Chapter 6
Multicriteria Decision Support Model for Selection of Fiberglass Suppliers:
A Case Study in a Wind Industry Company

Celina Rodrigues
Polytechnic of Porto, Portugal

Ana Paula Lopes
https://orcid.org/0000-0003-1603-6959
Polytechnic of Porto, Portugal

EXECUTIVE SUMMARY

This chapter presents a real case of a decision problem in supplier selection of one of the main raw materials of a wind blades industry. The study considered all currently qualified suppliers according to considerably rigorous standards and specifications and one in qualification process. It is a complex choice, given the strategic importance of the product and the multiplicity of criteria to be considered, both quantitative and qualitative. The strong competitiveness requires a special attention which concerns the supplier selection; not only the price matters; in fact, a day of stoppage due to failure in a delivery, for example, corresponds to high losses that would have justified the purchase from a supplier with a higher price but with no delivery failures. In order to contribute to the problem resolution, the methodologies PROMETHEE and AHP were applied, whose results allow the authors to stablish a ranking of the considered suppliers. The results will support the company on the selection of fiberglass suppliers and in some cases clarify where they can find the main trade-offs.

DOI: 10.4018/978-1-7998-9140-6.ch006

INTRODUCTION

The literature is unanimous with regard to the growing importance of the purchasing process and the consequent selection of suppliers, as is the case of (de Boer, Labro, & Morlacchi, 2001) when they mention that with the increasing significance of the purchasing function, purchasing decisions become more important. As organisations become more dependent on suppliers the direct and indirect consequences of poor decisions making become more severe.

According to (Izadikhah, 2012) cited by (Azadfallah, 2017), the success of a supply chain is highly dependent on selection of good suppliers.

On (Katsikeas & Leonidou, 1996) perspective, international supplier selection is a complex decision-making problem. The complexity stems from a multitude of quantitative and qualitative factors influencing supplier choices as well as the intrinsic difficulty of making numerous trade- offs among these factors.

According to (Monczka et al., 1998), cited by (Chen, Lin, & Huang, 2006), the supplier selection problem has become one of the most important issues for establishing an effective supply chain system. The overall objective of supplier selection process is to reduce purchase risk, maximize overall value to the purchaser, and build the closeness and long- term relationships between buyers and suppliers. In fact, on the company herewith studied the invitation to one supplier to start the qualification process came from a long term relationship supplying similar material.

The impacts of this choice, according to (Dias, 2015) may spread from the specific purchasing area to other areas of the company, with a final impact on the profits obtained. According to (Çebi & Bayraktar, 2003) the supplier selection problem involves several criteria that conflict with each other. It is therefore important in decision making to consider as many criteria as possible, covering different perspectives, in order to make the choice sustained and informed.

With the COVID-19 pandemic, all of world's wind turbine and component factories are now open following the easing of restrictions across world. Sanitary measures are strengthened within sites to guarantee full compliance with government recommendations. Wind power installations in 2020 were down 30% compared to industry forecasts. It was also found that any continuous restriction on the movement of goods and people reduced activity and increased capital expenditures (CAPEX). Like many other manufacturing or service enterprises, supply chains in the wind sector will continue to be impacted in the months ahead. Some project milestones will be deferred, with impacts being felt throughout the whole value chain, whilst at the operational level; turbines, blades, component and material orders will be cancelled or unfulfilled (Eddie Rae, 2020). The biggest challenges for entities of any size is the dramatic reductions in revenue creation that have occurred and continue to occur. Unfortunately, in a business crisis, one of the first immediate solutions

is to delay payments to creditors. You may be super-efficient in most aspects of your operations, have substantial reserves, long-term contracts, or access to deep corporate pockets or competitive financing, but sooner or later no cash generation equals no company.

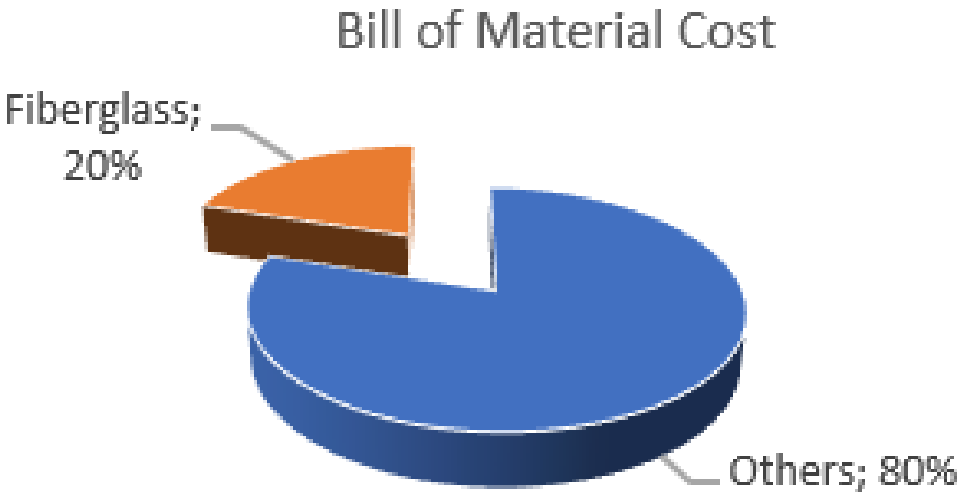
The Wind Industry, as many others, with the globalization and the COVID-19 pandemic, faces high levels of competitiveness. To survive and get success, has now to play in a field much more sensitive and instable, everyday confronting other players fighting for the same.

In the company herewith studied, which is part of a multinational, the competitors are both inside and outside the group and located in many different geographies.

Despite the importance of the raw material price, which frequently have the main attention, each improvement, even small, in the supply chain, such as, lead times, transit times or supplier flexibility, has a positive impact in the company performance. For the most of decision makers it is easy to understand that a lack of material due a supply failure may have a huge impact in terms of stoppage costs, so, the roll of the supplier is much more than offer a good price.

One of the more 200 materials necessary in the production of wind blades is fiberglass. The fiberglass for this kind of product is very specific and subjected to tight quality criteria, and that is the main reason for not having many qualified suppliers all over the world. It turns out that this raw material is strategic as represents 20% of the Bill of Material (BOM) cost.

Figure 1. Bill of material cost distribution
(Source: own)



The company understands that despite the price and direct costs related with the purchasing, there are other factors that well managed, at the end of the day, will may represent different kind of savings. At a phases that the company is distributing the volume to five suppliers, the strategy is to select only two of them, the question is, which two have the best combination between the criteria which are considered more relevant. The company is clearly facing a challenge of a multicriteria decision in choosing the best suppliers, from one hand, suppliers with good price but located in the other side of the globe, and on the other, suppliers in the neighborhood but with higher prices. This combined with other criteria, such as lead time or quality makes this a traditional problem that can be supported by different Multicriteria Decision Analyses Methods.

For this case study, in order to support the decision-makers, two MCDA were applied, the PROMETHHE (Preference Ranking Organization Method for Enrichment Evaluation) and AHP (Analytic Hierarchy Process).

