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Performance Evaluation with PROMETHEE GDSS and GAIA: A Study on the ITA-SAT Satellite Project

Tiago José Menezes Gonçalves*, Mischel Carmen Neyra Belderrain
Instituto Tecnológico de Aeronáutica – São José dos Campos/SP – Brazil

Abstract: *The increased complexity of organizational contexts in the end of the 20th century and beginning of the 21st century has resulted in the increment of the variables number to be considered during a performance evaluation. Therefore, many professionals began to search methods that would enable the simultaneous analysis of multiple criteria. Thus, this paper has investigated the application of a multicriteria approach to evaluate the performance in the development of subsystems during the development of complex products, by using the PROMETHEE GDSS and the GAIA methods. To achieve this objective, a study on the ITA-SAT satellite project was performed, in which a perception analysis of the members of the project regarding the development of each subsystem was carried out. Once these perceptions were captured, the proposed approach was used to identify subsystems with less satisfactory performances. Finally, the results were analyzed and brought to discussion at a meeting with managers and project members with a feedback to the conclusions of this study.*

Keywords: *PROMETHEE GDSS, GAIA, ITA-SAT Satellite.*

INTRODUCTION

According to Marmel (2008), there are two kinds of tasks in a project: one oriented by resources and one that is not oriented by resources. Resource-oriented tasks are those in which the addition or subtraction of resources directly affects the length or the quality of the task. On the other hand, tasks that are not oriented by resources have special characteristics that cause their length not to depend on addition or subtraction of resources.

Concerning the mentioned types of tasks, one of the ways to improve the development performance of a subsystem or component of a product is to add resources, when these are completely or partially comprised of resource-oriented tasks.

Even when adding resources results in the improvement of the performance, the amount is always a limiting factor for any project, thus it is necessary to identify the sources of inefficiency and to take initiatives to maximize the efficacy concerning the use of resources. Aiming at managing this situation, one of the tools to operate such variables is the performance evaluation that enables the manager to identify which aspects of a project need to be improved.

In the past decades, the increased complexity of organizational contexts resulted in the increment of the number of variables to be taken into account during the performance evaluation process. Therefore, many studies in this field began to search for methods that would enable the simultaneous evaluation of multiple criteria, thus using the multi-criteria decision aiding (MCDA). The studies by Bortoluzzi *et al.* (2011; 2010), Gallon *et al.* (2011), Nascimento *et al.* (2011), Ensslin *et al.* (2010), and Dutra (2008) are examples.

In this context, this study aimed at investigating the application of the following methods: Preference Ranking Organization Method for Enrichment Evaluations – Group Decision Support System (PROMETHEE GDSS) (Macharis *et al.*, 1998) and Graphical Analysis for Interactive Assistance (GAIA) (Hayes *et al.*, 2009) to evaluate the performance in the subsystems development of complex products.

In this study, a group decision-making method was chosen to use, due to the need for the team members to participate in the actions. These actions aimed at minimizing the criticality of the subsystems identified by the method, whose results are more easily recognized with the adoption of an approach that can maximize the participation of the team members and that incorporates their values and preferences.

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*author for correspondence: tiagojmg@ita.br
Pç Eduardo Gomes, 50- Vila das Acácias- CEP 12.228-901-São José dos Campos/SP-Brazil

THEORETICAL BASIS

MCDA

Most decision-related problems consist of issues involving contradictory multiple criteria, which represent one of the characteristics of a problem approached by MCDA. Since there is rarely one action that can simultaneously present the best performance in the considered criteria, the MCDA can be defined as an effort to solve the dilemma of conflicting criteria (Zeleny, 1982).

It involves a set of methods that can be found in literature with different names, such as: Multi-Attribute Decision Making (MADM), Multi-Criteria Decision Making (MCDM), Multi-Objective Decision Making (MODM) or Multiple Objective Decision Aiding (MODA) (Gomes and Gomes, 2001).

According to Roy (1996), MCDA can be used to face four kinds of decision-related issues, as follows:

- type α (selection problems – Pα) selects the best action among the ones being taken into account;
- type β (classification problems – Pβ) separates each action into classes, according to the performance;
- type γ (order problems – Pγ) orders the considered actions, according to the performance;
- type σ (description problems – Pσ) better understands the problem by describing it.

Next, we present the theoretical basis concerning the methods PROMETHEE GDSS (Macharis *et al.*, 1998) and GAIA (Hayes *et al.*, 2009), which were used in this study.

PROMETHEE GDSS

The PROMETHEE GDSS belongs to the outranking methods, also understood as subordination, prevalence, or outranking. Such methods aim at building an outranking relation to represent the preferences of the decision-makers and to solve the order problems (Pγ).

According to Le Téno and Mareschal (1998), the basic principle of outranking methods is that if one action performs better than another in most of the criteria and it does not present worse performance in the others, then the first action will be the chosen one. Besides, these methods consider that small differences in the evaluations do not always have a significant impact on the decision-maker (Vincke, 1992).

According to Silva *et al.* (2010), one of the advantages of the PROMETHEE method (I, II, III, IV, V, VI, and GDSS) is how each criterion is assessed by the preference functions. This leads to a more reliable understanding of perception differences among the decision-makers at evaluating each action, and it also does not allow an unlimited compensation of major advantages between the actions.

For Brans and Mareschal (2005), two kinds of information are necessary to use the PROMETHEE method: between criteria and within each criterion.

