# ANSPI: an Analytic Network Process Software Tool

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## Abstract
The analysis and identification of the best choices based on different criteria and alternatives is a difficult task, the results affect directly the achievement of the organization's objectives. In this sense, rigorous approaches of Multi-Criteria Decision Methods (MCDM) assist decision makers in sorting and selecting the best alternatives. Widely used on the solution of complex problems, the Analytic Network Process (ANP) is a decision-making tool that enables networking and calculates relationships between different network elements. This paper aims to present the ANSPI software developed in JavaScript language with the purpose of assisting in the use of ANP for complex decisions. Related work and tools are presented in order to identify advantages and difficulties. The tool has intuitive features and an easy-to-use interface, allowing multiple criteria and alternatives, and creating the representation of a networked system that considers interdependencies, feedbacks and complex relationships between different network elements.

## Keywords
Analytic Network Process, Decision-making, Multi-Criteria Decision, Multi-Criteria Analysis, Strategic Intelligence.

## 1. Introduction

Crucial to organizational competitiveness, decision-making must consider different criteria and alternatives to select the option that provides the best benefits to the organization (Czekster et al. 2019a). Multi-Criteria Decision Methods (MCDM) (Zavadskas et al. 2014) or Multi-Criteria Decision Analysis (MCDA) (Norheim 2018) are techniques that help managers to structure and choose the best solutions for problems involving different criteria and alternatives (Wang and Le 2019). It is noteworthy that the rigorous structuring of MCDM provides a complex approach to decision-making management, providing greater clarity about the problem studied, and is very indicated to treat problems with a high degree of complexity (Cohen et al. 2019). Given its advantages, the application of multi-criteria decision-making techniques has a growing and significant interest from researchers and scientists from different fields of study (Behzadian et al. 2010) with the purpose of assisting in decision making through classification, ranking and selection of the best alternatives (Kheybari 2020).

Over the years, different multi-criteria methods to support decision making have been developed, such as AHP (Analytic Hierarchy Process) (Saaty 1991; Ishizaka and Labib 2011; Ho and Ma 2018), ANP (Analytic Network Process) (Saaty, 1996; Sipahi and Timor 2010; Chen et al. 2019), TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution) (Yoon and Hwang 1995; Behzadian et al. 2012; Salih et al. 2018), PROMETHEE (Preference Ranking Organization Method for Enrichment of Evaluations) (Brans et al. 1986; Behzadian et al. 2010; Peterková and Franek 2018), MAUT/MAVT (Multi-Attribute Utility/Value Theory) (Dyer 2005; Allah 2019), MACBETH (Measuring Attractiveness by a Categorical Based Evaluation Technique) (Costa and Vansnick 1999; Marcelino 2019), ELECTRE (Elimination and Choice Expressing Reality) and variants (Current 2013; Govindan and Jepsen 2016), and VIKOR (Multi-criteria Optimization and Compromise Solution) (Opricovic 1998; Mardani et al. 2016; Gul et al. 2016), among others.

Multi-criteria decision-making methods are being used in several organizations, industries and universities worldwide as a decision-making support tool, helping managers in choosing alternatives that increase productivity and reduce costs and raw materials (Czekster et al. 2019b). Considering the importance and impact of decision making in organizations (Kipper et al. 2020; Furstenau et al. 2021a, 2021b; Furstenau et al. 2020a, 2020b; Sott et al. 2020a, 2020b; López-Robles et al. 2020; Sott et al. 2021), this paper aims to provide the software tool for the ANP method through an intuitive graphical interface that allows decision makers to model criteria and alternatives for complex problems. The free software entitled Analytic Network Process Software Tool (ANSPI) and its functionalities are presented in this article so that professionals and academics from various fields can make use of its resources.

## 2. Analytic Network Process (ANP)

Proposed in 1996, by Saaty, as an extension of the AHP method, the ANP approach differs from the traditional AHP hierarchical structure and suggests the construction of a network system. Many decision problems involve the dependence of higher-level elements on lower-level elements and cannot be hierarchically structured (Saaty 2006). In this perspective, while AHP defines weights for decision making without considering interdependency and correlation between decision making factors, ANP gains complexity by more easily representing the complex relationships between elements of a hierarchical structure (Gölcük and Baykasoğlu 2016; Zhang et el. 2019). ANP establishes a system composed of two hierarchies of elements; the first comprises the objectives and decision criteria, while the second one creates a network hierarchy, which includes dependencies and feedbacks of the elements and between the network elements (Chen et al. 2019).