Both methods were often used in supporting Multicriteria Selection Analysis in many different areas including the supplier selection problematic.

MULTICRITERIA DECISION ANALYSIS

There are several methods with different approaches but with the same goal, to support multicriteria decision making problematic. To (Alves, 2018), the multicriteria decision analysis aim to be a support tool to analysts and decision makers in scenarios where is needed to identify priorities having multiple criteria and involving two or more alternatives.

Even according to the author, it is common to classify the methods in two groups, the ones developed by the American school, which aims to reduce the various criteria to a synthesis criterion, in most cases, through a weighted sum, from which the AHP, TODIM and MACBETH methods stand out, and those developed by the French school, based on prevalence relations as ELECTRE and PROMETHEE family methods.

In this case study, to support a traditional supplier selection, two methods will be applied, one from the American school AHP (Analytic Hierarchy Process) and other from the French one, the PROMETTHEE (Preference Ranking Organization Method for Enrichment Evaluation).

Both methods have been widely applied over time to support the problem of selecting suppliers, as they consider the decision-maker's perception in the model, which translates into results that are suitable with the strategic vision of each one.

METHODOLOGY

Criteria Definition

Studies over the years have addressed a variety of criteria that are important in seller selection. The major premise of these studies is that many organizations spend a considerable amount of time evaluating their supply chain partners by the fact the strategic importance of supplier selection (Bayazit, 2006).

The criteria in evaluation were the ones usually considered more relevant for the decision makers, according to their own perception of what should be considered for this kind of analysis. Same as been discussed with three decision makers from Finance, Production and Procurement departments.

Price: the unit measure of this criteria is kg, to make easier the calculations and comparison same has been treated by €/10 Kg. Refers to the cost that the company has to buy this material. It is obviously a quantitative criterion to be minimized.

Transport Cost: depending on the delivery conditions negotiated with the supplier (Incoterm), the transport can be at company responsibility or can be on supplier's side as well as the risk. As the price it will be represented by €/10Kg.

Duties: In the case that the supplier is based out of the UE, import duties may be applied by the TAX authorities depending on the country of origin. In certain cases, also antidumping rules are in the game.

Transit Time: as longer as the transit time is, and again depending on the delivery conditions, the company will have higher inventory costs and higher will be the risk of having delivery delays, is so a quantitative criterion to be minimized and will be presented in days.

Payment Terms: cash flow is highly dependent on the balance of payment/receiving conditions, as longer is the payment term as better, this will be a quantitative criterion to be maximized.

Lead Time: the lead time is the time occurred between the order placement and material reception. As lower the better, at it will give more flexibility to the supply chain in which concern the orders adjustments in terms of quantities and/or delivery dates.

Stock Days: material stopped at warehouse represent a cost, the inventory cost is an important KPI for the company and is reported in daily basis to the board. Beside the cost, the fiberglass is a voluminous material which occupies a considerable area, so the idea is to have the fiberglass stock as lower as possible.

Quality: this criterion is not about the material quality himself as this was already approved on the supplier qualification phasis. It´s mainly regarding the

evaluation of supplier behavior in terms of accomplishment of deliveries, like time, quantity and right documentation. Not only the delay can be a reason for stoppage, wrong or incomplete shipping documents can be as well as can provoke retention at customs for days or weeks. It will be a qualitative criterion to be maximized.

Purchasing Complexity: purchasing decision maker considered that this criterion should be included in the study as they face some constraints with the purchasing process with some suppliers, losing more time to get confirmations and to have all the process clear. He preferred to keep it outside the quality criterion in order to be evaluated separately.

Flexibility: the production plan can have changes that have to be followed by adjustments to the materials orders, in order to anticipate or delays deliveries or even increase or decrease quantities. It is important to have suppliers which can be flexible on accepting as much as possible those changes without extra costs. It is so a criterion to be maximized.

Handling Complexity: this was a criterion raised by the production decision maker as he observed considerable deviations in terms of handling the fiberglass when it is coming from certain suppliers. From one side the transport system, truck or container, and from the other the way as the material is packed. The material goes through three handling processes: unloading from transport system; inbound picking and storage; picking for frontal feeding to cutting line.

Multicriteria Decision Methods

PROMETHEE: Preference Ranking Organization Method for Enrichment Evaluation

According to (J. P. Brans & De Smet, 2016) in order to build an appropriate multicriteria method some requisites could be considered:

Requisite 1: The amplitude of the deviations between the evaluations of the alternatives within each criterion should be taken into account:

$$d_j(a,b) = g_j(a) - g_j(b) \quad (1)$$

Requisite 2: As the evaluations g_j(a) of each criterion are expressed in their own units, the scaling effects should be completely eliminated.

Requisite 3: In the case of pairwise comparisons, an appropriate multicriteria method should provide the following information:

- a is preferred to b;
- a and b are indifferent;
- a and b are incomparable

Requisite 4: Different multicriteria methods request different additional information and operate different calculation procedures so that the solutions they propose can be different. It is therefore important to develop methods being understandable by the decision-makers. "Black box" procedures should be avoided.

Requisite 5: An appropriate procedure should not include technical parameters having no significance for the decision-maker. Such parameters would again induce "Black box" effects.

Requisite 6: An appropriate method should provide information on the conflicting nature of the criteria.

Requisite 7: Most of the multicriteria methods are allocating weights of relative importance of the criteria. These weights reflect a major part of the "brain" of the decision-maker. It is not easy to fix them. Usually the decision-makers strongly hesitate. An appropriate method should offer sensitivity tools to test easily different sets of weight.

To the author the PROMETHEE methods and the associated GAIA visual interactive module are taking all these requisites into account.

PROMETHEE I (partial ranking) and PROMETHEE II (complete ranking) were developed by JP Brands and presented for the first time in 1982 at a conference organized by R. Nadeau and M. Landry at the Université Laval, Québec, Canada (L'Ingénierie de la Décision. Elaboration d'instruments d'Aide à la Décision) (Brans, Jean-Pierre, De Smet, 2017).

According to (Jalalvand, Teimoury, Makui, Aryanezhad, & Jolai, 2011), This methodology includes various types such as PROMETHEE I (partial ranking), PROMETHEE II (complete ranking) and PROMETHEE III (ranking based on intervals) applied in different conditions for different purposes.

The model considers some possible alternatives and evaluate them through pre-established criteria, prioritizing the most appropriate ones, enabling the management to gain an overview of the business and become able to make multifunctional decisions, with possible solution strategies to minimize losses in the system (Morais & Almeida, 2006).

In a most practical view, (Pinho & Lopes, 2020) explain that PROMETHEE method is based on the ordering of a finite set of actions, where a given weight is assigned to each criterion, taking into account its importance. Thus, preference is calculated by combining pairs of alternatives, considering the deviation between two alternatives in a single criterion.

The alternative pairwise comparison of PROMETHEE model requires that a preference function must be associated to each criterion.