Information between criteria is comprised of the weight assigned to each of them. According to Macharis *et al.* (2004), with the PROMETHEE method, it is assumed that decision-makers are capable of properly evaluating the criteria weights without using any additional methods when the number of criteria is not high, in a way that the sum of weights is equal to one.

However, information within each criterion refers to the preference functions related to each criterion and its parameters (Chart 1), in which "*q*" represents the threshold of indifference, "*s*" represents the threshold of strict preference, and "*σ*" represents a value between "*q*" and "*s*" (Brans and Mareschal, 2005).

Thus, after defining the weights and choosing the preference functions for each criterion (as well as the parameters), the calculation of deviation modules $d_k (a_i, a_j)$ between judgments $f_k(a_i)$ and $f_k(a_j)$ for each pair of actions "a_i" and "a_j" wee performed, according to each considered criterion "*k*" and to the equation: $d_k (a_i, a_j) = f_k(a_i) – f_k(a_j)$. The results of such equation are the inputs for the preference functions (Behzadian *et al.*, 2011), and they are considered equal to zero when $d_k<0$.

According to Behzadian *et al.* (2010), for each value resulting from $d_k (a_i, a_j)$, a preference function is used that translates the difference between the evaluations obtained by two actions "a_i" and "a_j" over a criterion *k* in a value of $p_k(d_k)$, which ranges from zero to one. The values resulting from the preference functions are called intensities of preference, and they are the basis to calculate the preference index, which represents the intensity with which an action "a_i" is preferred over an "a_j", considering the weight ω_k of each criterion "*k*" for the "*n*" criteria analyzed.

Chart 1. Judgment scale.

Verbal scale	Numeric scale
Very good (VG)	5
Good (G)	4
Medium (M)	3
Poor (P)	2
Very poor (VP)	1

(Source: Freitas *et al.* 2009)

Its calculation is performed according to Eq. 1:

$$\pi(a_i, a_j) = \frac{\sum_{k=1} \omega_k p_k(d_k)}{\sum_{k=1}^{n} \omega_k} \quad (1)$$

After calculating the preference indexes, the positive, negative, and net flows were calculated for each action. According to Brans and Mareschal (2005), these flows were calculated according to Eqs. 2, 3 and 4, respectively, where "a_i" represents the actions for which the flow is being calculated, and "a_j" varies representing the m-1 different actions of "a_i".

$$\varphi_i^{+}(a_i) = \frac{\sum_{k=1} \pi(a_i, a_j)}{m-1} \quad (2)$$

$$\varphi_i^{-}(a_i) = \frac{\sum_{\forall j \neq 1} \pi(a_j, a_i)}{m-1} \quad (3)$$

$$\varphi_i(a_i) = \varphi_i^{+}(a_i) - \varphi_i^{-}(a_i) \quad (4)$$

According to Belton and Stewart (2002), the positive flow represents the intensity with which an action is chosen over the others. The negative flow represents the intention with which an action is overcome by others.

The net flow represents the balance between the positive and negative flows; therefore, the higher the value of the net flow, the better the performance of an action is considered (Nikolić *et al.*, 2011).

After obtaining the net flows of the actions according to each decision-maker, the final order with PROMETHEE GDSS can be conducted.

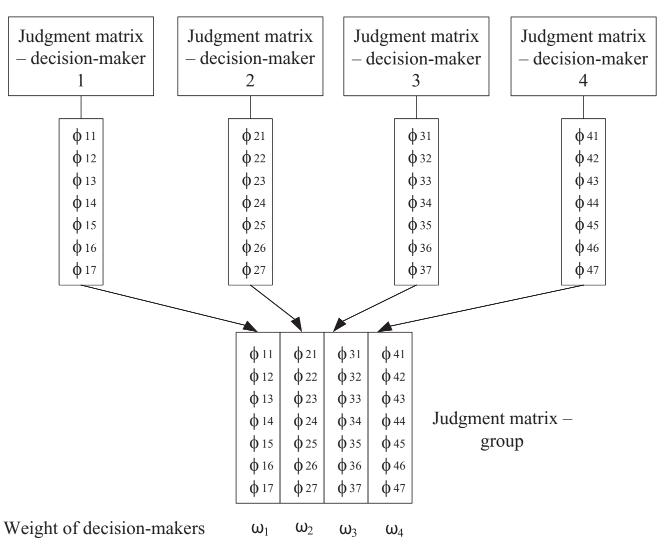


Figure 1. Functioning of PROMETHEE GDSS. (Adapted of Brans and Mareschal, 2005).

According to Macharis *et al.* (1998), in the PROMETHEE GDSS, the net flows of each decision-maker are used to compose a performance matrix, and weights are assigned for each of them, as demonstrated in Fig. 1 for four decision-makers and seven actions.

Thus, the net flow of each decision maker is used to build a matrix in order to calculate the final net flows of each action, resulting in the group evaluation (Brans and Mareschal, 2005).

GAIA

One of the advantages to use the PROMETHEE family methods is the possibility of interpreting geometrically the results by the GAIA method (Mareschal and Brans, 1988).

