Trabajo Fin de Grado

Multicriteria decision making. Planification, prioritization and selection. *Management of a portfolio reduction in a home appliance company.*

Autora

Celia Escudero Alonso

Directora

Mª Teresa Escobar Urmeneta

Facultad de Economía y Empresa

2020

ABSTRACT

As companies evolve and grow, the number of products commercialized by themselves usually increases as well. This can be seen as a good sign for the firm, but sometimes, high diversification of product can confuse the user. Besides the consumer problem, a huge product line complexity incurs higher costs for the company, which is not always recovered by the respective revenues of those extra products.

The aim of this project is to apply the Analytic Hierarchy Process to solve a product portfolio reduction occurred in BSH Electrodomésticos España. It will be managed using Expert Choice 11.5, a multicriteria decision software in which alternatives, criteria and goal are introduced, eventually providing with results and a sensitivity analysis.

RESUMEN

A medida que las empresas evolucionan y crecen, el número de productos comercializados aumenta también, como norma general. Esto puede ser visto como una buena señal para la empresa, pero a veces, una alta diversificación del producto puede confundir al usuario. Además del problema del consumidor, una gran complejidad de la línea de productos incurre en costes más altos para la empresa, que no siempre se ven compensados por los respectivos ingresos de esos productos adicionales.

El objeto de este proyecto es aplicar el Proceso Analítico Jerárquico para resolver una reducción de la cartera de productos en BSH Electrodomésticos España. Se gestionará utilizando Expert Choice 11.5, un software de decisión multicriterio en el que se introducen alternativas, criterios y objetivos, y que proporciona resultados y un análisis de sensibilidad.

TABLE OF CONTENTS

TABLE OF FIGURES

1. INTRODUCTION

When talking about decision making, and in this case about multicriteria decision making, we are not referring to such a complex idea as one may think. In fact, it is a process that we execute on a daily basis, and can appear in an infinite number of ways, since it is a combination of several criteria, scenarios and players.

A simple multicriteria decision would be “Where should I buy bread today?”. In this case we could find both quantitative and qualitative factors that determine our preferences, such as:

- Distance from home to the bakery - Quantitative
- Price of bread in each bakery - Quantitative
- Available types of bread - Qualitative
- Preference on the taste of the bread - Qualitative
- Service received by baker - Qualitative

As some of the values are not objectively measurable, and some criteria are more important to the Decision Maker, it could seem difficult to find a real “winner”. Nevertheless, there are tools that guide us in this decision-making process.

For this project, we will analyze a problem involving quantitative and qualitative factors as well but using the Analytic Hierarchy Process (AHP), that T.L. Saaty (2008) defined as “a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales. It is these scales that measure intangibles in relative terms. The comparisons are made using a scale of absolute judgements that represents, how much more, one element dominates another with respect to a given attribute.”

The method mentioned above will be applied using Expert Choice 11.5, a software created by Expert Choice® that simplifies AHP through a very straightforward interface. This will be further explained in the next chapters.

1.1. MOTIVATION AND OBJECTIVE

The academic reason for this project to be carried out is the need to elaborate a final thesis in order to obtain the diploma of the Degree in Business Administration and Management.

Also, the reason why this path was chosen was the interest in learning more about the multiple applications of statistics in companies, as well as the possibility to carry out the final thesis in English, instead of Spanish.

Furthermore, the decision to study a Product Portfolio Management issue was taken due to personal experience while doing an internship program in the Product Marketing Department of a home appliance company, BSH Electrodomésticos S.A.

The aim of this Project is to reduce one of the product portfolios of BSH Electrodomésticos, so the cost and complexity demanded from Product Management Headquarters (in Germany) are met. In a real situation, all the product lines of the company would suffer these reductions, but to keep this study achievable and simple, only one of the portfolios will be analyzed.

Previously, there had been another important decrease in the number of total products of BSH España. After that reduction, the quantity of variants was **1112**. However, that number was still too high according to the budget.

So, the new total goal imposed on the Product Marketing Department was to remove 30 extra variants, making the final number **1082** variants, adding the products of the seven families (Refrigeration, Hobs, Hoods, Ovens & Microwaves, Dishwashers, Laundry care and Small Domestic Appliances). All the Product Managers agreed to reduce their product family in a **2.5%** (approximately), so it was fair for every category. In this way, none of them had to drastically decrease their portfolio.

1.2. THE COMPANY

BSH Electrodomésticos is the Spanish subsidiary of the German group BSH Hausgeräte GmbH, founded in 1967 following a joint venture between Siemens AG and Robert Bosch GmbH, although since 2015 it belongs entirely to Robert Bosch GmbH.
BSH Hausgeräte includes well-known brands in the world of household appliances, such as:

- Bosch: Within the BSH group, the Bosch name is characterized by a more familiar image, since it is the only brand in the company that also sells small appliances, related to free time and easy handling.
- Siemens: This brand represents the most modern and futuristic style line of the BSH group. It is in a medium-high price segment within the appliance market, as its products often include innovative attributes.
- Neff: The Neff appliance brand is intended for the furniture segment, these appliances are sold in shops specialized in kitchens or directly on the brand's website, not in free-standing appliance stores. Its aesthetic is a little more premium than the other two brands.
- Gaggenau: This is BSH's most exclusive brand, with a much higher price compared to the other brands. Like Neff, it is also not found in general appliance stores. It is a brand characterized by its care and tradition and was founded in 1683.
- Balay: The last one is the local brand of BSH España. Balay sells products with a simpler image. In addition, it competes in a lower price segment than the rest of BSH's brands. The name Balay was born in 1947 when Esteban Bayona and José María Lairla created a small company of electrical equipment in Zaragoza. It wasn't until the early 1960s that they started selling appliances. Later, in 1989, the Spanish government sold 50.3% of Balay's shares to The German group BSH. Finally, in 1998 it was acquired 100% by BSH.

1.2.1. PRODUCT MARKETING DEPARTMENT

The department in which these issues occur is the Product Marketing one. It is a multi-brand department, unlike in the sections of each brand (Bosch Marketing, Siemens Marketing, etc.)

The functions that are enhanced in this area are often confused, as it is a department that is not usually present in other companies. It could be said that it is responsible for harmonizing the work of brands with that of factories. The employees of this section are Product Managers, that is, each of them manages a product line (Refrigeration, Dishwasher, Bells, etc.), and depend on the Product Manager of BSH Germany. This department does also some joint work with Supply Chain, Sales Analysis, Brand Marketing, etc.

1.3. BRIEF DESCRIPTION OF THE PROBLEM

The type of issue analyzed in this study is becoming more and more common nowadays: as companies and markets grow bigger, diversity existing among products of all kinds increases as well. Product diversification provides consumers with many options to choose from, each of them with different features. In this way, companies can approach their customers, making their products more appealing, depending on their own preferences. However, excessive product diversification can be counterproductive. “The proliferation of products in a company’s portfolio can create inefficiencies due to the greater complexity and the corresponding effort required to design and manufacture the set of products.” (Fellini, R. et al. 2003) For this reason, it is helpful to reduce the amount of products offered by big diversified brands, analyzing which of those goods are beneficial and which are just a burden for the portfolio.

The above-mentioned issue has occurred at BSH multiple times, as the company evolves. It does not necessarily mean the firm is going through a tough situation, it is just a step that must be taken at some point to reduce avoidable costs. As explained in the previous section, each portfolio had to reduce their numbers to keep things fair. BSH Home Appliances product families are:

- Refrigeration
- Laundry care (washing machines, drying machines and combined devices)
- Dishwashers
- Cavity (ovens, microwaves, built-in coffee machines, warming drawers)
- Hobs
- Cooker hoods

- Small domestic appliances (small kitchen appliances, vacuum cleaners, steam irons, coffee-on-demand devices, iron stations, indoor smart gardens, etc.)

The description of the problem occurred was the following:

- Every product line portfolio (cavity, laundry care, refrigeration, etc.) had been already reduced by each Product Manager, due to orders of Headquarters.
- These portfolio reductions were confirmed by the Head of the Product Marketing department.
- Headquarters stated that these reductions were not enough to achieve the cost decrease needed.
- The Product Managers were again urged to remove even more variants of their portfolios, in a short amount of time. The goal was to achieve a total of 1082 variants, adding up all the products in each portfolio.

The focus of this Project is on the Refrigeration product line, which had 193 variants at the beginning, and had to remove 5 extra variants, which would be the 2.5% of 193[1].

1.4. DEVELOPMENT OF THE PROJECT

Once the project, the problem and the company have been introduced, it is time to deepen the subject.

For that purpose, in the second chapter, the theoretical framework will be described to ensure a better understanding of the methodology and its origin.

Next, in the third section of the project, we will see the resolution of the problem, with all the necessary explanations of the criteria, alternatives, results, etc. The problem's resolution will be disclosed following the steps of Analytic Hierarchy Process.

And finally, the conclusions of the results obtained will be discussed.

[1] 2,5% * 193 = 4,825 ≅ 4,83 → 5 variants

2. LITERATURE REVIEW

Before deeply analyzing this multicriteria problem and explaining all the factors and alternatives, there should be a theoretical section for a better understanding of the used method and conclusions.

In this chapter, it is included a brief historical context on the origin of Multicriteria Decision Making (MCDM), as well as Analytic Hierarchy Process. Also, following that historical introduction, there will be a description of both concepts, MCDM and AHP.

Finally, this section includes a comment on previous AHP studies in the business framework.

2.1. ORIGIN OF MULTICRITERIA DECISION MAKING AND ANALYTIC HIERARCHY PROCESS

In 1785, Marquis de Condorcet published what could be considered as the first practical application of Multicriteria Decision theory, *Essay on the Application of Analysis to the Probability of Majority Decisions*. This paper defined the Condorcet's paradox, which was contemplated in a ranked voting situation (Malczewski and Rinner, 2015), approaching what we nowadays know as a Multicriteria Decision problem (Zunzunegui, 2017).

It was not until a century later that the main concepts of MCDM were established by Wilfried Pareto and Francis Ysidro Edgeworth. Although they did not work together, their findings convey in the same direction, introducing the optimality concept for vector optimization problems.