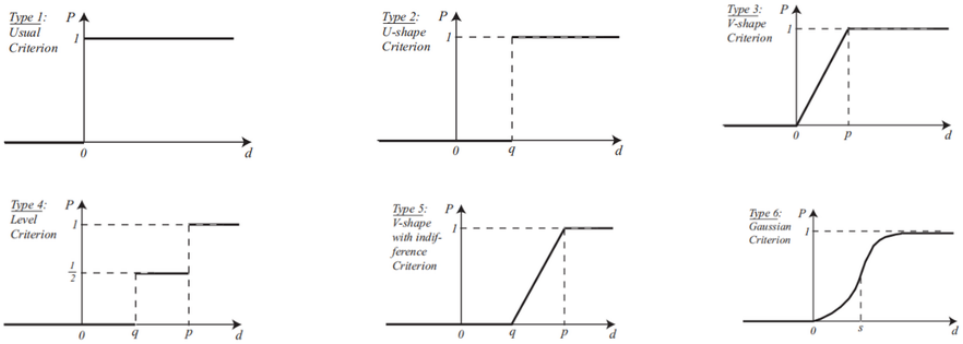
The purpose of the preference function is to translate the difference observed between two actions on a given criterion, from the criterion scale to a normalized

0-1 degree of preference (Mareschal, 2018). The 0-1 preference degree presents the decision maker preference between the alternatives on each criteria; the higher the number, the greater the preference.

As stated, PROMETHEE is based on the pairwise comparison of the alternatives. According to (Mareschal, 2013) it means that the deviation between the evaluations of two actions on a particular criterion has first to be modelled. For small deviations, there will probably be either a weak preference or no preference at all for the best action as the decision-maker will consider this deviation as small or negligible. For larger deviations, larger preference levels are expected.

Means that, beside the weight assignment to the criteria, which is the information between criteria required to apply PROMETHEE method, the decision maker, the method goes deeper in the subconscious of the decision maker with the information within criteria which is modelled by the preference functions.

Figure 2. Type of preference functions (Brans e Smet, De, 2016)



Depending on the chosen preference function, 0, 1 or 2 parameters have to be defined:

- q is a threshold or indifference;
- p is a threshold of strict preference;
- s is an intermediate value between q and p

The q indifference threshold is the largest deviation which is considered as negligible by the decision maker, while the p preference threshold is the smallest deviation which is considered as sufficient to generate a full preference (Brans, Jean-Pierre, De Smet, 2017).

To apply PROMETHEE method the first step is to compare each alternative with each other for all criteria.
So, given two alternatives *ai*, *aj*, we define the preference index as:

$$\pi\left(a_i, a_j\right) = \sum_{k=1}^{q} w_k P_k\left(a_i, a_j\right) \tag{2}$$

where, w_k refers to the weight assigned to the criterion k and $P_k(a_i,a_j)$ refers to the value of the preference function according to the difference between the evaluation of the alternatives a_i and a_j on the criterion k, where

$$d_k(a_i,a_j) = g_k(a_i) - g_k(a_j) \tag{3}$$

π(ai,aj) to be calculated for all criteria and represents the intensity of preference of the decision maker of alternative a*i* over alternative a*j* when considering simultaneously all the criteria. It is a figure between "0" and "1" and

π(ai,aj)=0 denotes a weak preference of "a1„ over "a2„ for all the criteria;
and
π(ai,aj)=1 denotes a strong preference of "a1„ over "a2„ for all the criteria (Anand & Kodali, 2008).

$$\sum_{k=1}^{n} w_k = 1 \tag{4}$$

P_k - Preference function
If the criterion is to be maximized then

$$P_k\left(a_i, a_j\right) = F_k\left[d_k\left(a_i, a_j\right)\right] \forall a_i, a_j \in A \tag{5}$$

where,

$$d_k(a_i,a_j) = g_k(a_i) - g_k(a_j) \tag{3}$$

and for which,

$$0 \le P_k(a_i,a_j) \le 1 \tag{6}$$

If the criterion is to be minimized, then

$$P_k\left(a_i, a_j\right) = F_k\left[-d_k\left(a_i, a_j\right)\right] \forall a_i, a_j \in A \tag{7}$$

Appling the methodology two indicators are used to evaluate the preference relationship between alternatives (Brans & Mareschal, 2005), those indicators are generated by the computation of the preference index $\pi(a_i, a_j)$ and $\pi(a_j, a_i)$ for each pair of alternatives

-the positive preference flow $\phi^+(a)$ measures how much an action a is preferred to the other n-1 ones. It is a global measurement of the strengths of action a. The larger $\phi^+(a)$ the better the action

$$\Phi^+\left(a\right) = \frac{1}{n-1}\sum_{a_j \neq a_i} \pi\left(a_i, a_j\right) \tag{8}$$

-the negative preference flow $\phi^-(a)$ measures how much the other n-1 actions are preferred to action a. It is a global measurement of the weaknesses of action a. The smaller $\phi^-(a)$ the better the action.

$$\Phi^-\left(a\right) = \frac{1}{n-1}\sum_{a_j \neq a_i} \pi\left(a_j, a_i\right) \tag{9}$$

The net preference flow $\phi(a)$ is the balance between the positive and negative preference flows:

$$\Phi\left(a\right) = \Phi^+\left(a\right) - \Phi^-\left(a\right) \tag{10}$$

It thus takes into account and aggregates both the strengths and the weaknesses of the action into a single score. $\Phi(a)$ can be positive or negative.

The larger the $\Phi(a)$ better the action (Mareschal, 2013).

Thus, so, two rankings will be generated:

- **PROMETHEE I** – partial ranking, is obtained from the positive and the negative outranking flows.

In some cases partial ranking will not decide which alternative is the best, assigning that responsibility to the decision maker, that's why (Brans, Jean-Pierre, De Smet, 2017) consider that the PROMETHEE I ranking as prudent.

- **PROMETHEE II** – complete ranking, is the balance between the positive and the negative outranking flows. The higher the net flow, the better the alternative.

  An alternative a_i will be preferred to a_j if $\Phi(a_i) > \Phi(a_j)$
  An alternative a_i will be indifferent to a_j if $\Phi(a_i) = \Phi(a_j)$

According to (Brans, Jean-Pierre, De Smet, 2017), when PROMETHEE II is considered, all the alternatives are comparable. No incomparability remains, but the resulting information can be more disputable because more information gets lost by considering the difference (10).

Based on (Mareschal, 2013) the PROMETHEE GAIA is used to minimize the loss of information, starting from a multidimensional representation of the decision problem. The objective is to graphically describe the main characteristics of the decision problems, among other aspects, determining if the alternatives are different or similar from each other, which criteria conflict, what is the impact of the weighting assigned to the criteria in the ranking obtained.

AHP - Analytic Hierarchy Process

According to (Saaty, 1990) a decision is defined by a structure which represents the elements of the problem: a goal, criteria, sub criteria and alternatives (options) and a set of judgements to establish relationships among them. The aim is to derive a scale of relative importance for the alternatives.

Developed by Thomas L. Saaty in the 1970s, the AHP, Analytic Hierarchy Process, uses hierarchy structures, matrices and linear algebra to formalize the decision process.