In this method, at first a uni-criterion flow for the criterion "*l*" is calculated according to Eq. 5, where "a_i" represents the action "*i*" for which the flow is being calculated (Hayes *et al.*, 2009).

$$\varphi_l(a_i) = \frac{1}{m-1} \sum_{j=1}^{m} \{ p_l[d(a_i, a_j)] - p_l[d(a_j, a_i)] \} \quad (5)$$

Equation 5 is then used to calculate the uni-criterion flow matrix Φ, where each column represents a criterion and each row, an action.

$$\Phi = \begin{bmatrix} \varphi_1(a_1) & \cdots & \varphi_n(a_1) \\ \vdots & \ddots & \vdots \\ \varphi_1(a_m) & \cdots & \varphi_n(a_m) \end{bmatrix} \quad (6)$$

Using the biplot method (Kohler and Luniak, 2005) in matrix Φ, the actions and criteria are projected in a plane shaped by the two first eigenvectors, which is called GAIA plane.

In GAIA plane, actions are represented by points and criteria by vectors. Moreover, the vector of weights $W(\omega_1, \omega_2, ..., \omega_n)$ in the k-dimensional space can be projected on the GAIA plane, as demonstrated in Fig. 2. The projection of the weight vector on the GAIA plane is called decision stick (β).

According to Alencar and Almeida (2010), the GAIA method provides graphic information about conflicting aspects concerning the criteria and about the impact of weights in the final decision, thus enriching the view of the decision-makers one the issue.

Brans and Mareschal (2005) state that the analysis of the GAIA plane helps at understanding the structure of the problem:

- criteria represented by longer vectors in the GAIA plane indicate more variable criteria;
- criteria with judgments that present a positive correlation coefficient are represented by vectors pointing to the same direction, or approximately to the same direction;
- criteria with judgments that present a negative correlation coefficient are represented by vectors in opposite directions;
- criteria with large weights are represented by vectors with directions near to that of the decision stick;
- criteria that are not statistically correlated are represented by vectors in orthogonal directions;
- similar actions are represented by points that are close to one another; and
- actions that stand out for being good at a certain criterion are represented by points located in the direction of the vector concerning the criterion in question.

In order to meet the objectives of this study, this approach was applied to evaluate the development of the ITA-SAT satellite project.

ITA-SAT SATELLITE PROJECT

The ITA-SAT satellite project is part of the pluri-annual plan of "*Desenvolvimento e Lançamento de Satélites Tecnológicos de Pequeno Porte*", concerning the development and launch of small technological satellites. It was created by Action number 4,934, from the Brazilian Space Agency (AEB), which aims at performing a series of missions in order to experiment, develop, and test technological innovations of satellites and to enhance the Brazilian industry, in order that it can meet the future needs concerning micro and nano-satellites.

This activity involves AEB, the National Institute for Space Research (INPE), and the Technological Institute of Aeronautics (ITA). Other upper education institutions may be associated with the project by means of a cooperation term with ITA.

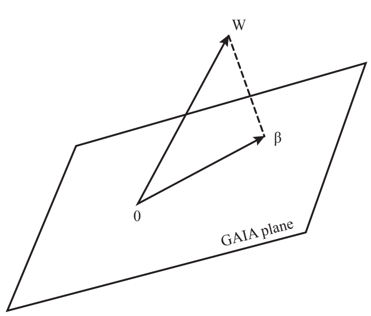


Figure 2. Vector of weights projected on GAIA plane. (Brans and Mareschal, 1994).

The ITA-SAT project was subdivided into stages, according to the Standards of the European Space Agency: (0) mission analysis/needs identification; (A) feasibility; (B) preliminary definition; (C) detailed definition; (D) qualification and production; (E) utilization, and (F) disposal. More details on each stage can be observed in the standard ECSS-M-ST-10C of the European Space Agency (ESA) (ESA, 2009).

The ITA-SAT project began in 2009, and stages 0, A and B are concluded, with their respective revisions, Mission Definition Review (MDR), Preliminary Requirements Review (PRR), System Requirements Review (SRR), and Preliminary Design Review (PDR). Details may also be seen in the standard ECSS-M-ST-10C of the ESA.

During the performance of this study, the ITA-SAT satellite project was facing many problems, including the difficulty to establish a well-defined scope for the project. The types of activities that should be performed were not previously known, so the scope was periodically altered as the team became more experienced and obtained more knowledge on the product that was being designed. Concerning deadlines and objectives, the pace of development in the project was different in several subsystems, and many activities were on hold because they depended on the conclusion of others, which were not concluded on time. Also, the communication and documentation of the activities were not efficient in the subsystems, and much of the knowledge that resulted from an activity was lost when a member of the team left the project. Such problems

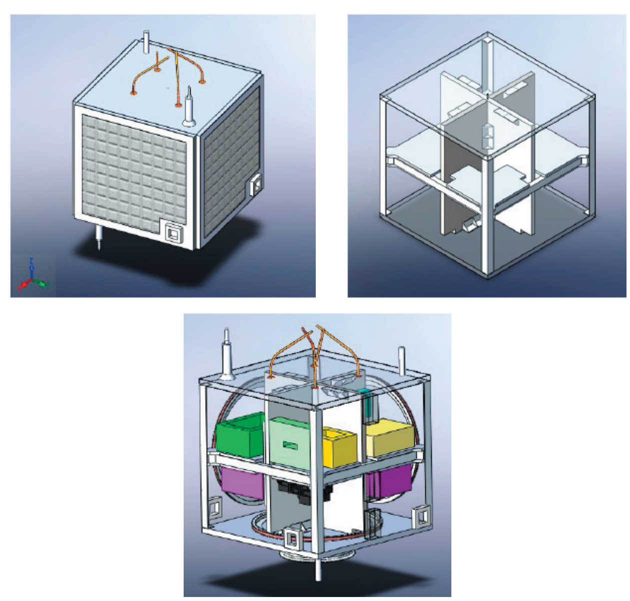


Figure 3. Internal and external configuration and disposition of equipment in the ITA-SAT satellite project. (Sato *et al.*, 2011)

justified the development performance evaluation in the ITA-SAT satellite project in order to search for ways to improve, solve, or ease those issues.

