Paper

A Level-Based Approach to Prioritize Telecommunications R&D

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Abstract—In this paper, an approach to evaluate R&D projects in telecommunications is presented. These projects have particular features that cannot be properly incorporated by classical evaluation methods. This approach incorporates different criteria, both quantitative and qualitative, and also management flexibility and uncertainty. Thus, it is an approach that can be applied to real data of R&D projects in a telecommunications company.

Keywords— multicriteria decision support, R&D project evaluation.

1. Introduction

Research and Development (R&D) projects in telecommunications have particular features that cannot be properly incorporated by classical evaluation methods. A correct evaluation of these projects must consider different criteria, both quantitative and qualitative, and moreover, management flexibility and uncertainty. The purpose of this paper is to present an approach to evaluate R&D projects in telecommunications. In these projects, there is much uncertainty, especially associated with management flexibility: it is necessary to make decisions under an environment of uncertainty. For example, it is necessary to decide when to start a project or when to launch a product. In other occasions, it is important to decide if there are reasons to abandon a project. There are several methods that evaluate R&D projects; in this paper, we present an approach that takes into account the specific structure of a telecommunications company.

The approach presented in this paper considers two levels of decision: the activity and the aggregate. An activity is a set of tasks with specific objectives and characteristics. It is planned at short term. An aggregate is a set of connected activities that are oriented towards a specific product or service. It is planned in the medium term (normally, 4 or 5 years).

In R&D projects in telecommunications, there are different decision levels: top management level; aggregate level (project managers); or activity level (task managers). To incorporate and coordinate these decision levels, two structures were considered: one for activities and another for aggregates. These structures allow, at each level, the identification of the relevant criteria and their relative importance by the decision makers (DMs) of the respective level in the structure. This approach is inspired on the evaluation process developed for the British Aerospace Military Aircraft and Aerostructures, presented in [1]. To infer the relative importance of criteria in each level, DMs make comparisons among criteria. However, in the present approach, the number of comparisons is limited in order to avoid overloading the DMs with excessive information requests. This process is based on Harker [2] and on Saaty [3]. The evaluation of aggregates can be made one by one. If just one aggregate is under evaluation, it is compared against benchmark aggregates, previously defined by the top management. If several aggregates are evaluated individually against benchmark aggregates, the results can give a proxy of the attractiveness of each aggregate. If several aggregates are compared among themselves, a relative performance proxy can be obtained. These proxy values are the basis for allocating human resources among the aggregates, providing managers with a global guide when deciding which projects to pursue and the level of activity in each of those projects.

The activities structure also has different levels of criteria. For each level, the respective DMs identify the relevant criteria and its relative importance. Activities are also evaluated in a process based on comparisons among themselves. These comparisons are made in each criterion. A global performance index is obtained for each activity. Note that each activity belongs to an aggregate. This value is used to help to determine the human resources allocation level of each activity, taking into account the resources allocated to the respective aggregate.

To test this approach, a prototype was created with two files (one to evaluate aggregates and another to evaluate activities) in "Microsoft Excel" and some aggregates and activities were evaluated. The results were considered to reflect the company policy, which was captured through the information requests along the evaluation process.

This paper is organized as follows: in Section 2, an overview in evaluation of R&D projects is presented. The developed approach is presented in Section 3 and Section 4 concludes.

2. An Overview in Evaluation of R&D Projects

The approach developed in this paper was inspired on the evaluation process developed for the British Aerospace Military Aircraft and Aerostructures, presented in [1]. The need of a process based on technology management was recognized by Gregory [4]. This process takes into account specific areas of technology management, such as competence analysis, innovation R&D management, among others [1]. There are different methods to evaluate R&D projects, but it is difficult to aggregate all issues that characterize these kind of projects. Some of these methods are described in [5].

