

A multi-criteria Approach to the Problem of Managing the new Product Development Project Portfolio

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Abstract— The management problem of the New Product Development Project Process (PDNP) is recurrent in the literature, as it reflects a question that exists in R&D companies, which is to decide which product project portfolio which will minimize the necessary development costs while maximizing the return for the organization. In this context, the present study aims to use two multi-criteria approaches - TOPSIS and PROMETHEE II - using the Analytic Hierarchy Process (AHP) method to establish, in a non-partial way, the weights and to determine which approach yields the best profit for NPDP, and raise the question of which approach is most appropriate for this problem. In addition, a practical example was proposed that shows the impact between the different orderings present in the work, to assist in achieving the goal. As a result, it was possible to obtain a study in which the non-compensatory approach is better for the practical example, making the present work the beginning of deeper studies on the subject.

Keywords— New Product Development Process (NPDP). Preference Ranking Organization Method Enrichment Evaluations II (PROMETHEE II). Technique for Order Preference by Similarity to Ideal Solution (TOPSIS).

I. INTRODUCTION

NPDPs in companies that value innovation are subjected to numerous stages and selective filters in order to compete for processing resources (DREI, 2018). Kaminski (2001) points out that the goal of new product development is to transform market needs into economically viable end products, encompassing a group of activities that essentially encompasses all departments of the company.

Thus, the decision to proceed with a specific project is not always easy, given the number of scenarios that these multiple products can generate (DREI, 2018). Rozenfeld et al. (2006) states that using the concept of the Development Funnel, or Innovation Funnel, brings benefits when having multiple products under development simultaneously. Fig. 1 illustrates this funnel.

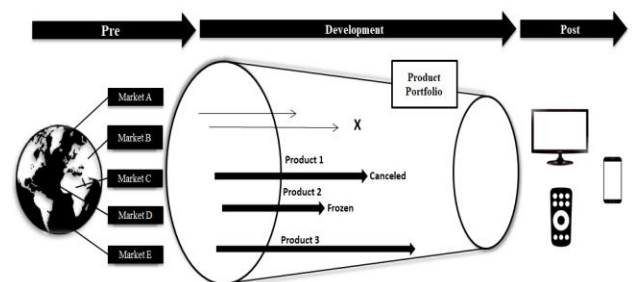


Fig. 1: Development Funnel

Source: Adapted from Rozenfeld et al. (2006).

Among the three macro phases - pre-development, Development and post-development - exposed (ROZENFELD et al., 2006), the Development phase is the most important for NPDP. This is because there are disputes of resources, continuation and even cancellation of projects, so it is the phase in which much of the decision making.

Noting that innovation and ability to understand market requirements are important in many industry sectors (COSTA, 2010) and that decisions made at the beginning of the development process, when there is great uncertainty, amount to 85% of final product costs (ROZENFELD et al., 2006), it is necessary to think of methods that help in decision making and project selection in the development phase.

According to Costa (2010) and Rozenfeld et al. (2006), several methodologies have been adopted in order to propose improvements in the strategic performance of new product development. In view of this, the purpose of this paper is to compare two distinct multi-criteria approaches, one compensatory and one non-compensatory, to determine which approach yields the best profit for NPDP.

The problem of determining an optimal portfolio for NDPs is recurrent in the literature, whether it is focused on the strategic approach, present in Junior et al. (2006), or even using other resolution methods, such as stochastic dynamic programming, present in Figueiredo e Loiola (2012) and Figueiredo e Loiola (2017). Moreover, the present problem has also been approached from the multi-criteria point of view, present in Bortoluzzi et al. (2018), but using different constraints and methods of the present work, and the issue of different approaches with and without compensation is not raised.

Thus, the differential of this paper is to present two methods - a compensatory and a non-compensatory one - with their criteria based on the work of Drei et al. (2018), raising the question about which best approach for this case. In this line, the main contribution presented will be to compare the existing abortions in the multi-criteria, raising the best return through a restriction of number of projects. As a secondary contribution, the study brings a comparison between these two multi-criteria methods through a practical example.