The Edgeworth Box studies the correlation and interaction of two players exchanging assets/goods. This type of analysis draws on the use of indifference curve analysis to analyze this trading behavior. It employs indifference curves to explain this trade behavior. In this diagram of Edgeworth's Box, O(A) and O(B) would be the respective origins for consumers A and B. Each consumer's Indifference Curve, IC(A) and IC(B), are convex to their own origins, and the initial portion or endowment P represents the amount of good X and good Y that these consumers have at the beginning.

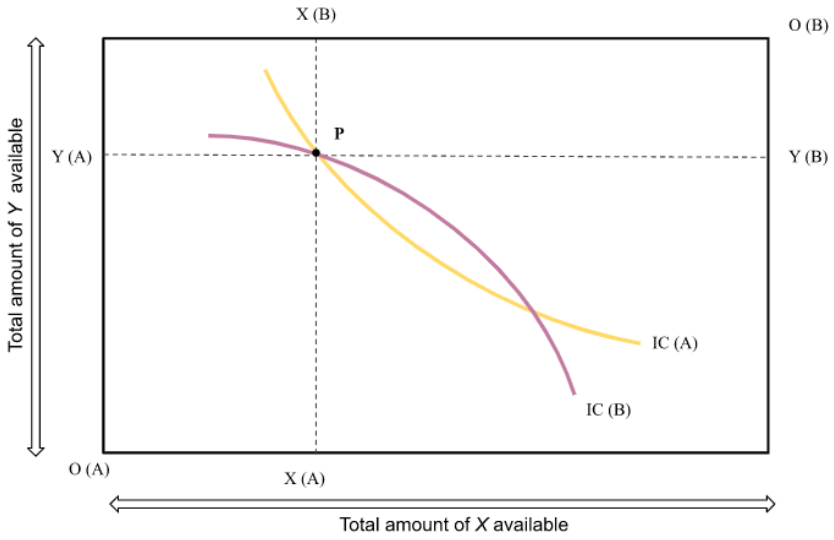


Figure 1. Edgeworth Box. Step 1 (self-elaborated).

The aim of general equilibrium analysis is to find out if it is achievable to put consumer 'A' and/or consumer 'B' *in a more advantageous position through* a trade process without causing any harm to the other player. For instance, if the two participants (A and B) moved to position 'T', that would mean that now B is in a more advantageous position than before, without causing any inconvenience to A. Any movement of these players within/on the border of the Negotiating Area will make one or both participants better off. This phenomenon is called Pareto Improvement.

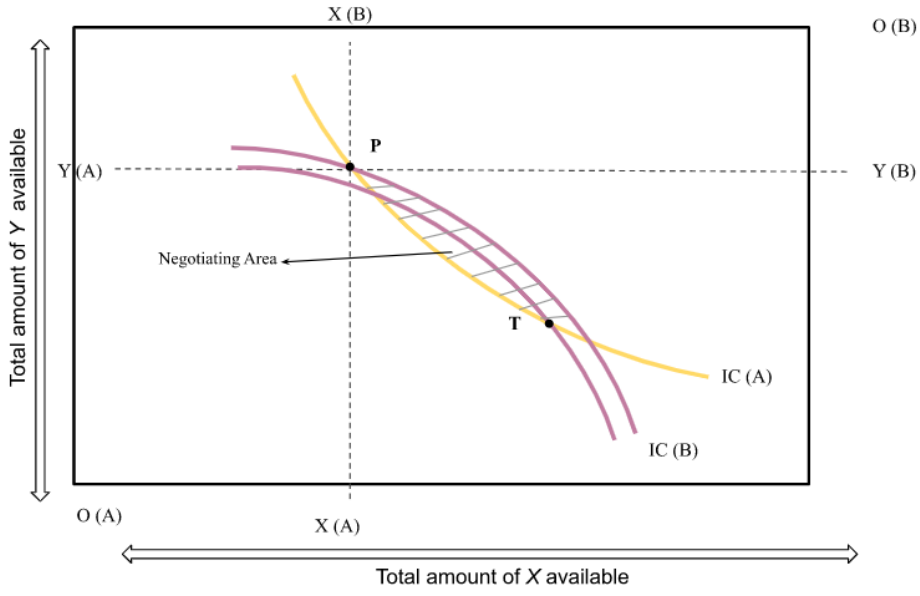


Figure 2. Edgeworth Box. Step 2 (self-elaborated).

Continuing with this trade process, if we kept on moving those individuals within the Pareto Improvement area (Negotiating Area), we would get to a point in which they can no longer reach a better position without making the other player worse off. This would mean the Pareto Optimality has been achieved. In the diagram below, it is represented as point 'S'.

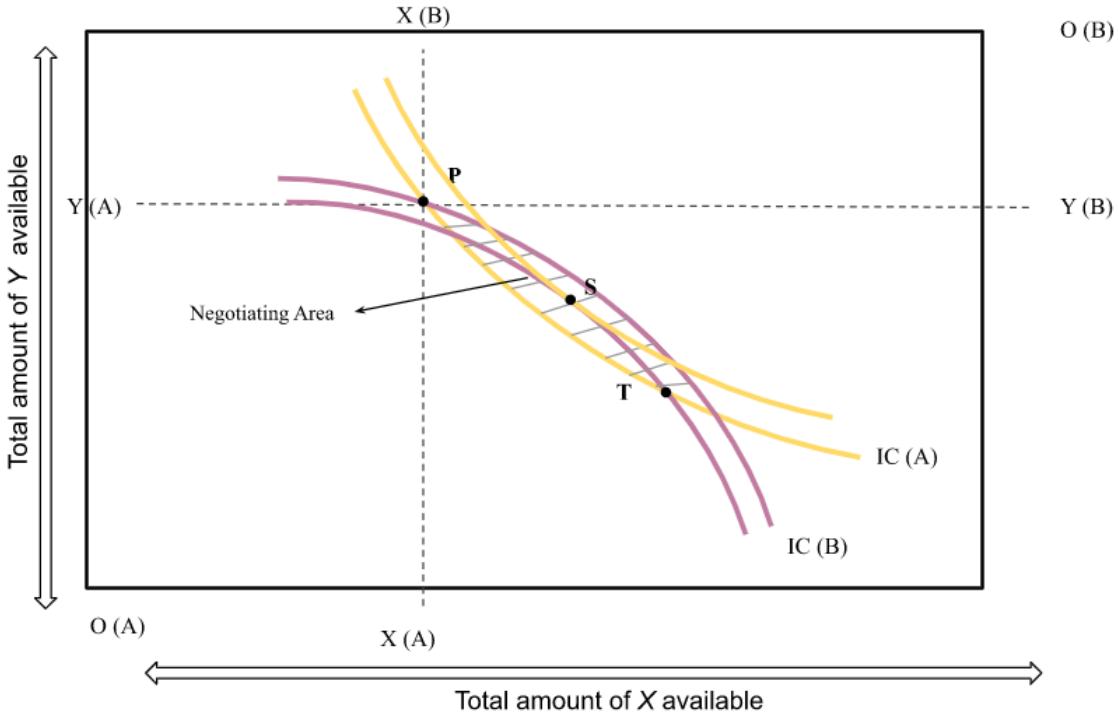


Figure 3. Edgeworth Box. Step 3 (self-elaborated).

It is remarkable to mention the work of A. Charnes and W. W. Cooper in what we know nowadays as Multicriteria Decision Making, with their work "GOAL PROGRAMMING AND MULTIPLE OBJECTIVE OPTIMIZATIONS", published in 1975 (Guerras Martín, L.A., 1989). In this paper, they proposed a concept to solve multicriteria problems through linear programming methods, choosing alternatives when several criteria are present.

Also, in the 1970s, we find Thomas L. Saaty, father of Analytic Hierarchy Process. He was the director of several research projects for the Arms Control and Disarmament Agency at the U.S. Department of State (Figueira et al., 2004). Saaty wanted to work with

brilliant people from the field of science and law, but he was disappointed with the results of the team he made. Apparently, there was some misunderstanding between lawyers and scientists, which made it very difficult to come up with sharp conclusions for the project. After some years, he decided to condense what he had learned in a clear and mechanical method to solve complex decisions. This led to the creation of AHP, nowadays used by companies, universities and even great organizations such as the CIA.

2.2. DEFINITION OF MULTICRITERIA DECISION MAKING

Multi-Criteria Decision Making, or MCDM, is most applicable to resolving problems that are considered a choice among several alternatives. It helps decision makers focus on what is important and to dismiss what is not, is logical and consistent, and is simple to use and explain its results. Roy (1985) defined multi-criteria analysis as "a decision aid and a mathematical tool allowing the comparison of different alternatives or scenarios according to many criteria, often conflicting, in order to guide the decision maker towards a judicious choice". Another valid name is Multicriteria Decision Analysis, MCDA.

The Natural Resources Leadership Institute (2008-2011) stated that "when used for group decision making, MCDA helps groups talk about their decision opportunity (the problem to be solved) in a way that allows them to consider the values that each one views as important. It also provides a unique ability for people to consider and talk about complex trade-offs among alternatives." Although this project is carried out by one person, it is intended to be further applied by a whole Department.

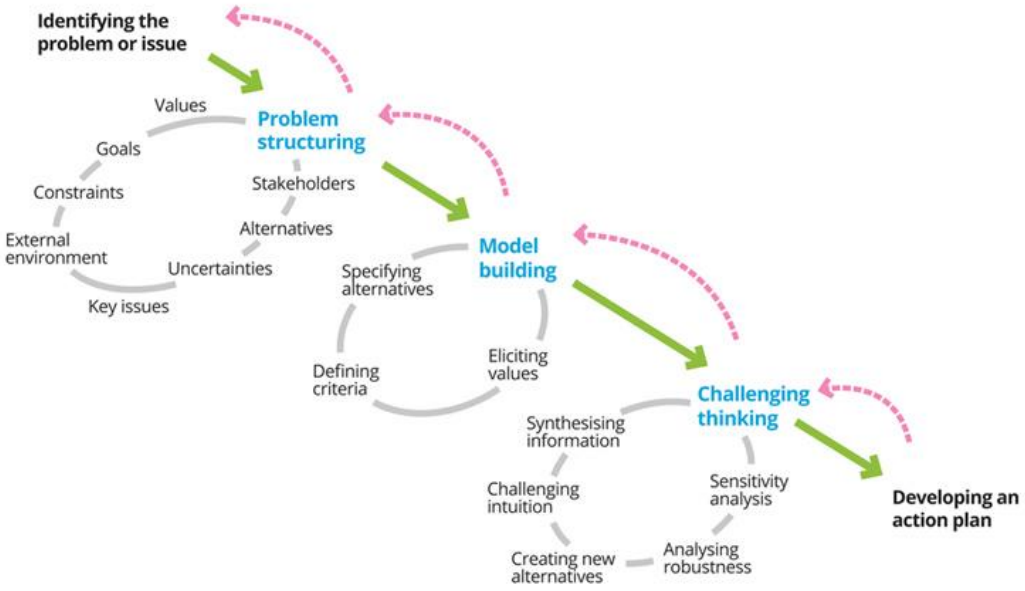


Figure 4. MCDM Stages. (*www.1000minds.com*)

There are several methods within MCDM, such as:

- Analytic Network Process
- Analytic Hierarchy Process
- ELECTRE (Elimination et Choix Traduisant la Realité)
- DEX (Decision Expert)
- Fuzzy Set Theory
- …

Our product portfolio issue will be solved through Analytic Hierarchy Process, which will be described in the next section.