Identification and analysis of the decision context

The ITA-SAT satellite project, whose preliminary configuration can be seen in Fig. 3, involves the development of subsystems for attitude control (AC), on-board computer (OBC), potency (PT), thermal control (TC), structure (ST), and telecommand and telemetry (TT).

The functions of these subsystems, according to Larson and Werts (1999) *apud* Sato *et al.* (2009), are next showed.

AC

It controls the direction the satellite should be pointed at, since it is necessary that some of its instruments are pointed at a specific point.

OBC

It controls internal communication, the satellite, and on-board data processing. Two types of data are processed by this subsystem: housekeeping data and scientific ones. The first ones are related to electrical tension, position, status of the active subsystems, temperature etc., which are used by the ground segment to work on the subsystems' function. Scientific data, however, are collected by on-board instruments for studies, such as images and radiation measurements. Due to the different nature of the activities in subsystem OBC, we divided the subsystem into OBC – Software (OBC-S) and Hardware (OBS-H).

PT

It generates, stores, conditions, and distributes energy for the satellite subsystems.

TC

It ensures that all subsystems and components of the satellite will function within the temperature ranges defined by the project.

ST

It represents the mechanical connection between the different subsystems and components in the satellite. It should be able to sustain the efforts during launch and at the moment of uncoupling the launch vehicle, consisting of a surface on which the equipment is put together. Also, it should provide protection against radiation, it should have a coupling interface with the launch vehicle, besides being in charge of grounding for thermal and electrical ends.

TT

It enables the information exchange between the satellite and the ground control station. As to decision-makers, four representatives were selected among the participants of the project. The general manager considered them as those who had more knowledge on the subject.

Structuring the problem and the multicriteria model

Taking into account that ITA-SAT consists of the first project for the development of a Brazilian university satellite, many traditional management methods established in literature, such as those mentioned in the Project Management Body of Knowledge (PMBOK) (PMI, 2008), were not used in this project. Therefore, no development indicators were prepared when this research was carried out.

Furthermore, the indicators used to assess each subsystem were obtained by literature analyses on management development indicators of projects. We have chosen to use the ones described in PMBOK and those by Terribili Filho (2010).

Time management

It evaluates the efficacy of the project management to define and continue activities, to estimate the length and necessary resources, to develop, and to control the project timetable.

Communication effectiveness

It analyzes the efficiency of the project management to make sure the information is properly generated, collected, stored, distributed, recovered, and organized.

Risk management

It evaluates the efficacy of the project management concerning planning, identification and analysis processes, as well as response planning, monitoring, and risk control.

Integration management

It analyzes the efficiency of the management concerning the performance of necessary activities to identify, define, combine, gather, and coordinate the processes of different subsystems that compose the project.

Cost management

It evaluates the efficacy of the project management to estimate, budget, and control costs in order to conclude the project without exceeding the budget.

Quality management

It analyzes the efficacy of the project management in order to define quality policies, objectives and responsibilities, so that the needs for which the project was initiated could be met.

Among the mentioned criteria, we observed that since this is the first project of a university satellite in Brazil, many of the necessary technologies should be developed. This fact did not allow us to predict the aspects related to cost or to the quality of the project, since we could not tell which type of technology would be used in the project's final configuration. Because of that, the cost management criteria, as well as the quality criteria, were excluded from the decision model.

In this study, we tried to evaluate the performance based on the perception of the project's team, using a judgment scale comprised of five categories, as presented by Freitas *et al.* (2009). This scale ranges from one (very poor) to five (very good), and it is detailed in Chart 1.

In order to determine the preference functions, the ones demonstrated in Chart 2 were presented to the decision-makers, and the usual function was considered as the most adequate for the used criteria and by the decision makers in this study. During the interviews, they said that, according to the adopted scale, any difference between judgments was significant, therefore, it would be taken into account for the final result. After the definition of the evaluation scale and the preference functions, each decision-maker was asked to ponder the criteria. Besides, the general manager was asked to ponder the knowledge of each decision-maker concerning the project. These data can be seen in Appendix 1.

Individual analysis

With the objective of evaluating the development performance of the project's subsystems, individual evaluations with the perceptions of each decision-maker were performed. Therefore, after a brief explanation about the PROMETHEE method, the verbal and numeric scales in Chart 1 were presented. Afterwards, every decision-maker was asked to think of an alternative that represented, in their opinion, a 'very poor' performance in an analyzed criterion. Based on this hypothetical alternative, each decision-maker had to answer how much better they considered the ITA-SAT satellite project in the evaluated criterion. Many of them answered they had pictured the ITA-SAT project as a 'very poor' alternative, thus obtaining one in the numeric scale. In other occasions, they said the ITA-SAT project performed twice, three times or four times better than the very poor hypothetical alternative. It is important to mention that no decision-maker considered the performance of the ITA-SAT project equal or five times better than the considered hypothetical alternative. With these questions, the evaluations of the decision-makers about the performance of each subsystem are demonstrated in Appendix 1.