After summarizing and presenting the problem in Section 1, Section 2 will deal with how the problem decisions were made as well as its methodology. Section 3 will expose the application of the chosen methods, as well as a practical example to illustrate the comparison between them, together with their results and, finally, the discussions and conclusions will be presented in Section 4.

II. METHODOLOGY AND DECISIONS

In this section we will present the steps that led to the construction of this article. Since the objective was to

treat the problem with a multi-criteria approach, it was necessary to define the evaluation criteria, the weights and, finally, which methods would be used.

2.1 Criteria

The criteria used in the multi-criteria methods were taken from Drei et al. (2018). We chose to use the study cited as the basis, because it performed a detailed literature review, taking into consideration criteria that are actually used in real companies and, consequently, in the decision-making of the NPDP.

It is noteworthy that not all parameters present in the work cited were used, since it addresses the problem with an approach from the standpoint of stochastic dynamic programming, unlike the present study. Thus, the criteria that best fit the execution of the multi-criteria approach were chosen.

2.1.1 Expected Return

The return on a project is a dear feature, as it determines how much profit a company can make, given the amount of resources that have been allocated to that NPDP (LI et al., 2015; LI et al., 2016; TIAN et al., 2016).

Therefore, the expected return will be taken into account as a criterion of maximization, through a monetary measure, in the multi-criteria models, however it will not be analyzed in a timely manner, taking into account each stage of project development, but in a global way, that is, how much return is expected at the time of project launch.

2.1.2 Runtime

Another important feature is the runtime of a NPDP. Companies dealing with R&D value projects that have a shorter time to launch, as the faster a product is launched, the greater the chance to stand out and serve customers before a competitor (LI et al., 2015; LI et al., 2016; TIAN et al., 2016).

Thus, the runtime is also a minimization criterion present in the multi-criteria methods of work, being arranged by the sum of all periods, along the development funnel, necessary for the NPDP to be launched.

2.1.3 Development costs

There are different ways to interpret resource needs in new product development. The most recurrent is the allocation of nonrenewable resources in each project, i.e. the financial cost of each project that can be seen in Loch and Kavadias (2002), Stummer and Heindenberger

(2003), Carazo et al. (2010), Li et al. (2015), Li et al. (2016), Tian et al. (2016) and Figueiredo e Loiola (2017).

It is notorious that companies work on a limited budget, so choosing to allocate a certain amount of resources directly affects NDPs within the innovation funnel. Therefore, to bring this feature into the model, the development cost will be taken into account as a minimization criterion, through a monetary measure, not only of one form, but of different modes of production, which have different resource needs, thus bring different improvements. Are they:

1. **Continue Mode:** Common mode of developing a product project that has a default feature requirement (DREI et al., 2018).
2. **Enhance Mode:** A mode that introduces more investment into a NPDP and therefore decreases its development time. It is more expensive than Continue Mode (DREI et al., 2018).
3. **Accelerate Mode:** Mode that introduces more investment in some NPDP and, consequently, decreases its development time, as well as uncertainties about that project. It is more expensive than Enhance Mode (DREI et al., 2018).

Importantly, multi-criteria methods will evaluate the cost of the modes mentioned as a whole, i.e., regardless of the return and time of project development, the objective is to evaluate the cost that a project adds in relation to its three modes and not the influence of one on the other.

2.1.4 Divisibility

Finally, the last criterion used is divisibility, which is the ability to freeze a project, that is, to stop investing financial resources on it, either for a momentary resource constraint, or even delaying launching purposely, in order to increase the return forecast (LI et al., 2015; LI et al., 2016; TIAN et al., 2016).

Therefore, the freeze criterion will also be assigned as a problem maximization criterion, interpreted by a binary variable, which assumes 1 if the project is divisible and 0 if not.