2.3. ANALYTIC HIERARCHY PROCESS

As its own name says, AHP is a process, composed by different steps, usually the following:

1. State the problem
2. Build the hierarchy system. Starting from the top with the goal of the decision, then the intermediate levels, criteria and subcriteria branches, to the lowest level, the set of alternatives to choose from.

3. Structure a set of pairwise comparison matrices. Each element in a higher level is used to compare the elements in the level immediately below with respect to it.
4. Weigh the local priorities, then the global/total priorities, which will be used to choose the best alternative, allocate resources, etc.

Now let us learn the different stages in a more detailed way.

The first step of AHP is to make clear what the problem is. The problem should be measurable, realistic and specific. In this way it is easier to state the goal of the problem's resolution.

The problem under study can have different goals, if it is complex enough. Separating the goals of a large problem can also help to visualize it better.

Secondly, the decision-making team must structure the hierarchy that must consider every element (scenarios, decision-makers, alternatives, criteria) that participate and are relevant for the problem, as well as the relationship between these. In a hierarchical model, there is no dependence between elements from one level with respect to those of lower levels. A simple hierarchy is formed by three levels:

- Top level: Goal or objective of the problem
- Intermediate level: Relevant criteria for the evaluation of candidates
- Lower level: Candidates that are being analyzed.

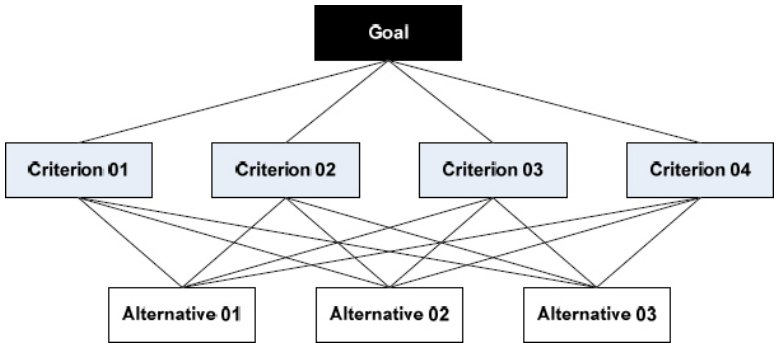


Figure 5. Example of a Hierarchy of Criteria/Objectives. Vargas, R. (2010).

The previous figure would represent the simplest form of hierarchy, with only three levels. These hierarchic systems can be more complex, with different scenarios, criteria and subcriteria, etc.

This would be a more elaborated example:

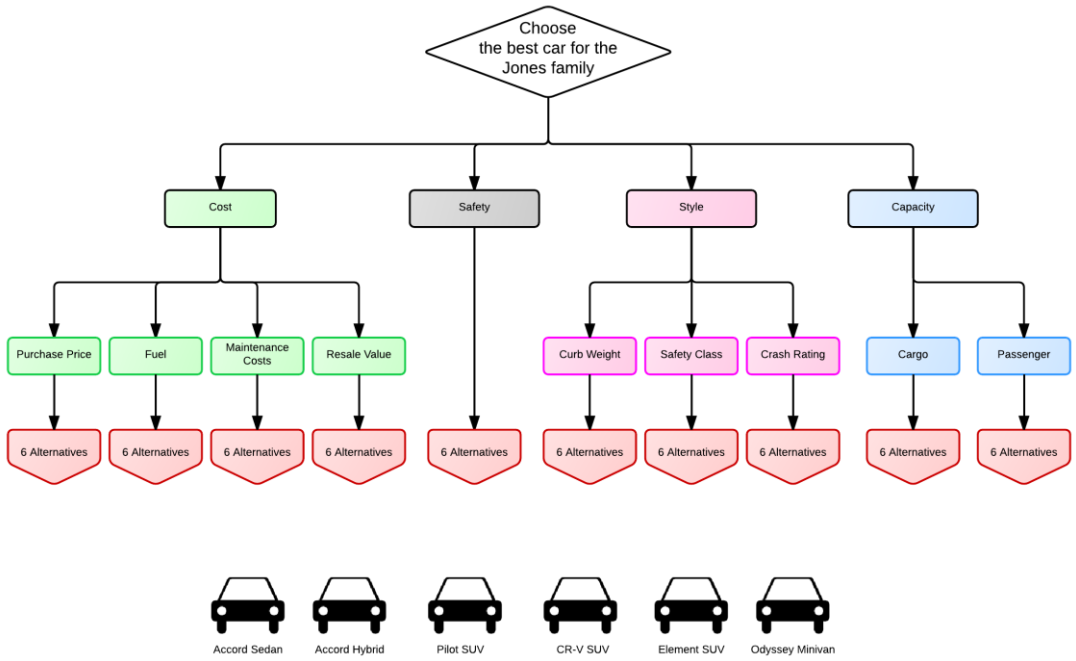


Figure 6. AHP Car example. Glur, C (2018).

As a third step, the decision makers must take pairs of elements and compare them with respect to the common element right on the upper level. In this way, the elements are compared based on the same characteristic. When using this method, comparisons must always be by pairs, and taking the fundamental scale presented by Saaty (1980) as reference.

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Figure 7. Fundamental scale of absolute numbers. Saaty (2008).

This table indicates how to weight those pairwise comparisons. For instance, if the compared alternatives are of equal importance for the Decision-Maker, the value assigned would be 1. If one of the alternatives is moderately preferred with respect to the other, the value assigned would be 3, or 1/3, depending on how the alternatives are distributed. And so on with the rest of alternatives and values.

As the alternatives are being rated, the preference values assigned and their reciprocals will form the comparison matrix, of dimensions nxn, being *n* the number of alternatives in the decision. Such as this one:

Project Manager Commitment						
	New Office	ERP Implem.	Chinese Office	Intern. Product	IT Outsourc.	Local Campaign
New Office	1	7	1/3	1/3	5	3
ERP Implem.	1/7	1	1/9	1/7	3	1/3
Chinese Office	3	9	1	1	7	7
International Product	3	7	1	1	7	9
IT Outsourcing	1/5	1/3	1/7	1/7	1	1/5
New Local Campaign	1/3	3	1/7	1/9	5	1

Figure 8. Projects Comparison Matrix for the Organization Commitment Criterion. Vargas, R. (2010)

In the case of the previous matrix, the criterion taken as reference is "Project Manager Commitment", and the alternatives are "New Office", "ERP Implementation", "Chinese office", "International Product", "IT Outsourcing" and "New Local Campaign".

Reading that matrix, we observe that "New Office" is very strongly preferred (7) compared with "ERP Implementation". Then, "Chinese Office is" extremely preferred (9) compared with "ERP Implementation". The same procedure is applied on the rest of comparisons.

Finally, it is time for prioritization and selection. We are going to make a difference between two kinds of priorities:

- Local priorities: priorities coming from elements hanging of a common node (as explained in the previous step). Measured based on relative magnitudes,
- Global priorities: which show the importance of elements with respect to the initial goal of the problem. (López Salcedo, J. 2014)

To compute these priorities the most used methods are:

- Eigenvector method: Perron (1907) and Frobenius (1912) stated that every real square matrix with positive elements, has a unique maximal eigenvalue, and its corresponding eigenvector. Comparison matrixes are always squared (nxn), so the theorem applies. In this method, the eigenvector of the comparison matrix is taken

as the weight vector, whose components are the weight of each element (Bana e Costa et al., 2008).

- Geometric mean method: For this method, the first thing to do is to multiply each value in every row of the pairwise comparison matrix and power the values by 1⁄n (dimension) to obtain the total row value. After that, the total row value is divided by the sum of all the total rows. The priority vector is the normalized vector derived after the process is completed. (Yadav and Jayswal, 2013)

3. CASE STUDY

In this central chapter, the resolution of the analysis will be justified step by step, describing the criteria used, the reasons to choose those criteria, the alternatives and their characteristics, and the software's performance and interface.

3.1. STATING THE GOAL

Our first step is to determine what we are looking for through this analysis.
In this case, the objective is to remove a 2.5% of the product line, which is equivalent to approximately 5 variants. So, starting from an initial point of seven alternatives, the goal is to choose two variants that will be kept in the product line, obtaining on the other side the 5 variants that are going to be eliminated from the portfolio.

3.2. CHOOSING THE CRITERIA

The next stage corresponds to criteria. It is very important, because they will determine everything, but they are also not objective. Of course, the chosen criteria depend entirely on the Decision Maker. If this project had been prepared by any other individual, they would be in that case the Decision Maker, giving them the privilege to change criteria.
In order to simplify this step, some of the criteria have been classified into categories.

The first category is the economic one. This group of criteria is the first one to be considered in most companies. As these data could not be disclosed, fictional but approximate data will be used instead.
There are two **economic criteria** that are considered in this case:

- Units sold per month. This one refers to the number of units of X variant sold during a natural month, taking the average of 2019 months. For this criterion, those alternatives with higher amount of units/month will receive a higher rating compared to those with lower quantity of units sold, because it is preferred that they remain in the portfolio. This number is usually measured using sell-in data, which represents the products sold to the distribution, and not to the final user, which would be sell-out data.
- Contribution margin: This criterion is represented as the percentage of the product's revenue that stays as firm's income, or the difference between the product's sales price and the cost of the product. With respect to this criterion, those variants with a higher contribution margin will be better rated than those with a lower margin. The firm is interested in keeping those products with higher contribution margin, as this guarantees profitability.