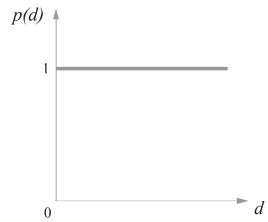
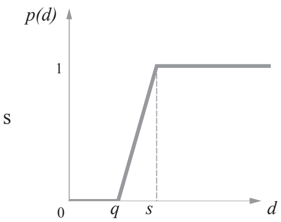
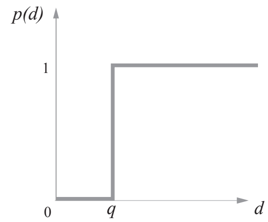
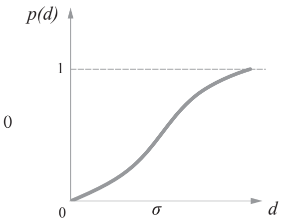
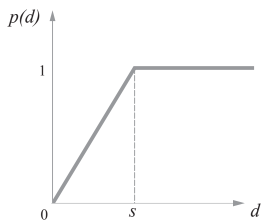
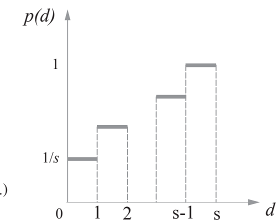
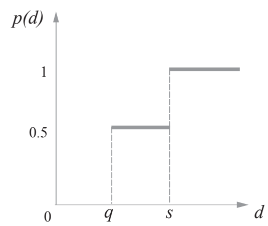
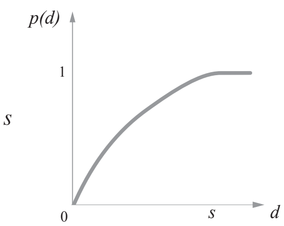
After collecting judgments, the subsystems were individually assessed with the software D-Sight (Macharis *et al.*, 2010). Net flows concerning the performance of each subsystem for each decision-maker DM_i (i=1,2,3,4) are demonstrated in Table 1, with the order of priority of each subsystem. It is worth to mention that when the net flows were the same, the number corresponding to the order of priority was repeated for the tied subsystems.

Each decision-maker analysis concerning the GAIA plane is presented in Chart 3. In these planes, vectors with squared extremities represented the criteria; triangles represented the actions; and the vector with the circular extremity, the decision stick.

Table 1. Net flows of each subsystem, for each decision-maker.

Subsystems	DM_1	Order	DM_2	Order	DM_3	Order	DM_4	Order
Attitude Control (AC)	-0.3833	6	-0.9167	7	-0.4333	3	-0.8333	4
Thermal Control (TC)	0.1667	3	0.8667	1	0.7333	1	0.5417	1
Structure (ST)	-0.4833	7	-0.1167	4	-0.4333	3	-0.0833	3
OBC – Hardware (OBC-H)	0.5667	1	0.7167	2	0.7333	1	0.5417	1
OBC – Software (OBC-S)	0.0167	4	0.2167	3	0.2667	2	0.5417	1
Potency (PT)	-0.1167	5	-0.5833	6	-0.4333	3	-0.8333	2
TT (TT)	0.2333	2	-0.1833	5	-0.4333	3	0.1250	3

Chart 2. Preference functions used by the PROMETHEE methods.

Criterion	Preference function	Graphic representation	Criterion	Preference function	Graphic representation
Usual	$p(d) = \begin{cases} 0, \text{se } d = 0 \\ 1, \text{se } d > 0 \end{cases}$		Linear	$p(d) = \begin{cases} 0, \text{se } d \leq q \\ \frac{d-q}{s-q}, \text{se } q < d \leq s \\ 1, \text{se } d > s \end{cases}$	
U Form	$p(d) = \begin{cases} 0, \text{se } d \leq q \\ 1, \text{se } d > q \end{cases}$		Gaussian	$p(d) = \begin{cases} 0, \text{se } d = 0 \\ 1 - \exp\left(-\frac{d^2}{2\sigma^2}\right), \text{se } d > 0 \end{cases}$	
V Form	$p(d) = \begin{cases} 0, \text{se } d = q \\ \frac{d}{s}, \text{se } 0 < d \leq s \\ 1, \text{se } d > s \end{cases}$		Multistage	$p(d) = \begin{cases} 0, \text{se } d = 0 \\ \frac{1}{s}, \text{se } 0 < d \leq 1 \\ \frac{2}{s}, \text{se } 1 < d \leq 2 \\ \ldots \\ \frac{s-1}{s}, \text{se } s-2 < d \leq s-1 \\ 1, \text{se } s-1 < d \leq s \leq \max r_j(.) \end{cases}$	
With levels	$p(d) = \begin{cases} 0, \text{se } d \leq q \\ 0,5, \text{se } q < d \leq s \\ 1, \text{se } d > s \end{cases}$		C Form	$p(d) = \begin{cases} 0, \text{se } d = 0 \\ \sqrt{\frac{d}{s}}, \text{se } 0 < d \leq s \\ 1, \text{se } d > s \end{cases}$	

(Adapted from Podvezko and Podviezko, 2010).