2.2 Analytic Hierarchy Process (AHP)

To generate the weights, we used AHP, which is a Multi-criteria Decision Support Method (MDSM) based

on evaluating alternatives in terms of additive preference (BELTON; STEWART, 2002).

Thus, it is not necessary to create weights from an arbitrary and even biased preference system, as AHP relies on the Absolute Measurement Method (SAATY, 1980). This means that each criterion is compared pairwise, generating numerical values for each performance level of one criterion over another (BELTON; STEWART, 2002). This scale is arranged by Saaty (1980) as follows:

- 1 – Equally preferable;
- 3 – Weakly preferable;
- 5 – Strongly preferable;
- 7 – Very strongly preferable;
- 9 – Absolutely preferable.

This analysis, in turn, generates a preference matrix from one criterion to another, and then the eigenvalue λ_{\max} and eigenvector of that matrix must be found. With the eigenvalue, it is necessary to test the consistency of the preference matrix by the following formula (BELTON; STEWART, 2002):

$$RC = CI/RI'$$

Where, according to Saaty (1980), RI' is a tabulated value that is associated with the amount of criteria (n), and CI is given by the formula:

$$CI = (\lambda_{\max} - n)/(n - 1)$$

If $RI > 0.1$, the preference matrix is inconsistent and must be redone. However, if $RI \leq 0.1$, the matrix is consistent, then the eigenvector associated with λ_{\max} is the weight vector (w) related to the preference matrix (BELTON; STEWART, 2002), and should be standardized so that the sum of the weights is equal to 1.

Thus, the preference matrix for the project criteria was made, respecting the following priority:

Expected Return P Development Cost P Runtime P
Divisibility.

2.3 Multi-criteria Methods

Multi-criteria methods are used as a collection of formal approaches that seek to explicitly consider various

criteria to help an individual, or group, explore decisions that matter (BELTON; STEWART, 2002). Following this line, two methods were chosen to show multi-criteria development in relation to the NPDP portfolio problem.

2.3.1 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The first method used was TOPSIS, which is to determine an alternative that is as far as possible from the negative ideal solution, while as close as possible to the positive ideal solution (JUNIOR; CARPINETTI, 2015).

To do this, TOPSIS normalizes the alternative values for each criterion and then multiplies that value by its given weight. Then determine the positive and negative ideal solution (JUNIOR; CARPINETTI, 2015):

$$A^+ = \max_j n_{i,j}, \quad \forall j \in Alt$$

$$A^- = \min_j n_{i,j}, \quad \forall j \in Alt$$

That done, we calculate the distance between the alternative scores and the ideal solutions (JUNIOR; CARPINETTI, 2015):

$$D_i^+ = \left[\sum_{i=1}^n (n_{i,j} - n_j^+)^2 \right]^{\frac{1}{2}}$$

$$D_i^- = \left[\sum_{i=1}^n (n_{i,j} - n_j^-)^2 \right]^{\frac{1}{2}}$$

Finally, we find the approximation coefficient, which is the overall performance of the alternative (JUNIOR; CARPINETTI, 2015):

$$CC_i^+ = \frac{D_i^-}{D_i^+ + D_i^-}$$

To determine the ordering, the alternatives are sorted in descending order of the approximation coefficient.

2.3.2 Preference Ranking Organization Method Enrichment Evaluations II (PROMETHEE II)

The second method used was the PROMETHEE II, which works with the preference between one alternative and another. Thus, alternative comparison matrices are made for each criterion present in the model, in order to determine an individual preference (BELTON; STEWART, 2002).