Next category of criteria is the **environmental category.** In this case, environmental refers to noise level and energy consumption:

- Noise level. Noise level has been placed into environmental criteria because the noise produced by one of these appliances affects the environment of the room where it is placed. As this is a not so good characteristic, those variants with lower noise level are better assessed than those with higher noise level. Noise level is measured by decibels, which form a logarithmic scale. Every 3-dB increase represents double the sound intensity.

- Energy consumption. This criterion is closely related to the Energy Efficiency Labels that have been previously explained. It is measured by kwh/annum and is also regulated by the European Union. It will be assessed in the same way as noise level, those variants with higher energy consumption will be worse rated than those that show a lower consumption. In this way, we follow the environmental-friendly path that was started when choosing the first seven candidates.

The last two criteria could not be grouped together as they do not belong to any common category. They are the following:

- Situation of brand after removal. This is a totally subjective criteria, because it represents the opinion of the Decision-Maker on the circumstances of the brand after removing the alternative in question. For example, if the alternative that is being analyzed is a “top freezer fridge”, and it is the only one present in the brand, the situation after its removal would be worse than that of a “side-by-side fridge freezer” that is not the only one present in the brand.
- ATP Stock. Available To Promise Stock is the amount of inventory that is left for clients to purchase it. The stock that is still in the company’s warehouse, but has already been allocated to some customer, is not ATP Stock, because it is not available to promise anymore. This criterion will rate better those alternatives with higher ATP Stock, in the interest of removing those whose stock is not as high. Because the remaining ATP stock of the removed variants will be sold in outlets (with a discount) or directly scrapped.

After choosing our goal and criteria, the AHP diagram for the moment would look like this:

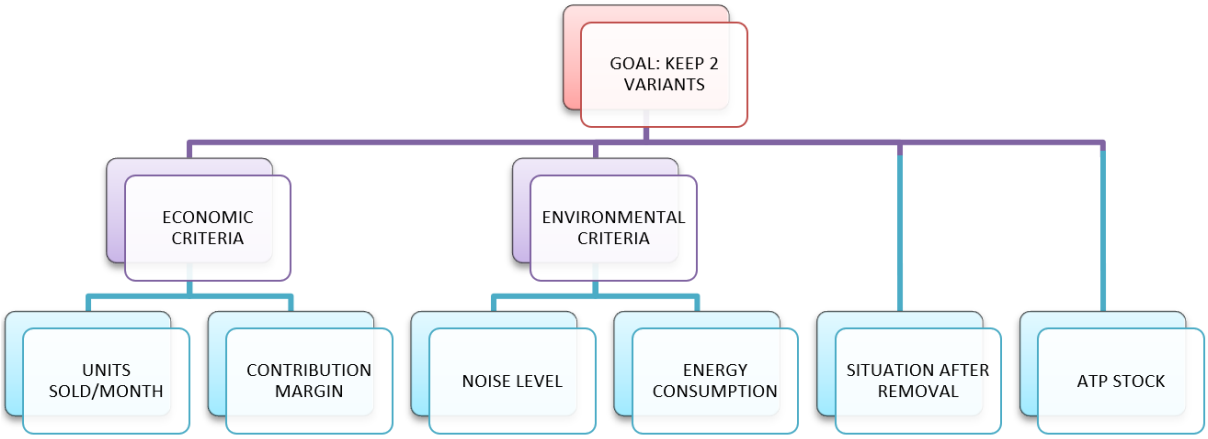


Figure 9. Goal and criteria of the AHP (self-elaborated).

3.3. CHOOSING THE ALTERNATIVES

As already mentioned, the result of the analysis will be provided by Expert Choice 11.5, in which the different alternatives are introduced, as well as criteria and ratings.

Not every alternative can be studied, as it would be too long and complex for a single Decision-Maker. The criterion chosen for that first round is Energy Rating. Since 2010, home appliances have been rated on a scale going from G to A+++, being G the least energy efficient and A+++ the most (Directive 2010/30/EU). As home appliance companies improved their energy efficiency levels, most of their products achieved the highest levels, A+ /A++ /A+++. To upgrade those levels and create room for those firms to improve, the European Union established a new standard, determined by Regulation (EU) 2017/1369 (Belt Project EU, 2019). In this way, devices currently rated as A+++ will get a B in the new standards, and companies will be "forced" to improve their energy efficiency levels. New labels will be included in their respective devices starting from March 2021.

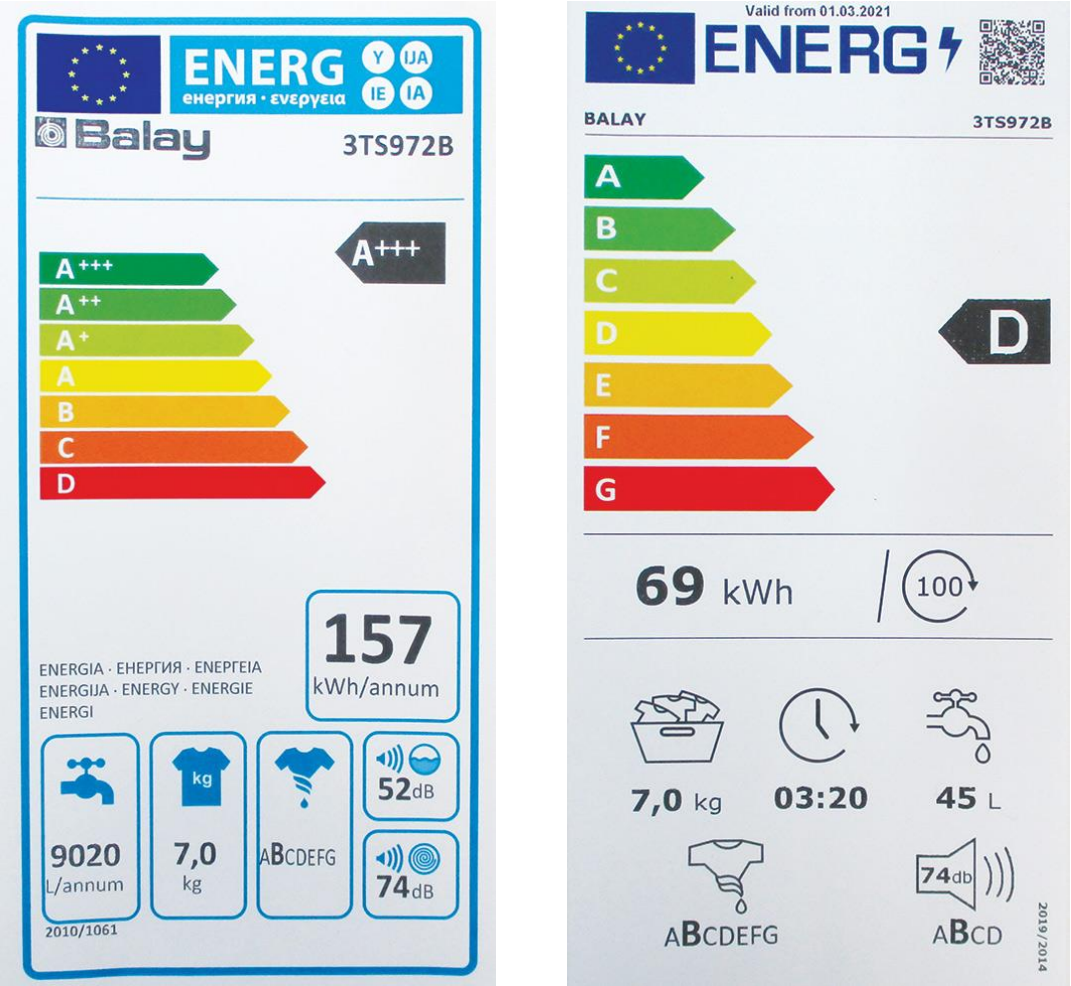


Figure 10. Current (left) and new energy label (right). OCU (2020).

Therefore, in this project, devices of the refrigeration product line with energy efficiency rating of A+ or less will be automatically selected as candidates to be removed from the portfolio.

Referring to section 1.3 *Development of the project*, not every variant of the product line can be considered for this analysis. The recommended number of alternatives compared is seven, and this is because of human short-term memory. Miller (1956), proposed seven (7 ± 2) as the standard number of elements that adult humans can keep in their short-term memory. In the case that more than 9 elements are being used, they could be confused for one another, leading to useless results. Another reason would be that it would be very time-consuming, and we would probably arrive to a similar conclusion.

For that reason, seven is the number of alternatives that have been used in this study.

As already explained, the best way to determine which seven products should be considered for the removal, is by applying a first filter based on the current energy efficiency labelling (Directive 2010/30/EU).

Those refrigeration products labelled as A+ (or less), will be directly marked as candidates for the removal. To simplify the process, each product will be given an easy alternative name (A*n*). So, the chosen alternatives would be the following ones:

- GU15DA55 (A1) - Siemens - Built-Under Freezer (A+)
- KA93DVIFP (A2) - Siemens- Side-by-Side Fridge Freezer (A+)
- 3KUB3253 (A3) - Balay - Built-Under Freezer (A+)
- 3FIB3620 (A4) - Balay - Top Freezer Fridge (A+)
- KAG90AI20 (A5) - Bosch - Side-by-Side Fridge Freezer (A+)
- KA3902I20 (A6) - Neff - Side-by-Side Fridge Freezer (A+)
- KAG90AW204 (A7) - Bosch - Side-by-Side Fridge Freezer (A+)

As it can be seen, there are four side-by-side fridge freezers and two built-under freezers, apart from a top freezer fridge. Why are there no other types of appliances? First of all, side-by-side fridge freezers are easily the most energy-consuming devices, due to their size and special features (ice-water dispenser), which means they are not likely to be rated as very energy efficient. Also, built-under freezers and top freezer fridges are not as sold as other devices, such as fridge-freezer combinations, so technical innovations will mostly be received by those top selling products, and not built-under freezers and top freezer fridges.