For decision-maker 1 (DM_1), the analysis of the GAIA plane showed that criteria with more heterogeneous judgments were: integration management (IM), communication effectiveness (CE), and time management (TM). Also, when analyzing the direction of the vectors, the presence of conflicts between risk management criteria (RMC) against time management (TM) and communication effectiveness (CE) were observed. This means that according to DM_1, the subsystems that presented better performance in the first criterion did not have good results in the last two ones, and vice-versa.

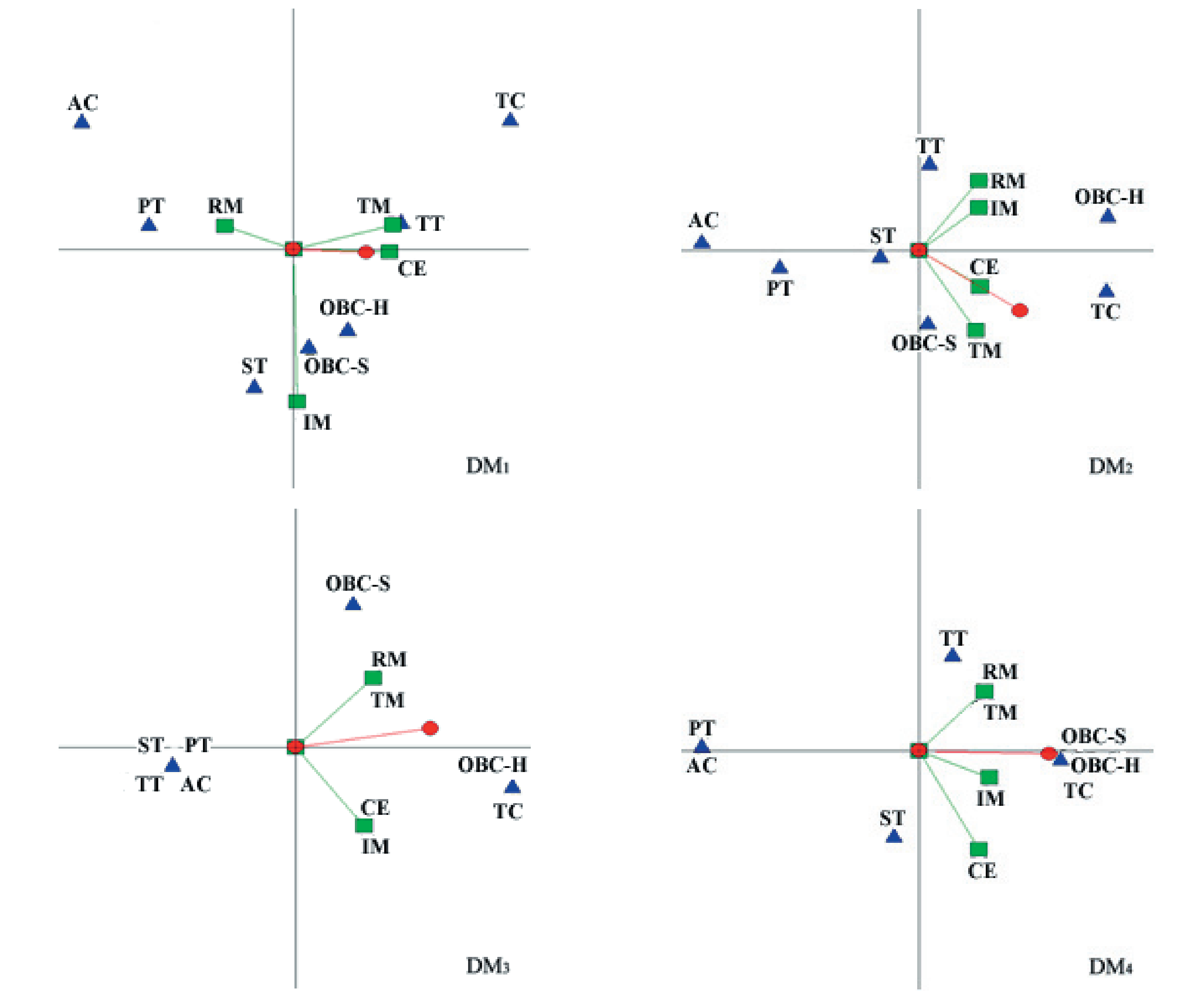
Such discrepancy in judgments was justified by DM_1 as related to resource allocation. The subsystems have limited resources to invest in managerial aspects related to each criterion, and only one subgroup out of these criteria is prioritized as to the adoption of managerial evaluations; this is why the performances differ in the subgroups.

Concerning decision-makers 2, 3 and 4, the size of criteria vectors indicates that they present approximate variances, thus influencing the final order in a more homogenous manner. Many criteria express similar preferences, so the vectors are pointed to the right. Besides, the subsystems AC, ST and PT are always located in an opposite direction to that of the criteria vectors, which shows there is conflict of preference (judgments of lower value) and, consequently, higher criticality, which can be observed in three out of the four orders exposed in Table 1.

Specifically in relation to decision-maker 2, vectors concerning risk management and integration present approximate directions, as well as those referring to CE and TM, thus reflecting more similar judgments when both groups of criteria are compared.