The method was built on three principles: the principle of constructing hierarchies, the principle of establishing priorities, and the principle of logical consistency (Badri & Abdulla, 2004).

AHP has been a popular approach for supplier selection and has been used in a wide variety of situations by a number of researchers (Perçin, 2006). According to (Levary, 2007), one advantage of the AHP is that forces the user to systematically and carefully evaluate the importance of each criterion in relation to the others in a hierarchical manner.

On supplier selection, with AHP the buyer is only required to give verbal, qualitative statements regarding the relative importance of one criterion versus another criterion and similarly regarding the relative preference for one supplier versus another on a criterion. (de Boer et al., 2001).

Pairwise comparisons were formulated to include all the combinations of criteria/ sub-criteria/alternatives relationships. The decision-team compared the criteria and sub-criteria by assigning corresponding numerical values based on the relative importance of alternatives under consideration to their parent element in the decision hierarchy. Each supplier selection criteria have first been compared against other criteria (Perçin, 2006).

For the methodology application according to (T. L. Saaty, 1980) cited by (Pinho & Lopes, 2020) in the elaboration of the square matrices or decision matrices, where *i* represents the line number of the matrix, *j* the columns and a ij represents the comparison between criteria and alternatives A_i and A_j, the following rules must be respected:

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix}$$

where, $a_{ij} = \frac{1}{a_{ji}}$ so, if $a_{ij}=k$ then $a_{ji} = \frac{1}{k}$ for all $k>0$ and $a_{ii}=1$ for all i - mean that in the fundamental scale each criterion or alternative compared to itself assumes equal importance.

The main principle of filling in the matrix is simple because an expert should indicate how much more important is a particular criterion than another. Saaty suggested a widely known 5-point scale (1-3-5-7-9) (Podvezko, 2009), known as the fundamental scale of Saaty (Table 1).

Table 1. Fundamental scale of Saaty (source:adapted from (Saaty, 1990))

Importance	Defenition	Explanation
1	Equal importance	Two atributes contribute identically to the objective
3	Moderate importance of one over the other	Experience and judgement slightly favors one attribute over another
5	Strong or essential importance	Experience and judgement strongly favors one attribute over another
7	Demosntrated dominance	An attribute's dominance is demosntrated in practice
9	Exrtreme dominance	The evidence favoring na attribute over another is affirmed to the highest possible
2,4,6,8	Internediate values	Further subdivision or compromise is needed

The second step, in order to obtain the relative weights, the matrix has to be normalized and will be defined by

$$A' = \left[a'_{ij} \right]$$

Where $a'_{ij} = \dfrac{a_{ij}}{\sum_{k=1}^{n} a_{ik}}$ for $1 \leq i \leq n$ and $1 \leq j \leq n$

Once the matrix is normalized in each line is calculated the average value $W=[w_k]$ where,

$$w_k = \frac{\sum_{k=1}^{n} a'_{ij}}{n} \text{ for } 1 \leq i \leq n, \text{ and } 1 \leq j \leq n$$

However, on the comparison process some inconsistency can be generated, especially when the problem has a considerable number of criteria.

In order to verify whether the evaluations were consistent or not, it is necessary to calculate the Consistency Ratio (*CR*) which correlates the Consistency Index (*CI*) with the Random Consistency Index (*RI*), and is given by the following expression:

$$CR = \frac{CI}{RI} \tag{11}$$

The Consistency Index (*CI*) is obtained by the following formula (Saaty, 1990),

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{12}$$

and the values for the Random Consistency Index are obtained from Table 2.

Table 2. The RI values

Matrix size	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51

(adapted from (Podvezko, 2009))

According to (Saaty, 1990), the value of CR, to indicate consistency, can take as maximum value 10%.

RESULTS AND DISCUSSION

All the quantitative data were collected accessing the informatics system of the company. The qualitative ones were discussed in formal and informal meetings with different work streams used to deal with the material in daily bases.

The alternatives were indicated by purchasing and planning departments and the criterion, as previously mentioned were discussed with financial, production and procurement departments.

Application of AHP

For the methodology application the structure of *Figure 3* was considered.

The comparison of the 11 criteria was done using the fundamental scale of Saaty in order to establish the relative importance of each criterion. The matrix was normalized doing the sum of the rows and dividing the result for each matrix element.

Figure 3. Problem structure
(source: own)

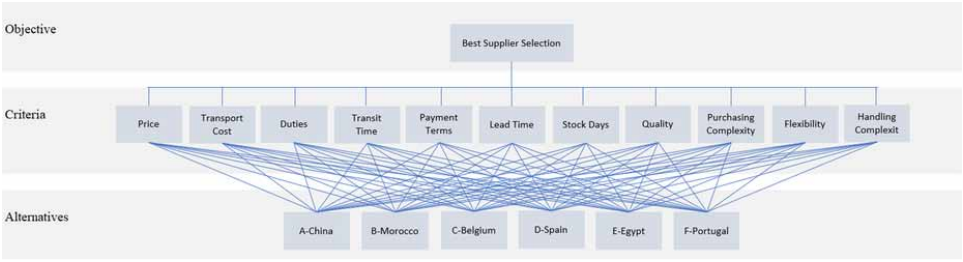


Table 3. Matrix normalized

Matrix size	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49	1,51

(Source: own)

According to the evaluation of the decision makers, the "Price" came as the criteria with the higher weight assigned, 25%, followed by "Transport cost" and "Duties" with the same importance, 19%, it is no surprise since the decision maker come from the financial department and obviously more focused on direct costs, the ones that he can easily percept. The "Stock days", the daily followed KPI, obtain the third place, 10%, and again the finance perspective it's clearly given the influence to this important criterion for the company.

Due the considerable number of criteria, inconsistency was expected, however it has not happened.

The consistency was calculated, manually and double checked using an online calculator on both obtaining a Consistency Ratio CR < 10 which represents the consistency of the comparisons.

In the case of the criterion comparison the CR was 7,94% which is more that acceptable.

The same procedure using the fundamental scale of Saaty was apply for the Alternatives on each criterion individually, all with CRs < 10. On this exercise some calculations were previously done to make easier the comparisons for the decision maker, again, showing the real differences of the values, was easier to apply the Satty scale.

"Purchasing complexity", "Flexibility" and "Handling complexity" were the criterion with the horst score, with the last one in the bottom of the evaluation. Actually, even understanding the impact on the cycle time, it's difficult to measure them and convert in cost, and when compared in a set of so many criteria it comes natural to be undervalued.

Finally, the weights obtained for the alternatives in each criterion will be weighted by the ones obtained for the criterion,

In order to obtain a ranking of the best suppliers, we calculate the weighted average of these parcels, which will allow to find the final value of importance of each supplier and establish priorities. *Table 4* presents a summary table with the global ranking obtained with "D-Spain" on the top of the ranking.