Only to have it in mind, and before passing onto the next chapter, here are the pictures of the products taken as references:

A1 (GU15DA55) Siemens - Built-Under Freezer (A+)

A2 (KA93DVFIP) - Siemens- Side-by-Side Fridge Freezer (A+)

A3 (3KUB3253) - Balay - Built-Under Freezer (A+)

A4 (3FIB3620)- Balay - Top Freezer Fridge (A+)

A5 (KAG90AI20)- Bosch - Side-by-Side Fridge Freezer (A+)

A6 (KA3902I20)- Neff - Side-by-Side Fridge Freezer (A+)

A7 (KAG90AW204)- Bosch - Side-by-Side Fridge Freezer (A+)

Now that the alternatives are defined, the AHP diagram would look like this:

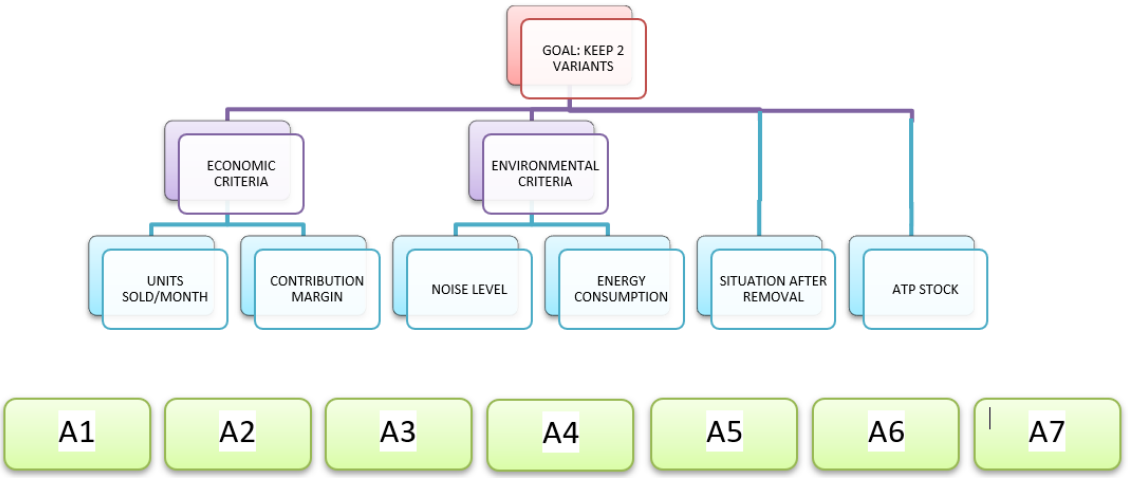


Figure 11. Goal, criteria and alternatives of the AHP (self- elaborated)

3.4. RATING THE ALTERNATIVES

Now that the hierarchical system is complete and explained, it is time to evaluate the alternatives with respect to the different criteria.

The data have been introduced in Expert Choice, and they were previously organized in this table:

ALTERNATIVES	DESCRIPTION	C. MARGIN %	UNITS SOLD/MONTH	NOISE LEVEL (dB)	E.CONSUMPTION (kwh/año)	SITUATION after removal	ATP STOCK	REF. BSH	BRAND
A1	Built-under freezer	56.88%	101	38	184	5	120	GU15DA55	Siemens
A2	Side-by-side Fridge Freezer	45.63%	151	42	436	8	179	KA93DVIFP	Siemens
A3	Built-under freezer	38.18%	31	38	118	4	240	3KUB3253	Balay
A4	Top Freezer Fridge	42.88%	20	39	244	3	190	3FIB3620	Balay
A5	Side-by-side Fridge Freezer	40.01%	45	43	432	7	53	KAG90AI20	Bosch
A6	Side-by-side Fridge Freezer	55.71%	33	43	436	6	77	KA3902I20	Neff
A7	Side-by-side Fridge Freezer	61.78%	85	43	432	4	235	KAG90AW204	Bosch

Figure 12. Table of alternatives and characteristics (self-elaborated)

As previously mentioned, real data of contribution margin percentages, units sold/month and ATP Stock cannot be revealed. However, the data used is approximate to the real one. Noise level and Energy consumption data used for this project is the official one.

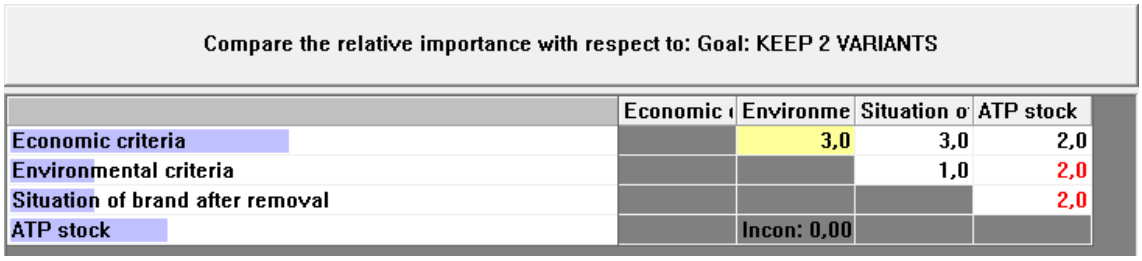
In the case of “Situation after removal”, the numbers employed for the scale in the respective column, represent the change after removing the chosen alternative. The

numbers are between 1-10, being 1 = much worse situation of brand after removal, and 10 = no bad effects on brand after removal.

To describe the rating stage of the process, there will be several images of Expert Choice interface, that will show how each alternative and criterion has been rated.
In order to keep things precise, the images will not show each pairwise comparison between alternatives, but the general visualization of those alternatives with respect to a common criterion.

Before passing onto the alternatives evaluation, it should be clear how the criteria have been rated, so we can see the importance of each one for the Decision-Maker. As usual in the business framework, the main thing that must be considered is the economic aspect of a decision. So, it can be expected that the most important criteria are going to be the economic ones, "Contribution margin" and "Units sold per month".

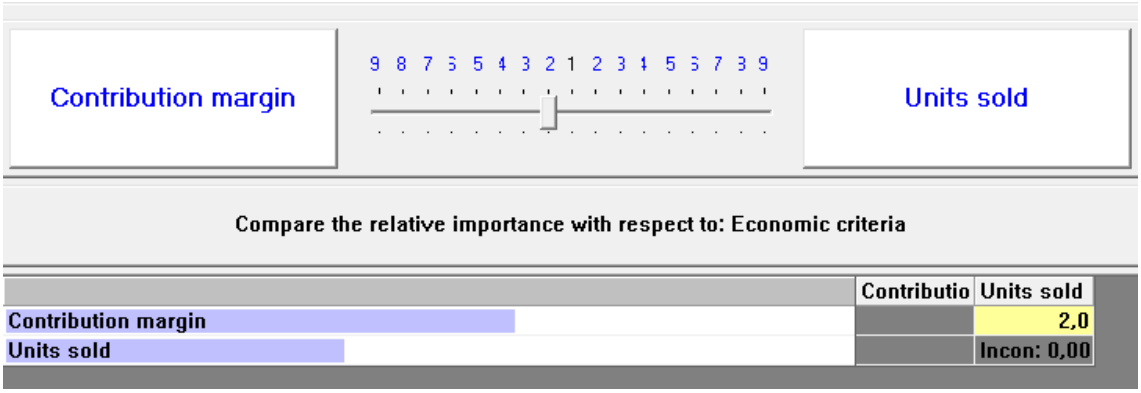
Here is the relation between the criteria with respect to the goal.



As said before, economic criteria are the most important when taking this decision. It is moderately preferred (3,0) with respect to Environmental criteria and the Situation after removal criterion. In pairwise comparison with ATP Stock, the difference is lower, it is only rated with 2,0 over ATP Stock.

Having that in mind, the priorities that are derived are shown in the following image:

Now, once the four main criteria are established and rated among them, let us see the subcriteria inside Economic criteria and their priorities:



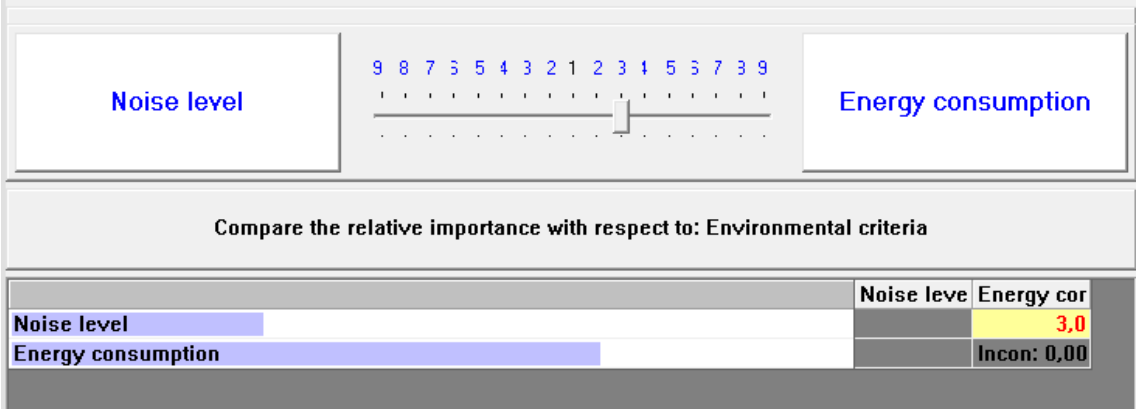
Contribution margin criterion is preferred over units sold, in a moderate way. They are both important, but contribution margin is usually taken as reference over units sold.

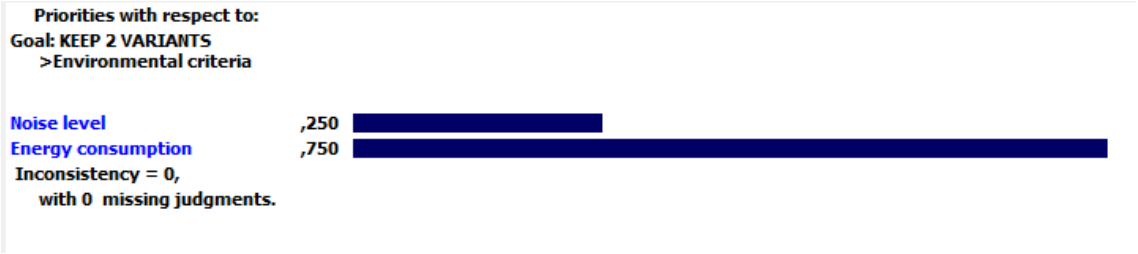
After analyzing Economic criteria, we will see the subcriteria within Environmental criteria.