Thus, arrays are created in which the alternatives receive 1 if they are preferable in the criterion under

consideration and 0 if they are equally preferable or not preferable. After that, the matrices are multiplied by the stipulated weight, in order to represent the impact of that preference, as shown by Belton and Stewart (2002):

$$P(a, b) = \sum_{i=1}^m \frac{w_i P_i(a, b)}{n - 1}$$

Then we find the positive and negative ranking from the preferences found above, summing the value of the rows and columns, respectively (BELTON; STEWART, 2002). Therefore:

$$\phi^+(a) = \sum_{b \neq a} P(a, b)$$

$$\phi^-(a) = \sum_{b \neq a} P(b, a)$$

For PROMETHEE II, there is an extra step that determines a single $\Phi(a)$ through the difference between the found values (BELTON; STEWART, 2002). Like this:

$$\phi(a) = \phi^+(a) - \phi^-(a)$$

Thus, the results found are organized in descending order of order. Finally, it is noteworthy that PROMETHEE still has different ways to apply its preferences, however, in this study; all were used in the usual way.

III. APPLICATION OF METHODS AND RESULTS

3.1 Weight calculation

Table 1 shows the comparative preference matrix between the criteria, created from the AHP method.

Table 1 - Preference for AHP

	Expected Return	Development cost	Divisibility	Runtime
Expected Return	1	3	7	5
Development cost	0.33	1	5	3
Divisibility	0.14	0.20	1	0.33
Runtime	0.20	0.33	3	1

Source: Authors.

After calculating the eigenvalues and eigenvectors of the matrix, λ_{max} assumed the value of 4,104. Thus, with

CI = 0.03 and RI (n = 4) = 0.9, RC equals 0.0385, which is less than 0.1, so this array has consistency, so the associated eigenvector assumes the weights shown in Table 2.

Table 2 - Weights by AHP

	Weights	Normalized Weights
Expected Return	4.82	0.57
Development cost	2.23	0.26
Divisibility	0.47	0.06
Runtime	1	0.12

Source: Authors.

Finally, as the Development Cost criterion is divided into three sub-criteria that will be used in the models, a proportion of the weight obtained by AHP was distributed, in order to respect the characteristics of each execution mode. Like this:

- Weight Continue = 20% of Weight Development Cost;
- Weight Continue = **0.05**.
- Weight Enhance = 30% of Weight Development Cost;
- Weight Enhance = **0.08**.
- Weight Accelerate = 50% of Weight Development Cost;
- Weight Accelerate = **0.13**.

3.2 Example projects

To execute the MDSM and obtain the sequencing of each method, six projects were randomly generated, with the aid of Excel software, satisfying the characteristics of each work criterion. The equations exemplify the formulas used:

- Expected Return = RANDBETWEEN (60.000, 120.000);
- Continue Mode Cost = 10% of Expected Return;
- Enhance Mode Cost = 20% of Expected Return;
- Accelerate Mode Cost = 30% of Expected Return;

- Divisibility = RANDBETWEEN (0, 1);
- Runtime = RANDBETWEEN (3, 20).

Therefore, Table 3 shows the designs used in the methods, as well as their values and, finally, the weights for each criterion.

Table 3 – Product Projects

Project s	Expected Return	Continue Mode	Enhance Mode Cost	Accelerate Mode Cost	Divisibility	Runtime
P1	\$74,447.00	\$7,444.70	\$14,889.40	\$22,334.10	0	4
P2	\$106,917.00	\$10,691.70	\$21,383.40	\$32,075.10	0	10
P3	\$94,492.00	\$9,449.20	\$18,898.40	\$28,347.60	1	3
P4	\$85,706.00	\$8,570.60	\$17,141.20	\$25,711.80	0	11
P5	\$86,087.00	\$8,608.70	\$17,217.40	\$25,826.10	1	15
P6	\$114,979.00	\$11,497.90	\$22,995.80	\$34,493.70	0	16
W	0.57	0.05	0.08	0.13	0.06	0.12

Source: Authors.

