the FITradeoff method (de Almeida et al., 2016) was used as an alternative approach in order to overcome some of the shortcomings found.

2.5 Intra-criterion Evaluation

A linear marginal value function v_j was used for all criteria j (Edwards and Barron, 1994) to associate the consequence values p_{ij} of suppliers on criteria to a point with a new scale ranging from zero to one. The normalization procedure used is shown in Eq. (1), creating a new interval scale in such a way that the best (B_j) and worst (W_j) performances are associated with values one and zero, respectively (de Almeida et al., 2015).

$$v_j(p_{ij}) = (p_{ij} - W_j)/(B_j - W_j) \tag{1}$$

The criteria of Price, Lead time and Time taken to answer a technical call are minimization criteria (indicated by the down arrow in Fig. 1), meaning that the marginal value functions for these criteria decrease monotonically against the natural scale, i.e., a lower value of consequence in these criteria is more desirable. The remaining criteria are the maximization ones, since the greater the value of a consequence, the more preferable it is.

2.6 Inter-criteria Evaluation

In order to obtain a global evaluation for the suppliers, the analysis was based on the additive model. When this model is used, the global score v_{s_i} given to a supplier s_i is calculated according to Eq. 2 (Keeney and Raiffa, 1993), which returns the weighted sum of the supplier's performance in each of the n criteria.

$$v_{s_i} = \sum_{j=1}^{n} w_j v_j(p_{ij}) \tag{2}$$

where w_j is the weight of a criterion j, for which $\sum_{j=1}^{n} w_j = 1$ and $w_j > 0, j = 1, \ldots, n$.

The criteria weights w_j play a substantial role in MCDM/A since their meaning refers not only to the importance of criteria but is also related to the range of performance values of competitor suppliers on the criteria (Weber & Borcherding, 1993; De Almeida et al., 2015). This elicitation process is explored in detail in the following section.

3. Application of the model

The application of the model was carried out by interviews with each DM separately. First of all, the criteria weights for each purchase case were ranked by the corresponding DMs. Table 5 shows the rankings obtained, where w_j represents the weight of a criterion C_j in Table 1.

Table 5

Rankings of criteria weights for all cases and DMs.

Case					
A		**B**		**C**	
DM	Ranking	DM	Ranking	DM	Ranking
D_{A1}	$w_3 > w_6 > w_9 > w_4$	D_{B1}	$w_9 > w_3 > w_7 > w_8 > w_4 > w_6$	D_{C1}^*	$w_9 > w_2 > w_5 > w_4 > w_3 > w_6 > w_7$
D_{A2}	$w_9 > w_3 > w_6 > w_4$	D_{B2}	$w_9 > w_8 > w_7 > w_4 > w_3 > w_6$	D_{C2}	$w_3 > w_9 > w_4 > w_2 > w_6 > w_7 > w_5 > w_1$
D_{A3}	$w_9 > w_3 > w_4 > w_6$	D_{B3}	$w_9 > w_4 > w_3 > w_8 > w_7 > w_6$	D_{C3}	$w_9 > w_4 > w_2 > w_7 > w_5 > w_3 > w_6 > w_1$
D_{A4}	$w_9 > w_6 > w_3 > w_4$	D_{B4}	$w_9 > w_3 > w_7 > w_6 > w_8 > w_4$	D_{C4}	$w_9 > w_2 > w_3 > w_7 > w_6 > w_5 > w_1 > w_4$
D_{A5}	$w_6 > w_3 > w_4 > w_9$	D_{B5}	$w_3 > w_6 > w_4 > w_8 > w_7 > w_9$	D_{C5}	$w_3 > w_6 > w_1 > w_2 > w_4 > w_9 > w_5 > w_7$
D_{A6}	$w_9 > w_4 > w_3 > w_6$	D_{B6}	$w_9 > w_4 > w_3 > w_7 > w_8 > w_6$	D_{C6}^*	$w_9 > w_4 > w_3 > w_7 > w_5 > w_2 > w_6$
D_{A7}	$w_9 > w_6 > w_3 > w_4$	D_{B7}	$w_9 > w_4 > w_6 > w_7 > w_8 > w_3$	D_{C7}	$w_9 > w_7 > w_5 > w_4 > w_2 > w_6 > w_3 > w_1$

*The DM did not consider criterion C_1 in the elicitation process.