The criteria were:

- Noise level
- Energy consumption

Noise level is not as important as Energy consumption, because the noise level range of the devices is not as crucial as the energy consumed per year, that affects the yearly fees paid by consumers.

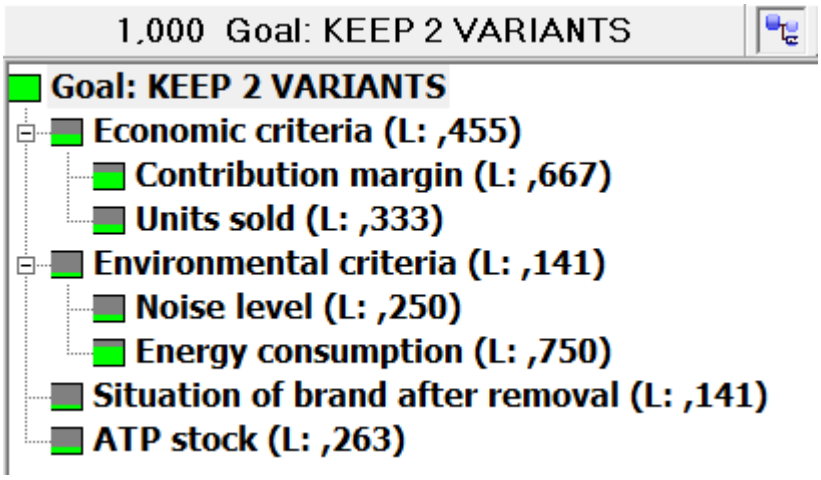




The rating between criteria is finished.

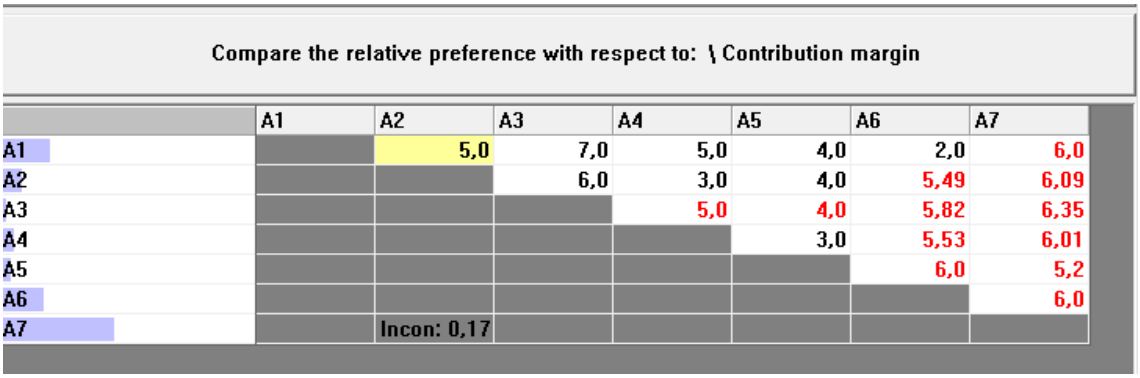
To sum up, economic criteria are preferred over the rest of criteria, followed by ATP Stock. Environmental criteria and Situation after removal are considered as equally important with respect to the goal.

The AHP model is now fully structured and forms this diagram:



3.4.1. ECONOMIC CRITERIA

Let us start by observing the ratings with respect to the economic criteria, first each of the two subcriteria, and then with respect to the economic criteria node.



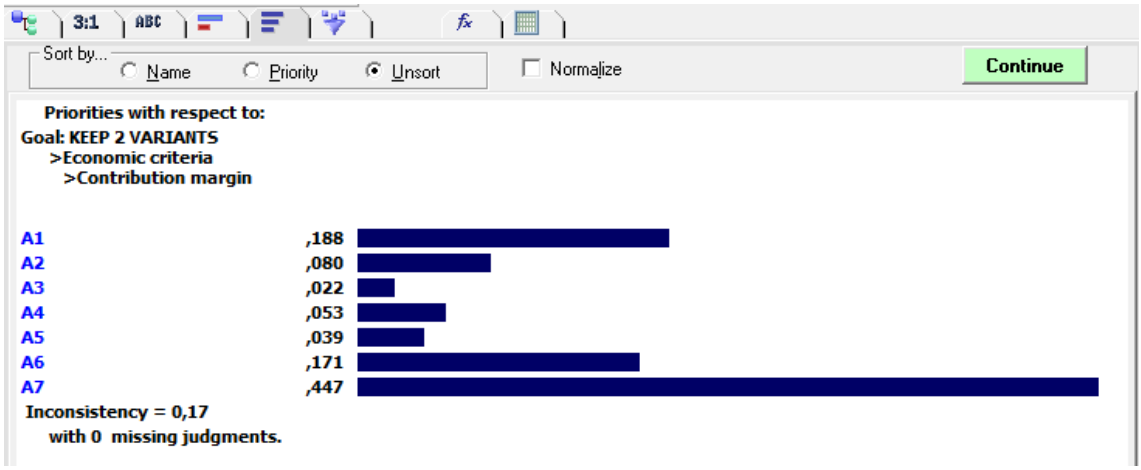
As this is the first criterion that is being evaluated, it is adequate to explain what is shown in these pictures, as they are very similar to those of each remaining criterion.

The image above shows the Comparison area, in which the user can compare alternatives by pairing them, rating those alternatives in the table shown on the right side of the picture. There are several modes to evaluate alternatives (numerically, verbally and graphically), but the preferred method by the Decision-Maker has been the numerical pairwise comparison mode. Through this mode, alternatives are rated following a scale of 1-9, being:

- 1 = Both alternatives are equal with respect to the criterion

- 9 = One of the alternatives is extremely preferred with respect to the criterion

Once the rating has been applied, following the table of alternatives and characteristics, the user obtains the priorities. Priorities of alternatives with respect to Contribution Margin are shown like this:



As we already saw in the table of alternatives and characteristics, the alternative with the highest contribution margin was A7 (61,78 %), followed by A1 (56,88%) and A6 (55,71 %). That is why A7 appears as the "winner" of this criterion. It had the best contribution margin per product sold.

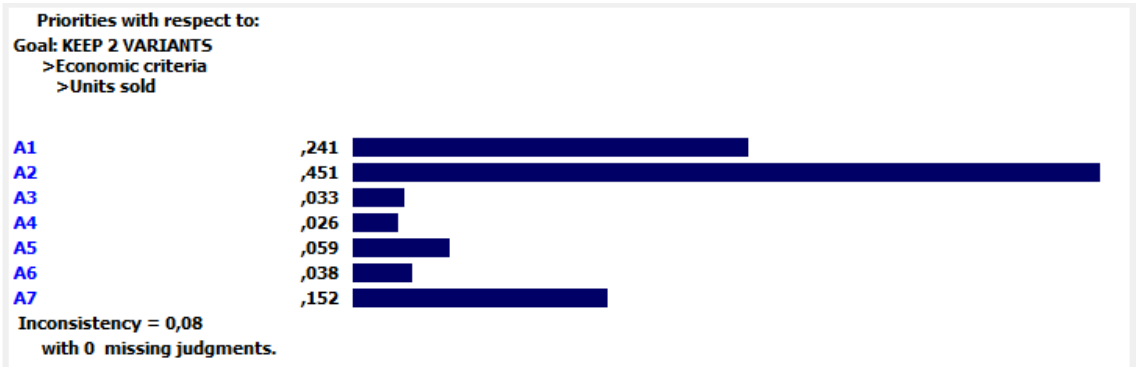
On the other hand, A3 and A5 have the lowest values for contribution margin, so they are not the ideal alternatives in this case.

Next economic criterion is "Units sold per month". Again, we have two pictures, first the pairwise comparison matrix:

Compare the relative preference with respect to: \ Units sold

	A1	A2	A3	A4	A5	A6	A7
A1		5,0	7,0	8,0	6,0	7,0	3,0
A2			8,0	8,0	7,0	8,0	4,0
A3				2,0	2,0	2,0	5,0
A4					3,0	2,0	5,0
A5						3,0	5,0
A6							6,0
A7		Incon: 0,08					

By looking at these paired comparisons and the left-side bar chart, we can anticipate that A2 and A1 are the preferred alternatives with respect to this criterion. If we look at the table of characteristics, we observe that they have the highest values, 151 and 100 units sold per month. We also appreciate that A3 and A4 have low values, only 31 and 20 units sold per month.



Having that in mind, we understand that A2 is the better alternative for this criterion, followed by A1 and A7.

3.4.2. ENVIRONMENTAL CRITERIA

The two different criteria that together form Environmental criteria are Noise level and Energy Consumption. It was previously mentioned that Energy consumption has been better rated than Noise level, as consumers are more aware of Kilowatts per hour / year than Decibels.

The rating of the seven alternatives with respect to Noise level is the following:

Compare the relative preference with respect to: \ Noise level

	A1	A2	A3	A4	A5	A6	A7
A1		4,0	1,0	2,0	5,0	5,0	5,0
A2			4,0	3,0	2,0	2,0	2,0
A3				2,0	5,0	5,0	5,0
A4					4,0	4,0	4,0
A5						1,0	1,0
A6							1,0
A7		Incon: 0,01					

With their respective priorities:

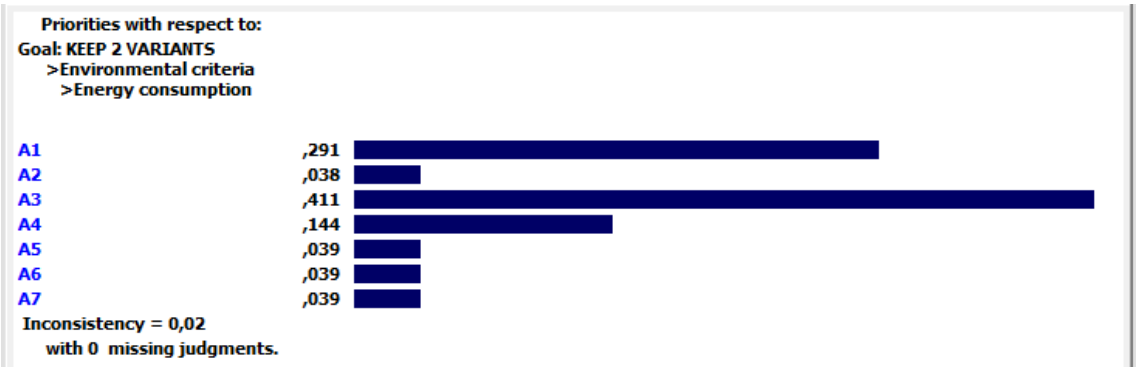
A1 and A2 are clearly preferred over the rest of alternatives, as their noise levels were the lowest ones in the range (38 dB). Then, the side-by-side fridge freezers (A2, A5, A6, A7) are louder devices, so they are less preferred.