3.3 TOPSIS Method

To develop TOPSIS, Excel software was used to assist in the mathematics present in the step-by-step method. Thus, a priori, the Project matrix presented in subsection 3.2 was normalized, respecting the criteria of maximization and minimization, and then each option was multiplied by the weight that corresponds to its criterion (Table 4).

Table 4 – Standardized Projects

Project s	Expected Return	Continue Mode	Enhance Mode Cost	Accelerate Mode Cost	Divisibility	Runtime
P1	0.07	0.05	0.07	0.11	0	0.11
P2	0.11	0.04	0.06	0.11	0	0.10
P3	0.10	0.04	0.07	0.11	0.06	0.11
P4	0.09	0.04	0.07	0.11	0	0.10
P5	0.09	0.04	0.07	0.11	0.06	0.09
P6	0.12	0.04	0.06	0.10	0	0.09

Source: Authors.

Taking these values, and following the TOPSIS method, it was possible to find the ideal positive (A⁺) and negative ideal (A⁻) solutions:

$$A^+ = (0.12, 0.05, 0.07, 0.11, 0.06, 0.11)$$

$$A^- = (0.07, 0.04, 0.06, 0.10, 0.00, 0.09)$$

Thus, to determine the rank of each alternative, one must calculate their distances from A⁺ and A⁻, shown in Table 5.

Table 5 – Solution distances

Projects	D ⁺	D ⁻
P1	0.06861526	0.026551429
P2	0.05821885	0.034839111
P3	0.02138686	0.064441224
P4	0.06460016	0.017250291
P5	0.03774901	0.057032394
P6	0.06202432	0.040755304

Source: Authors.

And finally, the approximation coefficient of each alternative is given, presented in Table 6.

Table 6 – Approximation Coefficient

Projects	CC ⁺
P1	0.27899917
P2	0.37438074
P3	0.75081742
P4	0.21075375
P5	0.60172557
P6	0.39653094

Source: Authors.

Therefore, the ordering given by the TOPSIS method, using the criteria and alternatives presented, is as follows:

$$P(3) > P(5) > P(6) > P(2) > P(1) > P(4).$$

3.4 PROMETHEE II Method

The PROMETHEE II method was developed with the aid of Visual PROMETHEE software, version 1.4.0.0. Table 7 shows the adapted input of the alternatives and criteria inserted in the software.

Table 7 – PROMETHEE II input adapted

	Expected Return	Continue Mode Cost	Enhance Mode Cost	Accelerate Mode Cost	Divisibility	Runtime
Unit of Measurement	Monetary	Monetary	Monetary	Monetary	Yes/No	Time
PRIORITY						
Min/Max	Max	Min	Min	Min	Max	Min
Weight	0.57	0.05	0.08	0.13	0.06	0.12
Priority type	Usual	Usual	Usual	Usual	Usual	Usual

STATS						
Min	\$74,447.00	\$7,444.70	\$14,889.40	\$22,334.10	0	3
Max	\$114,979.00	\$11,497.90	\$22,995.80	\$34,493.70	1	16
Average	93,771.33	9,377.13	18,754.27	28,131.40	0.33	9.83
Standard Deviation	13,666.39	1,366.64	2,733.28	4,099.92	0.47	4.95

OPTIONS						
P1	\$74,447.00	\$7,444.70	\$14,889.40	\$22,334.10	No	4
P2	\$106,917.00	\$10,691.70	\$21,383.40	\$32,075.10	No	10
P3	\$94,492.00	\$9,449.20	\$18,898.40	\$28,347.60	Yes	3
P4	\$85,706.00	\$8,570.60	\$17,141.20	\$25,711.80	No	11
P5	\$86,087.00	\$8,608.70	\$17,217.40	\$25,826.10	Yes	15
P6	\$114,979.00	\$11,497.90	\$22,995.80	\$34,493.70	No	16

Source: Authors.

Visual PROMETHEE, as explained in the subsection 2.3.2, sets the preference matrices and, as noted, all the criteria used in this study are usual, so Table 8 shows the Φ^+ , Φ^- and Φ obtained in each alternative.