3.1 A Tradeoff-Based Approach

Given the rankings in Table 5, the trade-off procedure (Keeney & Raiffa, 1993) is applied in order to obtain exact values for the criteria weights, which are then used in the additive model (Eq. 2) to associate a global value with each supplier. In this procedure, based on strict preference and indifference binary relations, two hypothetical alternatives, a and b, are presented to the DM, who must express his/her preferences with respect to them. Alternative a has an intermediate performance value p_{aj} in criterion j and the worst performance values in the remaining ones, while alternative b has the best performance in the criterion after j in the ranking and the worst performance values in the other criteria. When such questions are asked, the purpose of the procedure is to find, for each pair of consecutive criteria in the ranking, two alternatives a and b in such a way that the DM is indifferent between them. This can be accomplished by both changing the $p_{aj} \in (W_j, B_j)$ performance value until the DM feels indifferent between a and b, or asking the DM directly for the indifference point. In either case, when an indifference point $x_j^I = p_{aj}$ is found, the relation in Eq. 3 is obtained, since the indifference binary relation and properties in MAVT remain unchanged, and Eq. (1) normalizes the worst and best performance values for each criterion.

$$w_j v_j(x_j^I) = w_{j+1} \qquad (3)$$

Fig. 2 illustrates for case A and DM D_{A1} how the procedure works. Initially, the hypothetical alternatives are compiled taking into account the first pair of criteria in the ranking: C_3 and C_6. Regarding a and b, DM D_{A1} has to establish where the indifference point $x_3^I = p_{a3}$ is. Similarly, D_{A1} is expected to establish the indifference points $x_6^I = p_{a6}$ and $x_9^I = p_{a9}$ for the pairs of criteria C_6 and C_9 and C_9 and C_4. The indifference points found lead to three relations similar to that in Eq. 3. The fourth relation that is needed to solve the system of linear equations, and thus to obtain the exact values for the four criteria weights, is given by normalizing these weights, the sum of which must be one. In general, given a set of n criteria, the DM must set $n - 1$ exact indifference points in the trade-off procedure so that the additive model can be applied.

Fig. 2. Questions in the trade-off procedure – example for Case A, DM D_{A1}.

Table 6 shows, for the cases A, B and C, the values of the criteria weights obtained by applying the trade-off procedure with each DM.

Table 6
Criteria weights obtained by the trade-off procedure

Case	DM	Criteria Weights								
		w_1	w_2	w_3	w_4	w_5	w_6	w_7	w_8	w_9
A	D_{A1}	-	-	0.69245	0.04481	-	0.17311	-	-	0.08963
	D_{A2}	-	-	0.26013	0.00462	-	0.04157	-	-	0.69368
	D_{A3}	-	-	0.29689	0.10092	-	0.00841	-	-	0.59378
	D_{A4}	-	-	0.12130	0.02963	-	0.36389	-	-	0.48518
	D_{A5}	-	-	0.06038	0.02264	-	0.90566	-	-	0.01132
	D_{A6}	-	-	0.08478	0.16956	-	0.06741	-	-	0.67825
	D_{A7}	-	-	0.04870	0.01217	-	0.43826	-	-	0.50087
B	D_{B1}	-	-	0.31370	0.01876	-	0.00938	0.15008	0.03752	0.47055
	D_{B2}	-	-	0.03193	0.06386	-	0.01015	0.12772	0.25544	0.51089
	D_{B3}	-	-	0.13070	0.26141	-	0.00020	0.02829	0.05658	0.52282
	D_{B4}	-	-	0.23366	0.03130	-	0.07825	0.11179	0.06260	0.48240
	D_{B5}	-	-	0.85333	0.02133	-	0.10667	0.00533	0.01067	0.00267
	D_{B6}	-	-	0.07147	0.21440	-	0.01144	0.03661	0.02288	0.64320
	D_{B7}	-	-	0.00008	0.22189	-	0.11095	0.00125	0.00016	0.66568
C	D_{C1}	0*	0.27586	0.03448	0.06897	0.13793	0.01724	0.00575	-	0.45977
	D_{C2}	0.00165	0.05285	0.65270	0.10571	0.00330	0.02643	0.01321	-	0.14415
	D_{C3}	0.00088	0.13417	0.00787	0.26834	0.01574	0.00276	0.06709	-	0.50315
	D_{C4}	0.00725	0.31275	0.15637	0.00363	0.01450	0.02417	0.03453	-	0.44678
	D_{C5}	0.03856	0.01928	0.81263	0.00964	0.00120	0.11567	0.00060	-	0.00241
	D_{C6}	0*	0.00903	0.15301	0.30601	0.01806	0.00451	0.07223	-	0.43716
	D_{C7}	0.00272	0.01924	0.00321	0.03849	0.07698	0.00962	0.34989	-	0.49985

*The DM did not consider the criterion in the elicitation process.