Table 4. Ranking

Matrix Normalized	Price Avg	Transport cost	Duties	Transit time	Payment terms	Lead time	Stock days	Quality	Purchsing complexity	Flexibility	Handling complexity	w*
Price Avg	0,30	0,37	0,37	0,18	0,22	0,21	0,27	0,24	0,19	0,18	0,17	24,7%
Transport cost	0,15	0,19	0,19	0,16	0,22	0,16	0,27	0,24	0,19	0,18	0,17	19,3%
Duties	0,15	0,19	0,19	0,16	0,22	0,21	0,27	0,24	0,17	0,16	0,15	19,0%
Transit time	0,04	0,03	0,03	0,02	0,01	0,01	0,02	0,01	0,01	0,01	0,04	2,1%
Payment terms	0,04	0,03	0,03	0,07	0,03	0,08	0,02	0,02	0,07	0,08	0,07	4,8%
Lead time	0,06	0,05	0,04	0,07	0,02	0,04	0,02	0,02	0,07	0,08	0,09	5,0%
Stock days	0,08	0,05	0,05	0,09	0,09	0,12	0,07	0,15	0,12	0,13	0,11	9,5%
Quality	0,06	0,04	0,04	0,11	0,09	0,12	0,02	0,05	0,12	0,08	0,11	7,7%
Purchsing complexity	0,04	0,02	0,03	0,05	0,09	0,01	0,01	0,01	0,02	0,05	0,04	3,5%
Flexibility	0,04	0,03	0,03	0,07	0,01	0,01	0,01	0,02	0,01	0,03	0,02	2,6%
Handling complexity	0,04	0,02	0,03	0,01	0,01	0,01	0,01	0,01	0,01	0,03	0,02	1,8%
Sum	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**1,00**	**100%**

(Source: own)

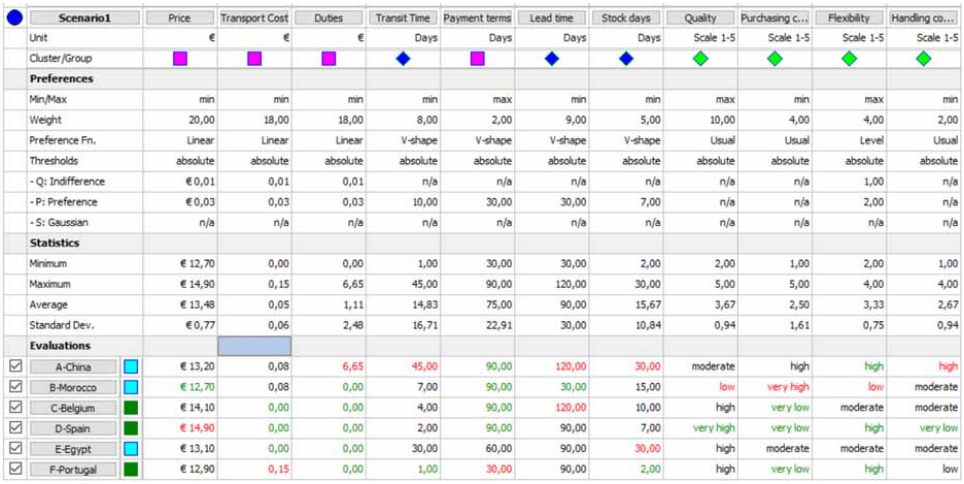
"F-Portugal" was the second best classified alternative, very close to "B-Morocco". "E-Egypt" and "C-Belgium" obtain very similar results, and finally "A-China" was the alternative with the lower classification.

Application of PROMETHEE

The *Figure 4* shows the representation on Visual PROMETHEE software that was used to support the PROMETHEE Method where 6 alternatives have been considered and evaluated in 11 criteria chosen by de decision makers.

A weight was assigned to each criterion according to the relative importance that the financial manager perception. Independently of camming from finance is a decision maker very involved with all the company areas and with a global overview of the company.

Figure 4. Visual PROMETHEE software interface
(source: Visual PROMETHEE)



Scenario1	Price	Transport Cost	Duties	Transit Time	Payment terms	Lead time	Stock days	Quality	Purchasing c...	Flexibility	Handling co...
Unit	€	€	€	Days	Days	Days	Days	Scale 1-5	Scale 1-5	Scale 1-5	Scale 1-5
Cluster/Group											
Preferences											
Min/Max	min	min	min	min	max	min	min	max	min	max	min
Weight	20,00	18,00	18,00	8,00	2,00	9,00	5,00	10,00	4,00	4,00	2,00
Preference Fn.	Linear	Linear	Linear	V-shape	V-shape	V-shape	V-shape	Usual	Usual	Level	Usual
Thresholds	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute	absolute
- Q: Indifference	€0,01	0,01	0,01	n/a	n/a	n/a	n/a	n/a	n/a	1,00	n/a
- P: Preference	€0,03	0,03	0,03	10,00	30,00	30,00	7,00	n/a	n/a	2,00	n/a
- S: Gaussian	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Statistics											
Minimum	€ 12,70	0,00	0,00	1,00	30,00	30,00	2,00	2,00	1,00	2,00	1,00
Maximum	€ 14,90	0,15	6,65	45,00	90,00	120,00	30,00	5,00	5,00	4,00	4,00
Average	€ 13,48	0,05	1,11	14,83	75,00	90,00	15,67	3,67	2,50	3,33	2,67
Standard Dev.	€0,77	0,06	2,48	16,71	22,91	30,00	10,84	0,94	1,61	0,75	0,94
Evaluations											
A-China	€ 13,20	0,08	6,65	45,00	90,00	120,00	30,00	moderate	high	high	high
B-Morocco	€ 12,70	0,08	0,00	7,00	90,00	30,00	15,00	low	very high	low	moderate
C-Belgium	€ 14,10	0,00	0,00	4,00	90,00	120,00	10,00	high	very low	moderate	moderate
D-Spain	€ 14,90	0,00	0,00	2,00	90,00	90,00	7,00	very high	very low	high	very low
E-Egypt	€ 13,10	0,00	0,00	30,00	60,00	90,00	30,00	high	moderate	moderate	moderate
F-Portugal	€ 12,90	0,15	0,00	1,00	30,00	90,00	2,00	high	very low	high	low

The preference functions were chose taking in account the type of criteria and the range of the evaluation.