Table 8 – PROMETHEE II Output

Projects	Φ^+	Φ^-	Φ
P1	0.35	0.61	-0.26
P2	0.57	0.39	0.18
P3	0.61	0.38	0.23
P4	0.37	0.60	-0.23
P5	0.45	0.54	-0.09
P6	0.56	0.40	0.06

Source: Authors.

Therefore, the order given by the PROMETHEE II method, using the criteria and alternatives presented, is as follows:

$$P(3) > P(2) > P(6) > P(5) > P(4) > P(1)$$

3.5 Method Comparison: Practical Example

To further demonstrate the comparison between the ordering difference of the two methods presented, a hypothetical situation was created in which only 50% of the NDPs would actually be produced. Thus, only the first three projects of each order were selected for launch, which are:

- TOPSIS Method: Launching the P(3), P(5), and P(6) projects;

- PROMETHEE II Method: Launching P(2), P(3) and P(6) projects.

In addition, it was also determined that for all projects, the Accelerate Production Mode would be used to obtain a faster return on the launched projects, as well as reducing the combinations between Modes, setting only one option. Thus, the equations show the profit generated by the TOPSIS method and for the PROMETHEE II (PII), respectively:

- Total TOPSIS Cost = \$28,347.60 + \$25,826.10 + \$34,493.70;
- **Total TOPSIS Cost = \$88,667.40.**
- Total TOPSIS Return = \$94,492.00 + \$86,087.00 + \$114,979.00;
- **Total TOPSIS Return = \$295,558.00.**
- **Total TOPSIS Profit = 206,890.60.**
- Total PII Cost = \$32,075.10 + \$28,347.60 + \$34,493.70;
- **Total PII Cost = \$88,667.40.**
- Total PII Return = \$106,917.00 + \$94,492.00 + \$114,979.00;
- **Total PII Return = 295,558.00.**
- **Total PII Profit = 221,471.60.**

Given that the profit obtained by the PROMETHEE II method is higher than that of TOPSIS by \$ 14,581.00 \$ and considering that the approximations made to the example could simulate a real situation in a multi-criteria decision making process in companies, it is valid to state that for the case , the PROMETHEE II non-compensatory method outperformed the TOPSIS compensatory method.

IV. DISCUSSIONS AND CONCLUSION

The present work aimed to study the problem of deciding a NPDP portfolio, through the multi-criteria approach, using two distinct methods, one compensatory - TOPSIS - and the other non-compensatory - PROMETHEE II - exposing the distinction in the final order, even if the alternatives and criteria used are the same for both.

Thus, it is possible to affirm that the article achieved its objective, with its main contribution, since the methods achieved different priorities, as regards the product projects under development. Thus, in addition to

the multi-criteria approaches being applicable to this decision, it is noted that, for the proposed case, there is a better return obtained by the non-compensatory method.

Of course, as a practical example, the result is very simple to ensure that all NPDP problems return a more profitable profit when using non-compensatory methods, but this work is the basis for further research about the theme.

Concerning the secondary contribution of the work, which was the practical example showing the impact of the ordering distinction of each method; it also achieved its goal, since there was a distinct return for each situation, showing that choosing a method multi-criterion directly influences the NPDP portfolio problem. However, it is noticeable to note that the approximations were assumptions made theoretically, that is, without grounding in information from any real company.

Thus, for future work, it is recommended that the data, both of the projects and the approximations made with the constraints of a company, be practical, i.e., provided by some organization, in order to generate more credibility, both for comparison between the multi-criteria methods, as well as the criteria used.

Finally, the most important thing is to continue the proposal, in order to compare other compensatory and non-compensatory methods, studying them more deeply about the NPDP, to determine, not which is the best method, since each NPDP will have its characteristics, but what is the best approach to such a problem.

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