Table 7 shows the final results obtained for each DM in each case by applying the approach based on the additive model and for which the trade-off procedure is used to elicit the criteria weights. The trade-off procedure is based on a strong theoretical foundation. However, setting the points that yield indifference between the hypothetical alternatives is critical in this procedure (Weber and Borcherding, 1993), and it is hard to implement it in the real world because of the amount of cognitive effort required from the DM (Hurson and Siskos, 2014). To overcome these drawbacks, in the next subsection an alternative approach based on the FITradeoff method is proposed. This method maintains the foundations of the traditional trade-off procedure while making use of partial information in order to lower the cognitive effort required from the DM.

3.2 An Alternative Approach Based on Partial Information

As mentioned before, the weights of criteria are crucial parameters that need to be estimated in MCDM/A models (Fischer, 1995), but difficulties arise, both in their interpretation and weight assessment procedures since these tend to be time-consuming, difficult, and boring for respondents (Hayashi, 2000). In addition, when dealing with agriculture-related problems, imprecision may arise due to time pressure and insufficient data, and methods are needed to take into account such characteristics (Hayashi, 1998). To deal with such critical issues, the FITradeoff method (de Almeida et al., 2016) is used in an attempt to lower the cognitive effort spent by the DMs during the process and reach a solution for the problem. This method conducts a flexible and interactive elicitation process. Similar to the trade-off procedure, at each interaction with the DM, this method presents two hypothetical alternatives, a and b, referring to which he/she is expected to express his/her preferences. If the DM prefers a over b, then the relation in Eq. 4 is obtained; otherwise, Eq. 5 is obtained. Thus, the purpose of the elicitation process conducted in the FITradeoff method is not to find exact indifference points x_j^I in order to obtain the criteria weights. Even with the x_j^I values being unknown, the preference statements given by the DM allow there to be informed about the lower and upper limits $x_j^{I'''}$ and $x_j^{I'}$ around x_j^I, which are used to restrict the values that the weights can assume.

$$w_j v_j\left(x_j^{I'}\right) > w_{j+1} \tag{4}$$

$$w_j v_j\left(x_j^{I''}\right) < w_{j+1} \tag{5}$$

The method uses each new level of information obtained from a DM's preferences to narrow the space of weights, that is, to reduce the possible values that the criteria weights can assume. The FITradeoff method then checks the potential solutions for each updated space of weights. These potential solutions are called current results, meaning that they are the results

obtained, given a certain level of partial information. This process is carried out until there is only one potential solution or until the DM chooses to stop the process since the current outcomes are sufficient for his/her purposes. Fig. 3 illustrates how the flexible elicitation process is conducted in FITradeoff.
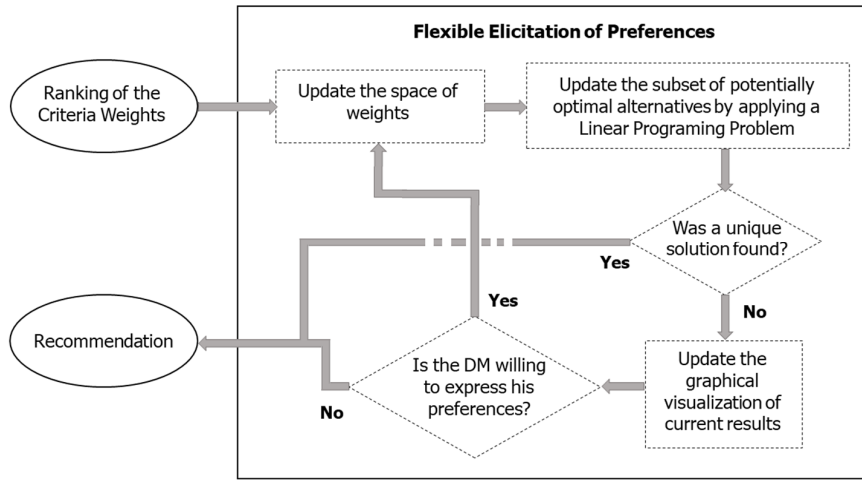