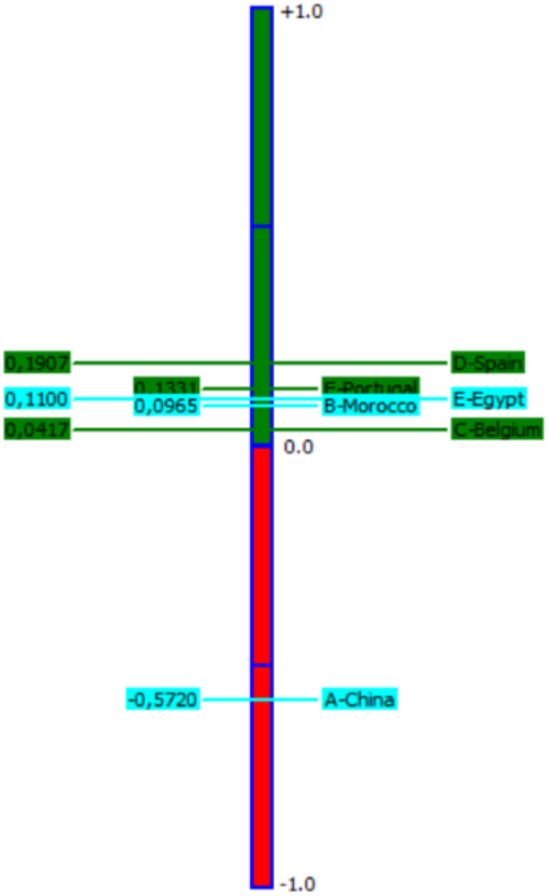
In a first approach it was difficult for the decision maker to decide some of the thresholds, to make the task easier, some calculations with different values were done, in order to give him the real impact in the BOM cost for small variations of the criteria value. Before the simulations he was not comfortable about what to define in order to generate preference or indifference, even understanding the importance of that for the model, instead showing him the real impact on BOM it came very easy to establish those thresholds.

PROMETHEE Rankings

As stated, the PROMETHEE II Complete Ranking (*Figure 5*) is based on the net preference flow (Phi) (Mareschal, 2013).

From the complete ranking of PROMETHEE II, where no incomparability remains, the upper half of the scale (green) corresponds to a positive Phi score and the bottom half (red) to negative score. Therefore, "D-Spain" is above all suppliers, which means that is the best option, followed by "F-Portugal", E-Egypt, B-Morroco, "C-Belgium" and finally with a considerable distance from the other options, "A-China" is the worst.

Figure 5. Complete ranking
(source: Visual PROMETHEE)



On the PROMETHEE Flow Table (*Figure 6*) we can see Phi, Phi+, Phi- score. Suppliers are ordered by PROMETHEE II complete ranking. The positive flow expresses how much an alternative is dominating the other ones, and the negative flow how much it is dominated by the other ones.

Hereupon the alternative with the larger Φ^+ is "B-Morocco" but the one with smaller Φ^- is "D-Spain" which is as well the one with the higher $\Phi(a)$ and so the best alternative according to PROMETHEE II.

The fact that alternative "B-Morocco" has a better Φ^+ but a horst Φ^- when compared to Spain, means that they may be incomparable. Same occurs between "B-Morocco" and "F-Portugal" and between "B-Morocco" and "C-Belgium". The result gives no doubts about the low performance of A-China, appearing with the worst Φ^+ and Φ^- presented.

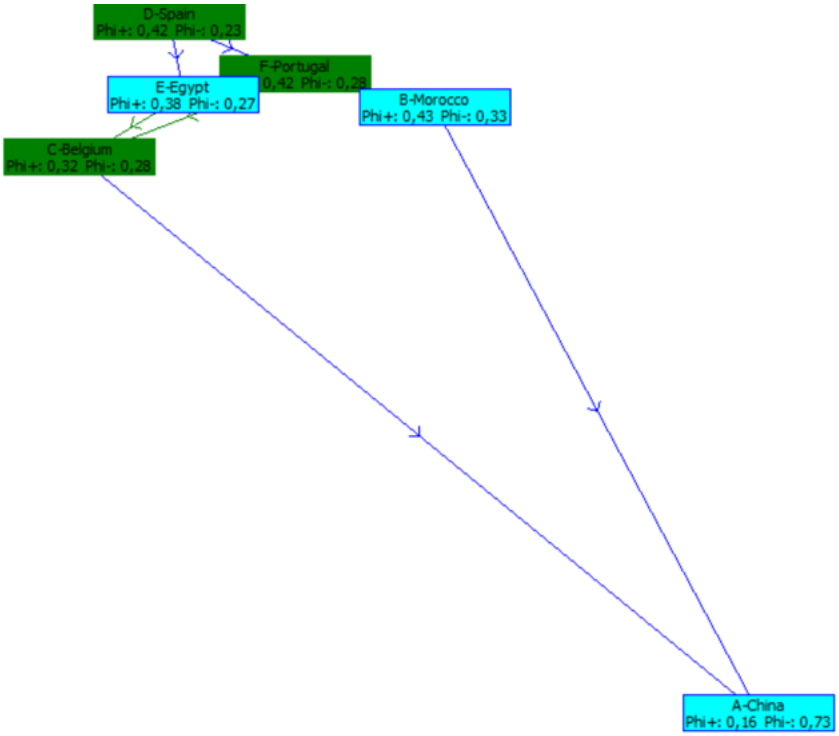
Figure 6. PROMETHEE flow table
(source: Visual PROMETHEE)

Rank	action	Phi	Phi+	Phi-
1	D-Spain	0,1907	0,4175	0,2267
2	F-Portugal	0,1331	0,4151	0,2820
3	E-Egypt	0,1100	0,3800	0,2700
4	B-Morocco	0,0965	0,4260	0,3295
5	C-Belgium	0,0417	0,3239	0,2823
6	A-China	-0,5720	0,1600	0,7320

PROMETHEE Network

On The PROMETHEE Network (*Figure 7*) the alternatives (suppliers) are represented by nodes and arrows are drawn to indicate preferences. PROMETHEE Network which presents PROMETHEE I partial ranking. "D-Spain" is significantly preferred to other suppliers.

Figure 7. PROMETHEE network
(source: Visual PROMETHEE)



With this graphical representation the similarity between alternatives is easy to detect, for instance "F-Portugal" and "E-Egypt" are very close to each other showing their similarity, in the other hand it is possible to observe that "B-Morroco" is only comparable with "A-China". In fact, "A-China" is completely overstepped from all the other alternatives.

GAIA Plane

On the GAIA Plane (*Figure 8*), the alternatives (suppliers) are represented by points, the criteria are represented by axes, whose length indicates their importance in the problem.

Figure 8. GAIA plane
(source: Visual PROMETHEE)

Clearly, we can observe that the "Price" is the criterion with the longer length.

Criteria expressing conflicting (opposite) preferences are represented by axes oriented in opposite directions. That is the case of "Price" and "Transport cost".

The position of the criteria indicates the similarity or conflict between them: the smaller the angle, the more similar two criteria are.

The angle between "Stock days" and "Transit time" is very small, showing their similarity, as long the transit time is, as much stock days the company has to cover.

Alternatives located near (far) have similar (dissimilar) performances; that is the case of "D-Spain" and "C-Belgium".

The 2D GAIA analysis presented on *Figure 8* is considered reliable when the quality level is above or close to 70%, which is the case as we got a result of 75,3%.