Economic models cannot take into account qualitative factors and treat each project in isolation [1]. Moreover, they also require solid financial data. Besides, traditional methods cannot incorporate management flexibility or some uncertainty factors. On R&D projects, new information may arrive and some changes on market conditions may take place. These aspects may lead to a change of strategy [6]. Real option methods incorporate both uncertainty and management flexibility [7], but it is difficult to apply them to real data, because of the complexity of the inference of some parameters.

There are other evaluation methods, such as the scoring method that evaluates each project in isolation or the comparative method that compares each project with another one or with a set of other projects. In the comparative method, different people can provide different comparisons, and evaluation may change over time [8].

Project evaluation can be made by mathematical programming, but it is difficult to incorporate uncertainty factors. Other difficulty concerns on the aggregation of different measures into a single value [9]. Charnes *et al.* [10] developed data envelopment analysis (DEA), a method based on linear programming that can incorporate variables with different units. Nevertheless, this method does not emphasize economical aspects neither uncertainty factors.

Multicriteria analysis can also be a tool to evaluate projects, where the projects are the alternatives which are being analyzed. The developed approach was inspired on the evaluation process developed for the British Aerospace Military Aircraft and Aerostructures, presented in [1]. Moreover, both quantitative and qualitative criteria were used. Boucher and MacStravic [11] also used quantitative criteria in a structure they constructed to evaluate R&D projects.

The structure used in this paper to evaluate R&D projects in telecommunications is based on the analytical hierarchy process (AHP) [12]. This methodology is used in many areas, including the evaluation of projects R&D. For example, Shin *et al.* [13] used this methodology to evaluate the national nuclear R&D projects in the case of Korea. Other example is given by Poh *et al.* [8]. They used AHP to compare methods that evaluate R&D projects.

Nevertheless, in the presented approach, some aspects of AHP were modified, in order to cope with some problems, like the number of comparisons and the integration of quantitative criteria. For a good review of AHP problems, see [14] and [15].

3. The Approach

The approach here presented results from meetings with telecommunications company staff. These meetings allowed to identify the information already available in the company, and the information that can be, reasonably, expected to be provided by project managers. The results of these meetings allowed to define the model structure. After constructing this structure, other meetings were made to define criteria and parameters that should be in evaluation model. Finally, through other meetings, criteria weights were defined.

Two levels of decision were identified to build the model and perform the evaluation of projects: the *activity* and the *aggregate*. An activity is a set of tasks with specific objectives and characteristics. It is planned at short term. An aggregate is a set of activities which are connected and guided to a specific product or service. The aggregate is planned in the medium term (normally, 4 or 5 years).

In the R&D sector of a telecommunications company, there are different decision levels: there are decisions made by the top management; project managers have to make decisions about the aggregates (aggregate decision level); task managers have to decide about activities (activity decision level). The proposed approach considers two structures to incorporate and coordinate these decision levels: one for the evaluation of activities and another for aggregates evaluation. Relevant criteria and their relative importance are identified at each level of both structures. These values must reflect institutional preferences. Thus, the criteria and their weights must be defined by the DMs of the respective level of the structure. The weights of the criteria reflect their importance in the category they belong to.

To infer the weights of criteria in each level, DMs make comparisons among criteria. However, the number of comparisons is limited to avoid requiring excessive information from the DMs. Thus, the DMs fill out part of a matrix of comparisons, $A = [a_{i,j}]_{i,j=1,\dots,n}$, where n is the number of the criteria in a level of the structure, and a_{ij} represents the comparison between the criterion i and the criterion j. The DMs can fill out the matrix with the values that are defined in the following scale:

$$1/9,\ 1/7,\ 1/5,\ 1/3,\ 1,\ 3,\ 5,\ 7,\ 9,$$

where $a_{ij} = 1/9$, means that the criterion i is extremely less important than the criterion j; $a_{ij} = 1$, means that both criterion have the same importance; $a_{ij} = 9$, means that the criterion i is extremely more important than the criterion j.