Fig. 3. Flexible elicitation process conducted at FITradeoff

As a result, to define the potential solutions, given a space of weights, the method uses the concept of potentially optimal alternatives. An alternative s_i is potentially optimal if and only if there is a point in the space of weights such that the overall value of s_i that is given by the additive model (Eq. 2) is at least as good as the overall value of all other competing alternatives (Eum et al., 2001). A linear programing problem is applied in order to verify a potential alternative. If alternative s_i is not potentially optimal for a space of weights φ^n, then it will also not be for a space of weights $\varphi^{n\prime} \subset \varphi^n$ which will be obtained after a future interaction with the DM. Thus, if s_i is not potentially optimal for a certain space of weights, it is discarded from the subset alternatives, and is no longer taken into account in future interactions. An important feature of the DSS (Decision Support System) of the FITradeoff method is that it allows the DM to track the updates in the subset of potentially optimal alternatives through graphical visualization. This can help him/her to have a better understanding of the problem and speed up the decision-making process. Furthermore, the FITradeoff elicitation process is flexible. The DM does not need to follow a rigid sequence of questions and answers. Instead, the method allows him/her to skip doubtful questions and adapt the process to the decision context. Tables 8, 9, and 10 indicate the number of questions required for each DM to obtain a subset with the corresponding number of potentially optimal alternatives. They show the evolution of the subsets as more information is obtained from each DM. As an example, for case A and DM D_{A1} in Table 8, at the beginning of the elicitation process, when zero questions were answered, only two alternatives remained in the subset as potential solutions. As the DM answered more questions, both alternatives remained in the subset. This happened until the ninth question was answered when a space of weights was generated in which only one alternative was a potential solution. Fig. 4 shows the graphic visualization of current results at the beginning of the process for this case and DM. As can be seen, for this level of information, suppliers s_{A4} and s_{A6} were the potential solutions. The graph allows the DM to compare the performances of both suppliers against the criteria considered proportionally. Notice, for example, that both suppliers have similar performances on the criterion of Price, while s_{A4} wins in the criteria of Technical capability and Warranty, and s_{A6} wins in the criterion of Lead time. In some situations, this kind of information can be useful. Specially, in this case, should the DM prefer s_{A6} over s_{A4}, he/she would not need to answer the other nine questions.

Table 8
FITradeoff current results for case A.

DM	Number of Potentially Optimal Alternatives			
	4	3	2	1
D_{A1}	-	-	0	9
D_{A2}	0	-	-	5
D_{A3}	0	-	-	2
D_{A4}	0	-	2	6
D_{A5}	0	2	3	9
D_{A6}	0	-	-	5
D_{A7}	0	-	2	11

Table 9
FITradeoff current results for case B

DM	Number of Potentially Optimal Alternatives				
	5	4	3	2	1
D_{B1}	-	0	4	5	12
D_{B2}	0	-	2	3	4
D_{B3}	-	-	0	2	3
D_{B4}	-	0	2	7	9
D_{B5}	-	-	-	0	12
D_{B6}	-	-	0	3	7
D_{B7}	-	-	0	3	7

Table 10
FITradeoff current results for case C

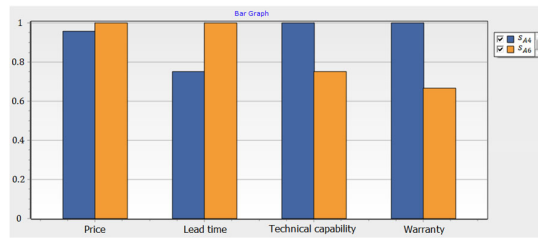| DM	Number of Potentially Optimal Alternatives		
	3	2	1
D_{C1}	-	0	3
D_{C2}	-	0	9
D_{C3}	0	2	4
D_{C4}	-	0	3
D_{C5}	-	0	9
D_{C6}	0	2	8
D_{C7}	-	0	10

Fig. 4. Current results for DM D_{A1} at the beginning of the elicitation process

The final solutions obtained by using the FITradeoff method for each DM and case remained the same as those obtained by applying the approach based on trade-offs, shown in Table 7.