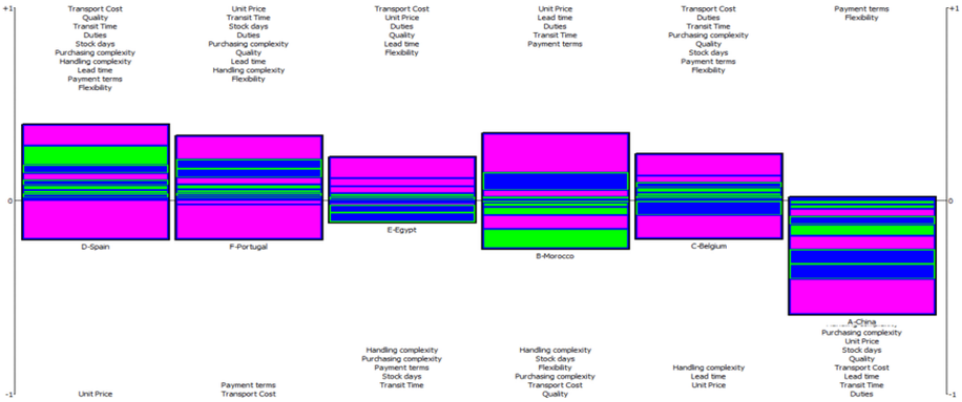
PROMETHEE Rainbow

The PROMETHEE Rainbow (*Figure 9*) is a disaggregated view of the PROMETHEE II complete ranking (Mareschal, 2013). It is a very easy way to understand how and how much each criterion is contributing for the alternative score.

Positive (upward) slices correspond to good features while negative (downward) slices correspond to weaknesses. This way, the balance between positive and negative

slices is equal to the Phi score. Actions are ranked from left to right according to the PROMETHEE II Complete Ranking (Mareschal, 2013).

Figure 9. PROMETHEE rainbow
(source: Visual PROMETHEE)



The alternative "D-Spain", the one on the top of the complete ranking only has the "Price" giving a negative contribute to the alternative but is also the one with the bigger slice, meaning that not even is the one with more negative contribute but as well the one with more intensity. All the remaining criteria have a positive contribution to this alternative with "Transport cost" and "Quality" with the best contributes.

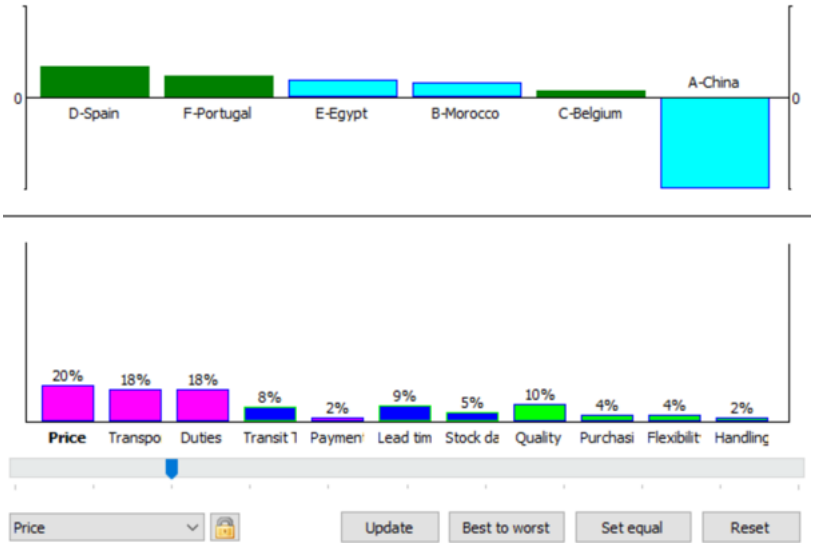
"F-Portugal", the second on the Phi classification, has two criteria on which the contribution is negative, "Payment Terms" and "Transport Cost", this one with a big negative impact.

If no major differences between the slices on one alternative, that means that this is an average alternative, and that's the case of "C-Belgium" and "E-Egypt".

Walking Weights

It is clear, that PROMETHEE II is influenced by weights allocated to the criteria, thus it is essential to know how the ranking changes when the weights change. Thus, using a special feature of the software called "Walking Weights" (*Figure 10*), a sensitivity analysis is carried out to verify how sensitive the results are when the weights change.

Figure 10. Walking weights
(source: Visual PROMETHEE)

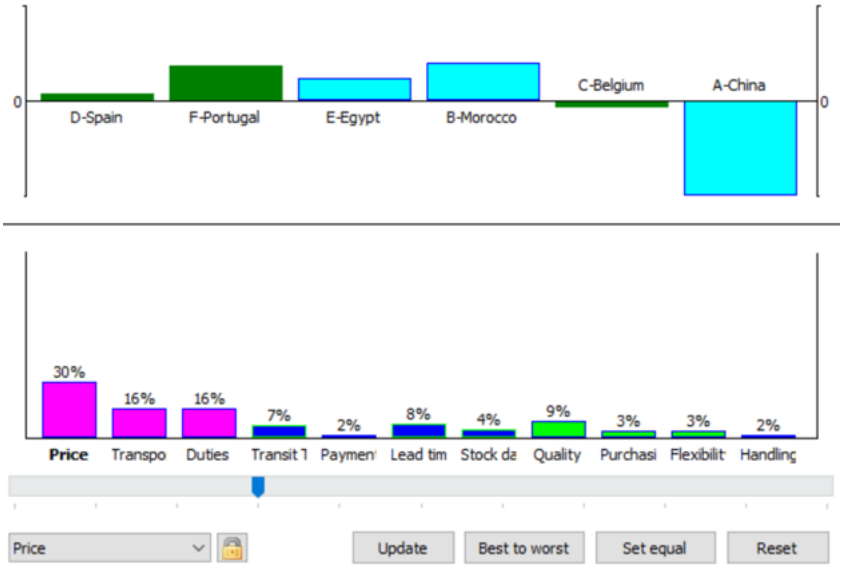


The walking weights feature of the Visual PROMETHEE software allows the weights of a particular criterion to be increased while proportionately decreasing the weights of the other criteria and see the impact on the Visual PROMETHEE analysis. Is especially useful when two alternatives are very closed to each other and in a simple and easy way, adjusting the weight of one criterion we can immediately observe the behaviour of the alternatives.

If, for instance we modify weights of the criterion "Price", increase the weight assigned to the criterion in 10%, from this analysis, it is clear that "D-Spain" will no longer be the best choice but "B-Morocco" (*Figure 11*), which means that most of the criteria (and their weights) have influence in the final ranking.

Therefore, changing the weights to the criteria allows us to simulate different scenarios, allowing us to quickly observe whether the ranking is changed or not.

Figure 11. Walking weights
(source: Visual PROMETHEE)



The walking weights can be used to interactively modify the weights of the criteria and immediately see the impact of the modification on the PROMETHEE II complete ranking and on the position of the decision axis in the GAIA plane. This can particularly useful when the decision-maker has no clear idea of the appropriate weighting of the criteria and wants to explore his space of freedom (J.-P. Brans & Mareschal, 2005).

CONCLUSION

With the application of both methods, we could establish a ranking of the suppliers, despite the differences between the two methodologies, especially on the way as the decision maker is invited to make the comparisons, the results are very similar, with the alternative "D-Spain" on the top of the ranking.

There is no objection on assuming that the way as weights were assigned, both in PROMETHEE method and AHP, was strongly influenced by the fact that the decision maker is from financial department and so more sensitive to criteria related with direct cost.