The DMs can also use other numerical values that are not directly defined in the scale.

Suppose that $n = 4$ and the DMs filled out the matrix with the following values:

$$A = \begin{bmatrix} 1 & 2 & 1/3 & 3 \\ & 1 & & 4 \\ & & 1 & \\ & & & 1 \end{bmatrix}.$$

Note that $a_{ji} = 1/a_{ij}$, which allows the DMs fulfill just part of the superior (or inferior) triangle of the matrix. Besides, $a_{ii} = 1$, because it represents the comparison of one criterion with itself.

Through this matrix, it is possible to get weights of criteria, $w_i,\ i = 1,\ldots,n$ by minimizing the inconsistency index of the AHP method [2], [3]. In the case of the example, the weights obtained were $w_1 = 0.212,\ w_2 = 0.15,\ w_3 = 0.586,\ w_4 = 0.052$.

It is also possible to provide the complete matrix of comparisons and the respective inconsistency index. The rest of the matrix of comparisons is given by $a_{ij} = w_i/w_j$, in order to make the matrix consistent with the judgments already provided. The weights of the criteria and the complete matrix of comparisons are shown to the DMs, which allow them to maintain or revise their judgements.

In the case of the example, the complete matrix is

$$A = \begin{bmatrix} 1 & 2 & 1/3 & 3 \\ 0.5 & 1 & 0.26 & 4 \\ 3 & 3.89 & 1 & 11.29 \\ 1/3 & 0.25 & 0.09 & 1 \end{bmatrix}$$

and the inconsistency index is 0.031. If this index was too high (larger than 0.1), the DMs should revise their judgements.

Once the criteria and their weights have been defined, it is possible to evaluate both aggregates and activities in the different criteria. These evaluations are made by DMs and taking into account data provided by project managers. With these evaluations, it is possible to aggregate them into a single value that represents the global evaluation of an aggregate or an activity.

In a global manner, aggregates evaluation is used to allocate human resources. Activities evaluation is used to allocate human resources, inside the corresponding aggregate.

3.1. The Evaluation of Aggregates

The level structure to evaluate aggregates begins by specifying the type of aggregate, because the weights of criteria may be different for different kinds of aggregates. After some interviews, it was concluded that there were two types of aggregates: strategic ones with long term objectives; and business ones, aiming to obtain profits at a shorter term.

The second level of the structure includes criteria of a superior level or categories of objectives. After some meetings and respective analysis, three categories were considered: strategic, operational and financial. These categories include different criteria that were identified by top management.

The criteria identified in strategic category included the contribution to the company's image, strategic partnerships, market leadership, acquired skills, importance of company credibility for the client and importance of technology.

In the operational category, the criteria that were identified are technical, like technological uncertainty, scarcity of needed resources, solution flexibility, dependence on external entities and client satisfaction.

In the financial category, an indicator that reflects the value of the aggregate in a perspective of 4 or 5 years was used. In addition, it was recognized that other factors were important in this category, like expected loss for abandonment and postponement possibility. These factors are modeled as qualitative criteria. Thus, in this category, there are two qualitative criteria and a quantitative one. Note that the quantitative criterion can be well represented by net present value (NPV), because this measure reflects all cash flows predicted for the following 4 or 5 years.

However, there are aggregates where it is not possible to make forecasts at a such term, due to uncertainty factors. In this case, the quantitative criterion (NPV) is replaced by qualitative factors and by one quantitative factor that reflects the aggregate's value at a short term (1 year). This quantitative factor can be NPV, but with reference to the following year. So, in the case that is not possible to estimate NPV for 4 or 5 years, this criterion is replaced by a financial value for short term (NPV for 1 year), plus the qualitative criteria growth perspectives and market trend.