4. Discussion of Results

Although great relevance is given to the criterion of Price regarding agricultural applications, in this study, its corresponding weight does not have the greatest value for all DMs, as shown in Table 5. This can be explained by the fact that the DMs consider other aspects besides the purchase price that would influence the company's future research activities. The results suggest that the more expensive the equipment, the greater the concern about meeting other criteria. This reflects the company's concern for consciously purchasing, bearing in mind the medium and long-term benefits associated with the economic investment made, and after carefully analyzing criteria such as warranty, maintenance, and a supplier's experience. Building the MCDM/A model by using a structured framework has aided DMs both to think objectively about the problem and to understand their role in the decision-making process. As shown in Table 7, for case A, supplier s_{A4} obtained the best overall score for five of the seven DMs. In case B, supplier s_{B4} won for four of the seven DMs. Supplier s_{C4} also won for four of the seven DMs in case C. For that reason, the company's managers could use this information to make purchases that meet the DMs' expectations and concerns in several criteria. Thereby, reaching a compromise solution. Table 11 compares the number of questions required by each approach to find the solutions for each case and DM. Overall, the FITradeoff method required DMs to answer fewer questions, which implies that DM time was saved. Additionally, FITradeoff DSS has the advantage of presenting the current results to DMs, which can help them to have a better view of the problem and the progress during the process. Note also from Table 7 that at the start of the FITradeoff elicitation process for case A, the subset of potential solutions was already reduced from seven to not more than four. Similarly, for cases, B and C, when no question was yet answered, based only on the rankings of criteria weights, the number of potentially optimal alternatives was reduced to not more than five and three, respectively.

Table 11
Comparison Trade-off results vs. FITradeoff for case A

Case								
	A			B			C	
DM	Trade-off	FITradeoff	DM	Trade-off	FITradeoff	DM	Trade-off	FITradeoff
D_{A1}	12	9	D_{B1}	14	12	D_{C1}	14	3
D_{A2}	10	5	D_{B2}	12	4	D_{C2}	12	9
D_{A3}	10	2	D_{B3}	12	3	D_{C3}	12	4
D_{A4}	8	6	D_{B4}	10	9	D_{C4}	10	3
D_{A5}	11	9	D_{B5}	14	12	D_{C5}	14	9
D_{A6}	9	5	D_{B6}	12	7	D_{C6}	12	8
D_{A7}	10	11	D_{B7}	10	7	D_{C7}	10	10

Although both approaches used in the case study are based on MAVT and the additive model and led to the same final results, some differences were found during their elicitation processes. When using the trade-off procedure, the DMs found it difficult to identify the exact indifference points, and some answers given were not consistent with the ranking of criteria weights, resulting in more time and effort being spent during the process. The application of the FITradeoff method, on the other hand, did not require DMs to establish exact indifference points by DMs. Comparatively; these were based on strict preference relations and did not let DMs be inconsistent in their answers. Thus, the FITradeoff method is a useful tool for the problem under study. One of the main needs for a developing country such as Colombia is to promote the transformation of the countryside by employing tools that make agricultural activities a source of wealth for farmers (Cotes et al., 2012). For this, it is necessary to articulate end-user knowledge with agile information mechanisms that facilitate decision-making and result in an effective articulation of actors and strengthening of local science, technology and innovation systems. Accordingly, there is a need to support services that meet the needs of producers. For instance ensuring the efficient use of

land and water resources obtaining commercial use for agriculture, which is achieved through the development of instruments aimed at the efficient use of the soil on appropriate scales (represented by decision-making tools based on real-life examples) considering the real producers' demands and the particularities of their productive systems (Dietze et al. 2019). In this context, the proposed model aims to support DMs through a reliable tool based on partial information for decision-making, contributing to the development of agricultural research processes.

5. Conclusions

In this paper, a model was developed to help managers from an agricultural research company to purchase laboratory equipment. The model takes multiple criteria and the concerns and preferences from different DMs into account. Even though the price is one of the most reviewed criteria in the literature, in this case, the study did not have overriding relevance when compared to the other criteria. This was because DMs were asked to specify other criteria that helped the company to achieve its strategic objectives and this study shows that these DMs consider that other criteria can be of greater importance than price. In other words, this case study demonstrates that the value to a company of positive attributes of a given supplier may outweigh the financial advantage of the same equipment, being offered more cheaply by one or more of the company's other suppliers, and therefore criteria other than price should normally be considered in this type of problem. The proposed model was implemented by applying the additive model with an elicitation procedure so as to obtain the criteria weights, and an alternative approach based on the FITradeoff method was also used. These two approaches are based on MAVT. However, the former requires complete information from DMs, while the latter only requires partial information regarding the criteria weights. The results obtained by both approaches were compared as well as the cognitive difficulties faced by the DMs during the elicitation processes. It was found that the FITradeoff method is a good option for overcoming some difficulties that were found when the trade-off procedure was applied.

Conflict of interest

The authors declare that there is no conflict of interest.

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