In relation to decision-maker 3, we observed the presence of two groups of criteria with the same judgments, and those

Chart 3. GAIA plane of decision-makers (i=1, 2, 3,4).



referring to RM were similar to those of TM; the ones referring to CE are the same as the judgments of IM. Besides, two groups of actions are similar; the first one is comprised of PT, TT, ST and AC, and the second one is comprised of TC and OBC-H. Something similar happened in relation to the GAIA plane of decision-maker 4, with similar judgments for two criteria (RM and TM) and two groups of action with the same judgments, being the first TC, OBC-H and OBC-S, and the second PT and AC.

After analyzing data from the GAIA planes, it was observed that the planes by decision-makers 2, 3 and 4 are very similar. The groups of criteria observed in these planes lead to the conclusion that decision-makers 3 and 4 associated RM with TM, which also brings similarities between CE and IM.

Global analysis

After the individual evaluations, the global analysis was performed with PROMETHEE GDSS. In this step, net flows of each decision-maker presented in Table 1 were used to make a performance matrix (as presented in Table 2). Procedures of PROMETHEE II were used with data in this performance matrix in order to calculate the flows of each subsystem, resulting in the group evaluation.

It is worth to mention that subsystems AC, ST and PT were considered as the most critical ones in the global evaluation, which is in accordance with many of the results obtained with the individual analyses. After prioritizing the subsystems, a sensitivity analysis was performed with the

Table 2. Performance and flow matrix for each subsystem.

Subsystems	DM_1	DM_2	DM_3	DM_4	φ	Order
Attitude Control (AC)	-0.3833	-0.9167	-0.4333	-0.8333	-0.713	7
Thermal Control (TC)	0.1667	0.8667	0.7333	0.5417	0.643	2
Structure (ST)	-0.4833	-0.1167	-0.4333	-0.0833	-0.570	5
OBC – Hardware (OBC - H)	0.5667	0.7167	0.7333	0.5417	0.837	1
OBC – Software (OBC - S)	0.0167	0.2167	0.2667	0.5417	0.267	3
Potency (PT)	-0.1167	-0.5833	-0.4333	-0.8333	-0.527	6
TT (TT)	0.2333	-0.1833	-0.4333	0.1250	0.063	4

software D-Sight, obtaining the minimum and maximum intervals; in between, the weight values of each decision-maker can vary without changing the priority order of the subsystems. As demonstrated in Table 3, the priority order is not even changed after 25% alterations (or more) in the pondering of the decision-makers, which makes the priority of the subsystems more acceptable for this study.

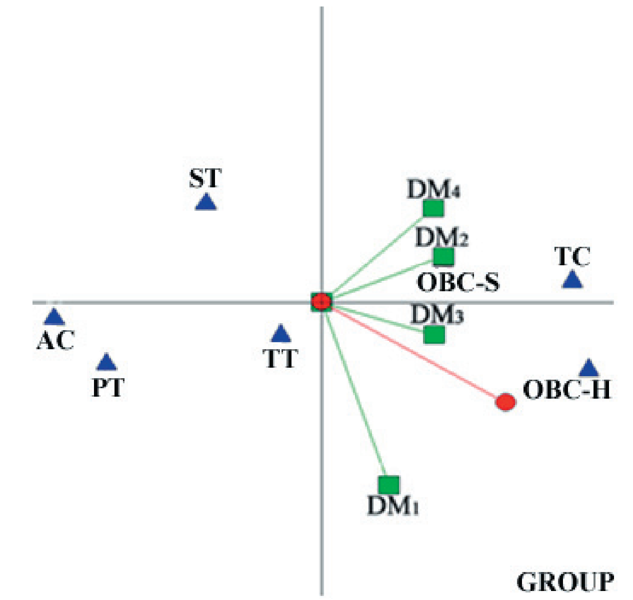
Table 3. Range of variation of the weights.

Decision-makers	Minimum weight (%)	Current weight (%)	Maximum weight (%)
1	12.68	38.00	100.00
2	0.00	18.00	48.10
3	0.00	26.00	100.00
4	0.00	18.00	100.00

Chart 4 presents the GAIA plane of the group decision, and it is possible to observe there is a conflict of preferences between DM_1 and the others. As seen, DM_1 is the same that had net flows with major differences in relation to the others. This aspect was seen as an indication that this decision-maker knew more about the project and, consequently, his/her judgment was different from the others, since the general manager pondered it as being the most important one (according to Chart A4).

When analyzing the conflict presented by the decision-makers, we noticed that DM_1 presented the three subsystems ST, AC and PT as those with the worst performances, while decision-makers 2 and 3 consider subsystems AC, PT and TT having the worst performances. The exception is decision-maker 4, who presents (because of ties) the four subsystems previously presented (AC, ST and TT) as those with the worst performances. Such discrepancy was discussed in a workshop with the general manager, with the decision-makers, and the other members of the team. The consensus was that the considerations of DM_1 were more coherent to the reality of the project. It is important to say that the three subsystems regarded as having the worst performance by the group of decision-makers coincided with the choice of DM_1.

Chart 4. GAIA plane of the group of decision-makers.



With the objective of addressing the actions and improving the performance within the subsystems that had the worst performance, a complementary analysis took place to identify which indicators were more deficient. In this analysis, the considerations of each decision-maker in relation to each indicator and subsystem were added, as presented in Table 4. For example, to obtain the performance index of subsystem AC, in relation to the criterion TM, the judgments of decision-makers 1, 2, 3 and 4 in this criterion were added, and, according to Appendix 1, the result is 2 + 1 + 1 + 1 = 5.