Figure 1 represents the structure of evaluation. Aggregates can be evaluated either in isolation or by comparing them with each other. The evaluation of one aggregate is made by comparing it with benchmark aggregates. These benchmarks are previously defined by the company administration. The financial values are defined in each benchmark aggregate both at short term and at long term. For the qualitative criteria, for each benchmark aggregate, the percentile relatively to real aggregates in the company is given. These benchmark aggregates are defined in order to make it possible to compare them with the aggregates under evaluation.

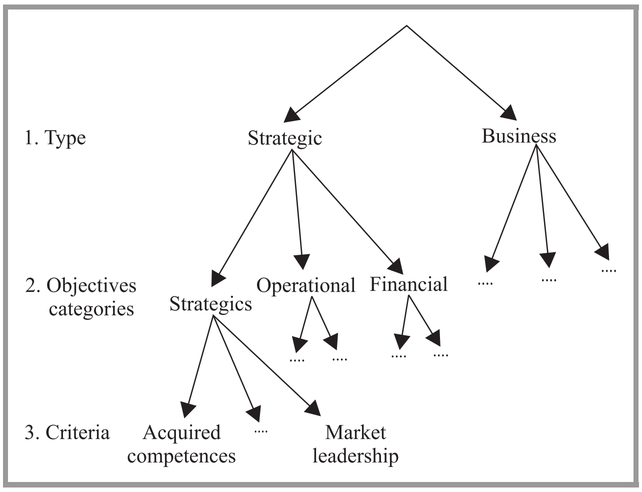

Fig. 1. Structure to evaluate aggregates.

For each criterion, the DMs fill out part of a matrix of comparisons, $A = [a_{ij}]_{i,j=1,\ldots,m}$, where m is the number of aggregates that are being evaluated, with values that compare the aggregate under evaluation against the benchmark aggregates. These values are defined in a scale that is constituted by the values

$$1/9,\ 1/7,\ 1/5,\ 1/3,\ 1,\ 3,\ 5,\ 7,\ 9,$$

where if $a_{ij} = 1/9$, then aggregate i is extremely worse than aggregate j in the criterion; $a_{ij} = 1$, then both aggregates have the same performance in the criterion; $a_{ij} = 9$, then aggregate i is extremely better than aggregate j in the criterion.

However, DMs can fill out each cell of the matrix with other values that are not in the scale. The process described previously for the inference of weights of criteria is also used in this case (based on [2], [3]). In this case, the process is used to infer the relative importance of each aggregate in the criterion. For each qualitative criteria, the relative importance of the aggregate under evaluation and of the benchmark aggregates are calculated. These values of relative importance provide a relative evaluation of aggregates in the criterion, i.e., a higher relative importance means a better performance in the criterion. With the process described on [2], [3], the inconsistency index and the complete matrix are calculated and shown to the DMs. This information allows DMs to realize if the comparisons they have introduced are coherent. If the index of inconsistency is very high or the complete matrix is, somehow, unexpected, the DMs can review their comparisons.

To evaluate the aggregate on the quantitative criterion, the aggregates (the aggregate under evaluation and the benchmark aggregates) are compared, through their financial values. These comparisons are based on weights of negative and null financial values defined before.

During the meetings, it was defined that negative and null financial values are not linear. This happens because, for example, a loss of 100 (NPV $= -100$) may not be half as bad as a loss of 200 (NPV $= -200$). However, it can be assumed that there is linearity for positive financial values.

Thus, company's representatives compare negative and null financial values, fulfilling a matrix of comparisons. With this matrix of comparisons (that is possibly incomplete) and applying the previous methodology for incomplete matrices of comparisons, the weights or impacts of those negative and null values are calculated.

With the aggregates financial values, a global matrix of comparisons is constructed. The purpose of this matrix is to compare the values of reference defined before and the financial values that represent the aggregates. Its construction is based on impacts of negative and null values defined previously, and on the assumption that there is linearity among positive values.

Thus, this global matrix includes the comparisons among negative and null values and the linear comparisons among the positive values.