Regarding the energy consumption, it is observed the same issue. The biggest devices, again side-by-side fridge freezers, show the highest consumption values, so they are worse rated than smaller appliances.
The rating is the following:

Compare the relative preference with respect to: \ Energy consumption

	A1	A2	A3	A4	A5	A6	A7
A1		8,0	3,0	3,0	8,0	8,0	8,0
A2			8,0	5,0	1,0	1,0	1,0
A3				3,0	8,0	8,0	8,0
A4					4,0	4,0	4,0
A5						1,0	1,0
A6							1,0
A7		Incon: 0,02					

Obtaining these priorities:



The most preferred alternatives are in this case A3 and A1, as their consumption values are really low compared to those of the side-by-side devices.

3.4.3. SITUATION OF BRAND AFTER REMOVAL

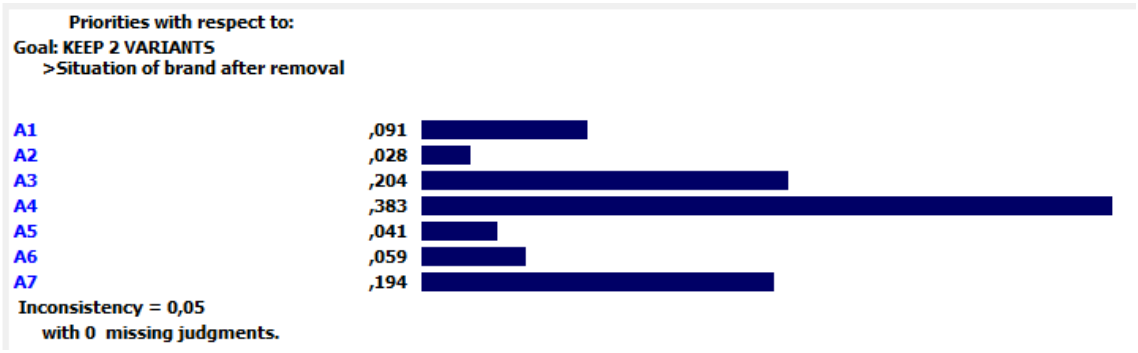
One of the independent criteria left to see is Situation of brand after removal, which is the most subjective of the criteria studied. The different alternatives were given numbers between 1-10, being 1 = much worse situation of brand after removal, and 10 = no bad effects on brand after removal.

The pairwise comparison map in this case looks as follow:

Compare the relative importance with respect to: Situation of brand after removal

	A1	A2	A3	A4	A5	A6	A7
A1		4,0	3,0	4,0	3,0	2,0	3,0
A2			6,0	7,0	2,0	3,0	8,0
A3				3,0	6,0	5,0	1,0
A4					5,0	5,0	4,0
A5						2,0	5,0
A6							4,0
A7		Incon: 0,05					

A4 and A3 hold the first two positions for this rating, because their removal wouldn't worsen the brand's situation as much as in the case of the rest of alternatives.



3.4.4. ATP Stock

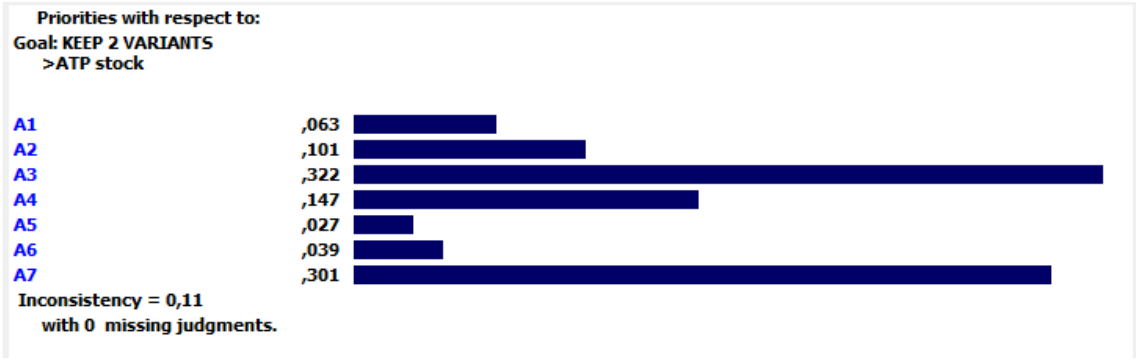
Last criterion to be analyzed is ATP Stock. It is not as important as economic criteria, but is also crucial for this decision, because variants with high stock still available should not be removed from the product line.

The map of pairwise comparison is as follows:

Compare the relative preference with respect to: ATP stock

	A1	A2	A3	A4	A5	A6	A7
A1		4,0	7,0	6,0	5,0	4,0	7,0
A2			6,0	2,0	5,0	3,0	5,0
A3				3,0	7,0	6,0	1,0
A4					4,0	3,0	3,0
A5						2,0	6,0
A6							5,0
A7		Incon: 0,11					

Which results in their priorities looking like this:

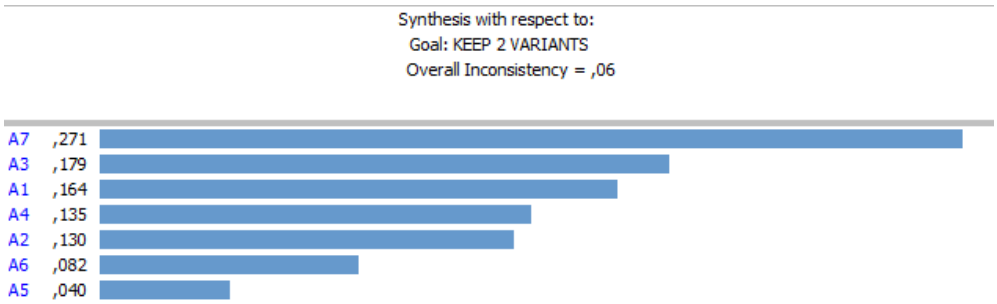


So, the clear “winners” in this criterion are A3 and A7, as their ATP Stock numbers were higher than the rest, 240 and 235 units respectively. It would mean higher costs for the company if they were removed.

3.5. RESULTS OF THE RATINGS

After rating every alternative with respect to the criteria, and every criterion with respect to the goal, the result is obtained.

The initial goal was to select 2 variants to keep in the portfolio, and the 5 left, would be the ones removed. The synthesis with respect to the goal is as follows:



The best alternatives coming from this analysis are A7 (KAG90AW204) and A3 (3KUB3253), with a rating of 0,271 and 0,179 over 1. These two alternatives are the chosen ones by the Analytic Hierarchy Process, and they should stay in the product portfolio.

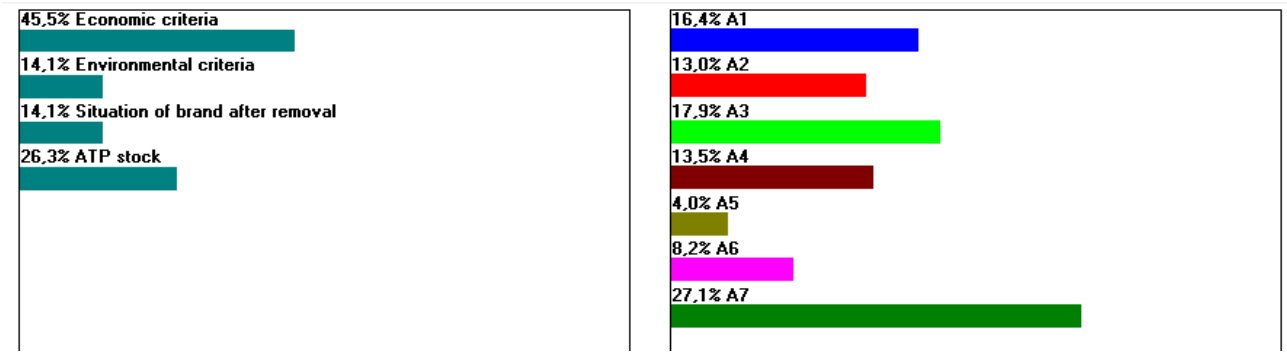
4. DISCUSSION OF RESULTS AND CONCLUSION

In order to conclude the project, this last chapter is dedicated to explaining the results, observe them in different scenarios, and define what would be the conclusions of the study.

In the previous chapter the results of the ratings showed that the alternatives that should stay in the refrigeration portfolio were A7, which is the clear winner, and A3, not that far from A1. In fact, the difference between A1 and A3 is very small (A1 has 0,164 and A3 0,179), and just with a light variation in any of the criteria could alter the solution.

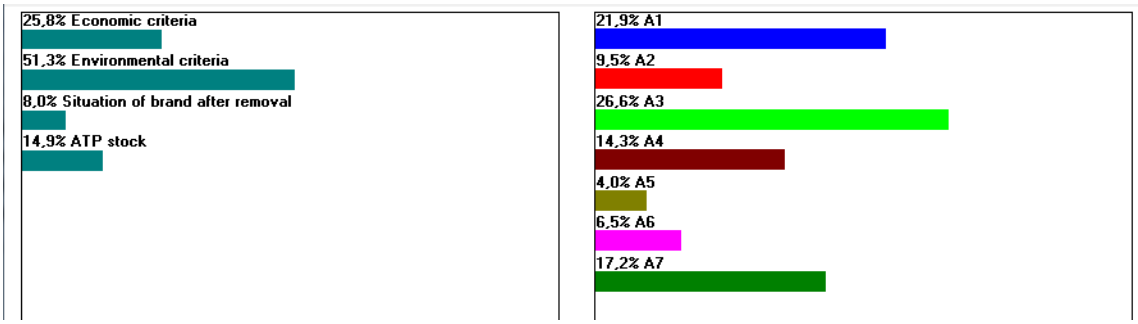
What must happen for this situation to change? To observe this new scenario and some others, a sensitivity analysis has been carried out with the Sensitivity-Graphs tool of Expert Choice.