With this procedure, the priority orders to perform the improvement actions in each subsystem were obtained. The most critic situations were in subsystems AC and PT, concerning indicator CE, and in the subsystem ST, the indicator RM. With this result, the auditing of the indicators that presented worse performance in the subsystems was proposed to the general manager.

Table 4. Prioritizing indicators within each subsystem.

Subsystems/Criteria	TM	CE	RM	IM
Attitude control (AC)	5	4	6	5
Structure (ST)	7	10	6	10
Potency (PT)	6	5	6	7

FINAL CONSIDERATIONS

This study aimed at investigating the application of PROMETHEE GDSS and GAIA methods for the performance evaluation in the subsystems of the ITA-SAT project. Based on the study, advantages were observed as to the use of such methods.

- Higher adherence of the project's team: the use of PROMETHEE GDSS enabled the higher adherence of the team to the obtained results, due to the participation of different decision-makers, each one representing different interests inside the project.
- More dependability to analyze judgments: due to the use of preference functions, the behavior of the values given by decision-makers in relation to different performances presented by a criterion can be shaped in a way to get better accuracy as to the characteristics, which are really valuable for the decision-makers.
- Geometric interpretation of data: the GAIA method enabled the identification of similarities and conflicts of preference between decision-makers and criteria, which can be used to check a consensus among them.

Concerning the first mentioned advantage, it was proved to be essential when the results were presented during a meeting for the other project members. Therefore, it was questioned if there was the participation of members with points of view that reflected the diversity of the work groups. Even though the PROMETHEE GDSS method does not restrict the number of decision-makers for the performance of judgments, their number can be limited due to the lack of accessibility of the facilitator and/or because of their maximum ability to collect and insert data in the model. Therefore, the general manager was asked to point out the most important decision-makers, indicating the four ones mentioned in this study.

In order to assist the general manager in facing the problems of the project, improvement actions were proposed on the subsystems and indicators that presented worse performances. Such actions consisted of creating or improving the management plans for each analyzed subsystem and indicator; redefining the frequency with which each management plan is revised and updated; updating the management plan, in order to involve the representatives of the project's subsystems; implementing mechanisms of learned lessons; consolidating a system of periodic evaluation/auditing; developing methods to make sure each member of the team is being instructed as to the activities to be performed, and, finally, to come up with ways to make sure the members of the project have feedback on their performance.

In relation to the limitations of this study, it is important to say that we did not consider the criteria CM and QM, which might have influenced the model in order to change the performance ranking of the subsystems. In this sense, it is clear that the results obtained in this study do not completely show the general performance of each subsystem, but their performance in relation to the criteria TM, CE, RM and IM. Besides, the adopted scale uses qualitative levels (concerning the following performances VG, G, M, P and VP), with unclear definitions, which possibly resulted in the imprecision of judgments.

Finally, the suggestion is that future researchers perform studies with the objective of handling the presented limitations, be it by investigating ways for the decision-makers to define their judgments concerning cost and quality indicators in innovation projects, be it with the construction of scale of judgments that use qualitative levels with a more precise definition. Furthermore, it is possible to investigate the use of other MCDA methods to evaluate the performance of each subsystem.

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Appendix 1. Judgments and weights of the decision-makers.

Chart A1: Decision-maker 1

Criteria	TM	CE	RM	IM
Attitude Control (AC)	2	1	3	2
Thermal Control (TC)	4	4	1	2
Structure (ST)	2	2	1	4
OBC – Hardware (OBC-H)	3	4	3	4
OBC – Software (OBC-S)	3	2	2	4
Potency (PT)	2	2	3	3
TT (TT)	3	4	2	3

Chart A2: Decision-maker 2

Criteria	TM	CE	RM	IM
Attitude Control (AC)	1	1	1	1
Thermal Control (TC)	4	4	3	4
Structure (ST)	2	3	2	2
OBC – Hardware (OBC-H)	3	4	4	4
OBC – Software (OBC-S)	3	3	2	2
Potency (PT)	2	1	1	2
TT (TT)	2	2	3	3

Chart A3: Decision-maker 3

Criteria	TM	CE	RM	IM
Attitude Control (AC)	1	1	1	1
Thermal Control (TC)	2	2	2	2
Structure (ST)	1	1	1	1
OBC – Hardware (OBC-H)	2	2	2	2
OBC – Software (OBC-S)	2	1	2	1
Potency (PT)	1	1	1	1
TT (TT)	1	1	1	1

Chart A4: Decision-maker 4

Criteria	TM	CE	RM	IM
Attitude Control (AC)	1	1	1	1
Thermal Control (TC)	3	4	3	4
Structure (ST)	2	4	2	3
OBC – Hardware (OBC-H)	3	4	3	4
OBC – Software (OBC-S)	3	4	3	4
Potency (PT)	1	1	1	1
TT (TT)	3	3	3	3

Chart A5: Weights of criteria and decision-makers

Decision maker	TM	CE	RM	IM	Weights of decision makers
DM_1	0.30	0.30	0.30	0.10	0.38
DM_2	0.40	0.40	0.10	0.10	0.18
DM_3	0.20	0.30	0.40	0.10	0.26
DM_4	0.25	0.25	0.25	0.25	0.18