With this global matrix, it is possible to calculate the impacts for all values that are being compared. Taking only values of aggregates (aggregate under evaluation and benchmark aggregates), it is possible to normalize them to get impacts or relative importance of aggregates in the quantitative criterion.

With the relative importance of the aggregate under evaluation in all criteria, it is possible to determine a value for the aggregate, taking into account the relative importance of the criteria and the importance of the categories of objectives.

If several aggregates are evaluated individually against benchmark aggregates, the results of each evaluation can give a proxy of attractiveness of each aggregate.

To evaluate a set of aggregates, the same methodology described before is used, i.e., the aggregates are compared among themselves in all criteria. After having the relative importance of the aggregates in all criteria, a global value is calculated for each aggregate (the value that includes the relative importance of the aggregates in all criteria weighed by the relative importance of criteria and the weights of the categories of objectives). So, the evaluation of a set of aggregates provides a relative performance proxy for each aggregate. These proxy values will be the basis for human resources allocation among aggregates, providing managers with a global orientation about decisions of human resources allocation. Moreover, it is possible, with these values, to have a global guide about the level of activity in those aggregates and an orientation if it is necessary to decide which projects to pursue.

3.2. Activity Evaluation

Activity evaluation is based on a similar approach to the one developed to evaluate aggregates. However, the structure has different levels of criteria. There are activities very different and, thus, different types of activities were identified:

- **Exploratory research**: these activities aim to explore and study new technologies to know if it is possible to achieve interesting results.
- **Experimental development**: these activities have a defined objective on a defined application. So, the investigation is guided to advance on a specific orientation.
- **Product development and engineer services**: the purpose of these activities is to develop a product for immediate sale, or to provide support to an existing product.

The type of activity (see Fig. 2) corresponds to the first level of the structure. The category of objectives is in the second level, similarly defined to the one used with the aggregates: strategic, operational and financial. These categories and respective criteria were identified through meetings with members of the company's administration. The identified criteria in the strategic category were: contribution to the company image, market leadership, acquired skills, strategic partnerships, company credibility for the client and importance of technology. In the operational category, the criteria that were identified were: technological uncertainty, scarcity of needed resources, importance of the activity to the respective aggregate and dependence from external entities. In the financial category, the long term perspective is not considered. In this way, the criteria presented and identified in this category were financial value at a short term, growth perspectives, market trend, expected loss for abandonment and postponement possibility.

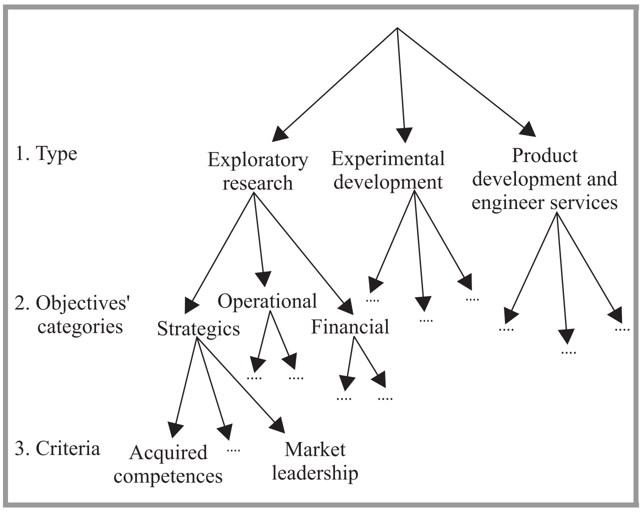

Fig. 2. Structure to evaluate activities.

The activities that belong to the same aggregate are compared among themselves. Through a process similar to the one used to evaluate a set of aggregates, a proxy value is calculated for each activity.
Note that each activity belongs to an aggregate and its evaluation is used to allocate human resources inside the aggregate. With the criteria weights and the performance of each activity on each criteria, it is possible to determine a global performance indicator or the evaluation of each activity. This indicator is the basis of human resource allocation decisions within the aggregate. For these decisions, one of the following procedures can be used.