All the PROMETHEE and GAIA computations take place in real-time and any data modification is immediately reflected in the output windows. The PROMETHEE rankings, action profiles and GAIA are displayed in separate windows and can easily

be compared. In which concerns PROMETHEE, the weight assignment was quite simple for the decision maker, the main difficulty was faced defining the preference function thresholds, to support on that, same calculations were made to give the impact on the BOM for some variations, with this exercise it came much easier to understand for each difference he considered important to prefer an alternative over the other or to up which value no preference should be generated.

The first interesting fact is that on both methods the supplier with higher evaluation was the one with the higher price, that shows that, even not directly realizing, the decision maker has token in account the relative importance of other criteria.

Making a comparison between the weight directly assigned by the decision maker when applying PROMETHEE method and the ones calculated trough AHP methodology, it was interesting to observe that they are very similar, especially the ones related with direct costs, actually, was on the ones which are not so familiar to the decision maker where we found some discrepancies.

Although, the decision maker was surprised with the results, due the fact that the alternative on the top of the ranking is actually the one with the higher price, despite being the criteria with the higher weight assigned, for sure that there was not transport costs or duties applied to this alternative, however, even so, if we due the sum of all the direct costs, "D-Spain" will be the alternative with the second higher value, so it was expected no to be the one on the top, but actually it was. The rainbow from Visual PROMETHEE is a good tool to understand why, the price was the only one with negative contribute and the positive contribute of all the other criteria were more than enough to compensate that, actually, during the interviews with the different work streams this alternative always had the best impression in terms of performance; no delivery failures, easy to handle, right documents, etc. Even with AHP, where the decision maker is given the preferences comparing criteria and alternatives by pairwaising, a more subjective way to assign weights, the result came the same with supplier D-Spain on the top as the best option.

As explained, the goal was to have 2 suppliers selected, and in both methods "F-Portugal" came in the second position on the ranking, with only two criteria not favourable, appears to be the second choice, however, the qualification is not yet completed, and despite that there's always a chance, even small, of not be qualified, in that case, the company will face a new challenge as the alternatives in third and four position are very close to each other and must be considered not comparable, they are average alternatives and it's difficult to understand which is the better.

The Gaia Plane, as the Rainbow, may support the new problematic, has it is easier to see where the straight and weaknesses are, as well as the walking weight with the simulation tool, moving the weight bar and "playing" with the weight distribution it's easy to identify the trade-offs and see how the alternatives behave.

A new element came during this study related with supplier "B-Morocco" which can suffer a change at medium term due an inquiry raised by the European Union to the fiberglass coming from Morocco due suspicion of anti-trust rules violation, if it is confirmed, antidumping rate will be applied, and this alternative will follow down in the ranking.

In that case the second supplier selected by PROMETHEE will be Egypt.

With Visual PROMETHEE the decision makers will have the opportunity to any time change or adjust the data in the software and run it again.

REFERENCES

Alves, M. A. (2018). *Proposta de Agregação Robusta de Múltiplos Métodos com Incertezas em Problemas de Tomada de Decisão Multicritério*. Academic Press.

Anand, G., & Kodali, R. (2008). Selection of lean manufacturing systems using the PROMETHEE. *Journal of Modelling in Management*, *3*(1), 40–70. doi:10.1108/17465660810860372

Azadfallah, M. (2017). Evaluation and selection of suppliers in the supply chain using the extended group PROMETHEE I procedures. *International Journal of Supply Chain and Operations Resilience*, *3*(1), 56. doi:10.1504/IJSCOR.2017.087161

Badri, M. A., & Abdulla, M. H. (2004). Awards of excellence in institutions of higher education: An AHP approach. *International Journal of Educational Management*, *18*(4), 224–242. doi:10.1108/09513540410538813

Bayazit, O. (2006). Use of analytic network process in vendor selection decisions. *Benchmarking*, *13*(5), 566–579. doi:10.1108/14635770610690410

Brans, J-P., & De Smet, Y. (2017). *PROMETHEE methods* (Vol. 3). doi:10.1007/978-1-4939-3094-4

Brans, J. P., & De Smet, Y. (2016). *PROMETHEE methods* (Vol. 233). International Series in Operations Research and Management Science. doi:10.1007/978-1-4939-3094-4_6

Brans, J.-P., & Mareschal, B. (2005). PROMETHEE methods. In *Multiple criteria decision analysis: state of the art surveys*. Springer. doi:10.1007/0-387-23081-5_5

Çebi, F., & Bayraktar, D. (2003). An integrated approach for supplier selection. *Logistics Information Management*, *16*(6), 395–400. doi:10.1108/09576050310503376

Chen, C. T., Lin, C. T., & Huang, S. F. (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics*, *102*(2), 289–301. doi:10.1016/j.ijpe.2005.03.009

de Boer, L., Labro, E., & Morlacchi, P. (2001). A review of methods supporting supplier selection. *European Journal of Purchasing and Supply Management*, *7*(2), 75–89. doi:10.1016/S0969-7012(00)00028-9

Dias, E. M. P. da S. (2015). *Modelo de apoio à decisão multicritério para selecção de fornecedores de azeite*. Faculdade de Economia do Porto.

Jalalvand, F., Teimoury, E., Makui, A., Aryanezhad, M. B., & Jolai, F. (2011). A method to compare supply chains of an industry. *Supply Chain Management*, *16*(2), 82–97. doi:10.1108/13598541111115347

Katsikeas, C. S., & Leonidou, L. C. (1996). International Supplier Selection. *Journal of Global Marketing*, *9*(3), 23–45. doi:10.1300/J042v09n03_03

Levary, R. R. (2007). Ranking foreign suppliers based on supply risk. *Supply Chain Management*, *12*(6), 392–394. doi:10.1108/13598540710826317

Mareschal, B. (2013). *Visual PROMETHEE manual*. Academic Press.

Mareschal, B. (2018). *Preference functions and thresholds*. Academic Press.

Morais, D. C., & de Almeida, A. T. (2006). Modelo de decisão em grupo para gerenciar perdas de água. *Pesquisa Operacional*, *26*(3), 567–584. doi:10.1590/S0101-74382006000300007

Perçin, S. (2006). An application of the integrated AHP-PGP model in supplier selection. *Measuring Business Excellence*, *10*(4), 34–49. doi:10.1108/13683040610719263

Pinho, R. R., & Lopes, A. P. (2020). *Multicriteria Decision Support Model for Selection of Tinplate Suppliers*. doi:10.4018/978-1-7998-2216-5.ch006

Podvezko, V. (2009). Application of AHP technique. *Journal of Business Economics and Management*, *10*(2), 181–189. doi:10.3846/1611-1699.2009.10.181-189

Rae, E. (2020). *COVID-19 and impacts on global wind supply chain*. Retrieved from https://gwec.net/covid-19-and-impacts-on-global-wind-supply-chains/

Saaty, T. L. (1990). The analytic hierarchy process in conflict management. *International Journal of Conflict Management*, *1*(1), 47–68. doi:10.1108/eb022672