The initial position would be the original result, which is as follows:

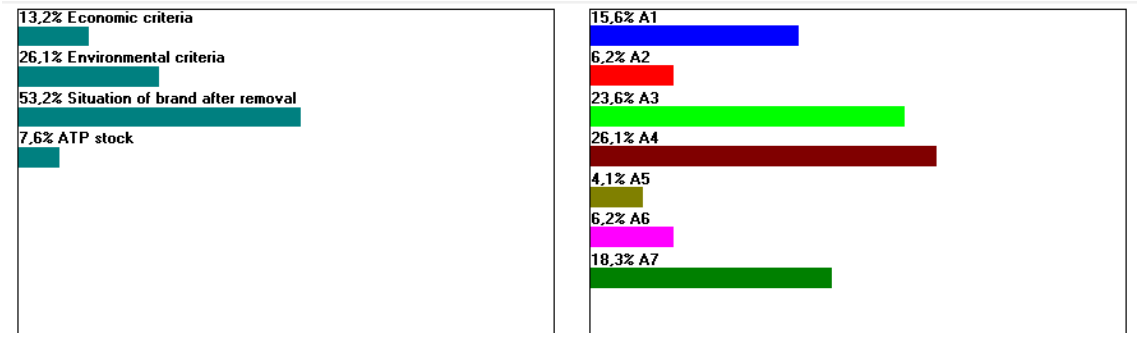


First, the environmental criteria bar indicator has been improved until reaching a 51.3% within the rest of criteria. The other criteria were reduced automatically by Expert Choice.

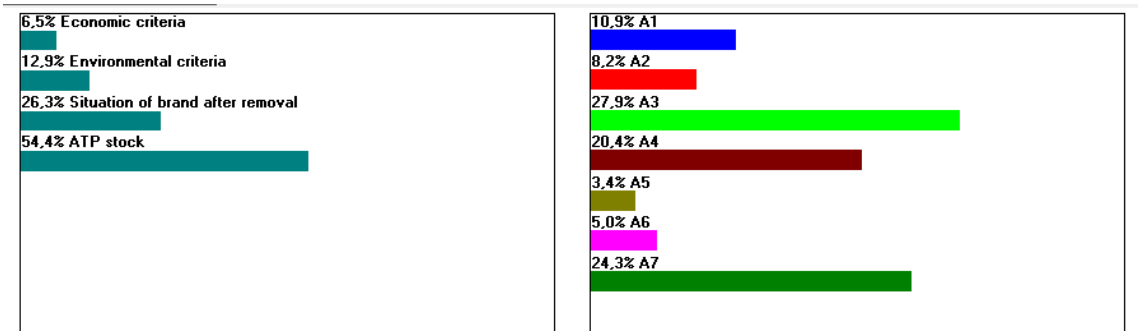
In this new scenario, A7 is no longer the most preferred alternative, it is A3 instead, because of its low noise level and energy consumption, 38 dB and 118 kwh/annum. After A3 comes A1, with the same noise level value and 184 kwh/annum. A5 is still the least preferred alternative.



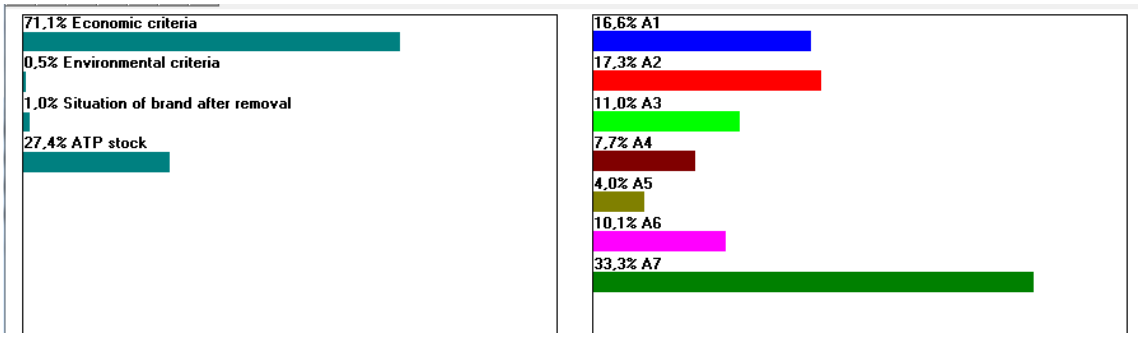
For the next hypothetical situation, the criterion that was altered is “Situation of brand after removal”. It was improved until surpassing the 50,0%. As it can be seen in the image below, now A4 and A3 are the most preferred alternatives. This change happens because their values in that criterion are the lowest, 3 and 4, meaning that the brand portfolio would be quite affected after their removal.



Another scenario analyzed is the one in which ATP Stock is by far the most valued criterion. Its value was improved until 54,4%. Now, A3 is the best rated alternative, followed by A7 (similar situation to the original scenario). Their ATP Stock values are the highest among the alternatives, 240 units in the case of A3 and 235 units of A7.



The last scenario that was checked is the one in which economic criteria assessment is boosted, until having a 71,1% among the other criteria. It is only in this new scenario that A1 wins over A3, but again A7 is the most preferred, and drastically in this case, due to its contribution margin of 61.78%. Next alternative in line is A2, with a 17,3%, as a result of its success in the category of Units sold per month, 151.



Having observed those other scenarios, it can be said that A7 is the most preferred alternative because of its good economic criteria and ATP stock number, but it is not as competitive when it comes to environmental criteria or situation of brand after removal.
Then A3 is a really good alternative in every criterion except in the economic aspect, where it is a bit less competitive due to its low contribution margin and number of units sold per month, 38.18% and 31 units.
A1 is remarkable in the environmental aspect, as a result of its 38 dB and 184 kwh/annum.
A4 on the other hand is outstanding with respect to the situation of brand after removal, due to its 3 on the scale.
Finally, we have A2, A5 and A6. A2 is slightly better rated than the other two alternatives, and this is by reason of the number of units sold per month, as it is the most sold alternative. Then A5 and A6 are the worst rated alternatives and are not worthy in any of the criteria.
If it was the other way, two products leave and five stay in the portfolio, A5 and A6 would be the ones removed.

Summarizing, the objectives of the paper were met. A hierarchic decision model was built, and two alternatives (A7 and A3) have been clearly chosen to be kept in the refrigeration portfolio of BSH Electrodomésticos España, and the other five would be removed, by cause of the previously mentioned reasons.
This same method and software could be used by the other product families, not only refrigeration, to speed up the management of a reduction in their own portfolios. It can also be applied by other departments of BSH, to manage new sales projects, find a good location for a new warehouse, launch new marketing campaigns, etc. It is suitable for many departments due to its ease of use and possibilities.

The use of Expert Choice has been of great help, to organize the hierarchic model, and to rate and compute the different priorities. It would have been much more time-consuming doing it with Excel or manually on paper. It has also provided the project with the sensitivity analysis, which was simple to manage and understand.

The elaboration of this project was carried out using previous knowledge of Mathematics II, Statistics I and Microeconomics I, learned during the degree. Also, product knowledge acquired in the company has been of great help.

REFERENCES

Bana e Costa, C. A., & Vansnick, J. C. (2008). A critical analysis of the eigenvalue method used to derive priorities in AHP. *European Journal of Operational Research, 187*(3), 1422-1428.

Belt Project European Union. (2019). https://www.belt-project.eu/about

Fellini, R., Kokkolaras, M., & Papalambros, P. Y. (2003). Efficient product portfolio reduction. In *World Congress of Structural and Multidisciplinary Optimization: 19/05/2003-23/05/2003*. Schönenfeld & Ziegler.

Figueira, J., Greco, S., & Ehrgott, M. (2004). Introduction. In *Multiple criteria decision analysis: state of the art surveys* (pp. xxi–xxxiv). Springer.

Frobenius, G., (1912). Über Matrizen aus nicht negativen Elementen. *Sitzung der physikalisch-mathematischen.* https://upload.wikimedia.org/wikipedia/commons/4/44/Ueber_Matrizen_aus_nicht_negativen_Elementen.pdf

Glur C. AHP Examples (2018) https://cran.r-project.org/web/packages/ahp/vignettes/examples.html

Guerras Martín, L. A. (1989). Gestión de empresas y programación multicriterio. *ESIC Editorial, Madrid.*

López Salcedo, J. (2014). TFG Ingeniería en Tecnologías Industriales. Valoración de activos industriales mediante AHP. *Universidad Politècnica de València.*

Malczewski, J., & Rinner, C. (2015). Multicriteria Decision Analysis in Geographic Information Science. *Analysis Methods*, (Massam 1993), 331. https://doi.org/10.1007/978-3-540-74757-4

Miller, G. A. (1956). The magical number seven, plus or minus two: Some limits on our capacity for processing information. *Psychological review*, *63*(2), 81.

Nueva Etiqueta Energética de electrodomésticos. (2020). Organización de Consumidores y Usuarios (OCU). https://www.ocu.org/vivienda-y-energia/equipamiento-hogar/noticias/cambio-certificacion-energetica

Perron, O. (1907). Zur theorie der matrices. *Mathematische Annalen*, *64*(2), 248-263.

Roy, B. (1985). Méthodologie multicritère d'aide à la décision (No. BOOK). Economica. English translation: Multicriteria Methodology for Decision Aiding, Kluwer, 1996.

Saaty, T. L. (1980). The analytic hierarchy process: planning, priority setting, resource Allocation. *MacGraw-Hill, New York International Book Company*, 287.

Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International journal of services sciences*, *1*(1), 83-98.

Vargas, R. V. (2010). Using the analytic hierarchy process (AHP) to select and prioritize projects in a portfolio. *PMI® Global Congress 2010—Washington, DC. PA: Project Management Institute.*

Yadav, A., & Jayswal, S. C. (2013). Using geometric mean method of analytical hierarchy process for decision making in functional layout. *International Journal of Engineering Research and Technology (IJERT)*, *2*, 5.

Zunzunegui Suárez, Á. (2017). La teoría de decisión multicriterio. *Universidad de Cantabria.* https://repositorio.unican.es/xmlui/bitstream/handle/10902/13320/ZUNZUNEGUISUAREZALVARO.pdf?sequence=1&isAllowed=y