- Defining global priorities for each activity, and selecting activities according to their priority. Restrictions may be used, like minimum and maximum values for human resources, for each type of activity.
- Mathematical programming to maximize the sum of priorities, taking into account some constraints, like limits on the number of human resources in each type of activity.

The activity and aggregate evaluation can give managers indications for resources allocation and allow them to gain sensibility for future decisions in the area.

3.3. The Prototype

A prototype was created, in "Microsoft Excel", and tested with data of a telecommunications company. Some aggregates and activities were evaluated, after getting the organizational preferences.
This prototype has different functionalities relatively to criteria. For the criteria, DMs can introduce new criteria or categories of objectives. It is possible to treat quantitative criteria (which are, mostly, financial) and the prototype guarantees their compatibility with the qualitative criteria.
The prototype computes the weights of criteria, through comparisons among them.
To evaluate aggregates or activities, the prototype allows to compare them with each other, in order to get their global evaluation. In addition, it is possible to introduce new aggregates or activities in the evaluation. If DMs want to evaluate one aggregate in isolation, they may use benchmark aggregates, which are defined in the prototype.
The evaluation provides a relative priority index for each aggregate or activity under evaluation. If one aggregate is being evaluated in isolation, a global priority index is calculated.
These indexes provided by the prototype allow DMs to support or justify the resources allocation of the aggregates and of their activities.
Some aggregates and activities were evaluated, taking into account the preferences of the company. The results of evaluation reflected these preferences and the company policy.

4. Conclusions

In this paper, it was presented an approach to evaluate telecommunications projects, taking into account two distinct levels: the activity and the aggregate. In each level, there are different types of decision, allowing the construction of a structure. These structures (one for the activities, another for the aggregates) allow the incorporation and coordination of the different decision levels presented in the activities and aggregates evaluation. In each level of the structure, different criteria are used. The decision makers responsible for each level define its criteria and respective weight.
The evaluation of aggregates can be made individually, through comparisons between the aggregate under evaluation and benchmark aggregates. If several aggregates are evaluated individually, the results can give a proxy of attractiveness of each aggregate. The evaluation of a set of aggregates may be made by comparing themselves with each other. The evaluation gives a global performance indicator for each aggregate.
The evaluation of activities is made through comparisons among a set of activities which belongs to a specific aggregate. A global priority index is given for each activity under evaluation.
A prototype was created to evaluate both aggregates and activities. These evaluations were based on data from a telecommunications company. In general, the results reflected the company policy. This policy was integrated in the evaluation process through the requested information.

The evaluation of aggregates and activities supports managers decisions on resources allocation. The presented approach may detect incoherences in evaluation when DMs have to compare criteria, aggregates or activities. On the other hand, this model may integrate new decisions when new opportunities arise that were not foreseen when the projects began. This integration also gives an orientation for resource reallocation. Finally, it is possible to identify the sources of evaluation errors, when such errors are detected.

With this approach, it is also possible to provide incentives to the identification of strategic opportunities and operational flexibility, through the definition of multiple criteria.

To conclude, the tool here presented may help to achieve better resource allocation decisions in a telecommunications company.

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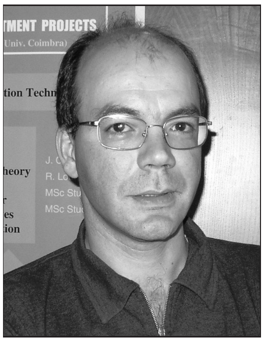

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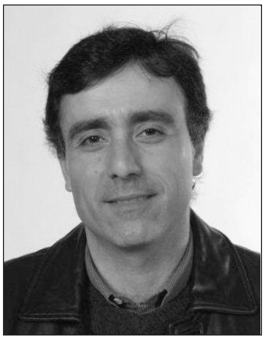

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