In the network, the element clusters influence each other, and the loops indicate the existence of internal dependencies, so the network extends in different directions and its element clusters do not follow a specific order (Saaty 2004; Chen et al. 2019). ANP has the flexibility and simplicity of AHP, allowing the use of quantitative and qualitative criteria simultaneously (García-Melón et al. 2008; Kheybari et al. 2020), but replacing the traditional hierarchical structure of AHP by a network structure to calculate the complex relationships between different network elements (Saaty 1999). Hence, when considering interdependent interactions between elements (Lin and Huang 2015), ANP has demonstrated superiority over AHP in uncertain decision environments, and the judgment elicitation technique guarantees advantages over other methods because it reduces decision-making errors (Saaty 2005; Latif et al. 2019). Figure 1 shows the hierarchical structure of AHP (a) in comparison with ANP network system (b), highlighting the evolution from the first to the second method, since ANP allows relationships of greater complexity, interdependence and feedbacks between network elements (Sipahi and Timor 2010).

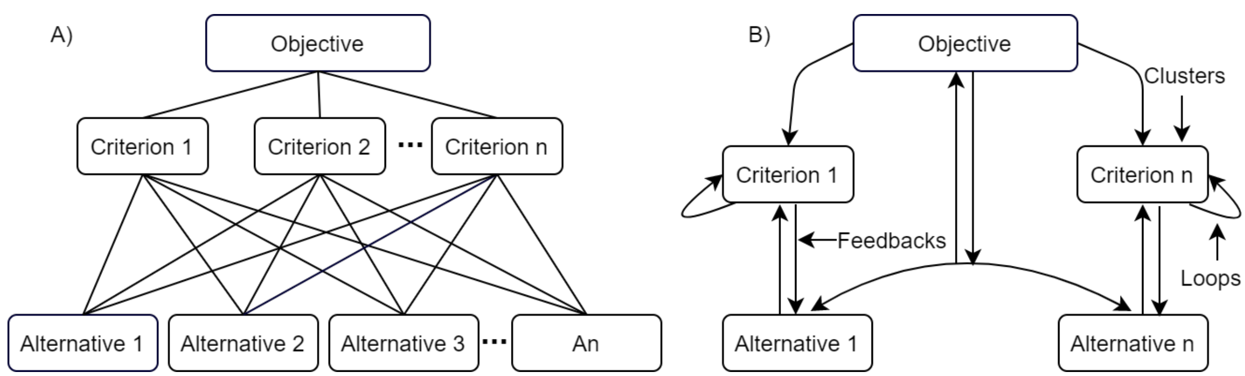


Figure 1. (A) The AHP hierarchy (Adapted from Santos et al. (2018) and Czekster et al. (2019a)). (B) The ANP network (Adapted from Gkountis and Zayed (2015) and Abdel-Basset et al. (2018)).

ANP considers several criteria, sub-criteria and alternatives in a network, and feedbacks and interconnection between clusters (Kheybari 2020), providing a modeling that allows to deal with complex situations of interdependence in different scenarios (Smith-Perera et al. 2010). Lin and Huang (2015), Abdel-basset et al. (2018), Latif et al. (2019) and Kheybari et al. (2020) present the 4 steps of the ANP:

Step 1 - Build a model and develop a network structure: In this step the problem, once identified, is transformed into a network structure where all elements can communicate with each other.

Step 2 - Formulation of a Pair Comparison Matrix: In this step, the decision elements are compared in pairs. The relevance of the elements can be measured on a scale of 1 to 9 (where 1 assigns equal importance and 9 is extreme importance).

Step 3 - Super Matrix Generation: In this step, a super matrix is created to relate system interactions; this super matrix must be later transformed into a weighted super matrix.

Step 4 - Choose the best option: This step consists in choosing the best option, which must be based on the highest weights.

Given its characteristics, benefits and applicability, it is possible to observe that ANP has been widely used in several areas of knowledge, including sustainability (Lin et al. 2015; Wicher et al. 2019; Ngan et al. 2019 ), energy (Sadeghi and Larimian 2018; Khan et al. 2018; Hu et al. 2019; Dong et al 2019; Fetanat et al. 2019), risk assessment (Thilini and Wickramaarachchi 2019), supplier selection (Chen et al. 2018; Wang et al. 2019), project management (Matthies and Coners 2018; Keskin 2019), Big Data (Latif et al. 2019), and others.

## 3. Related works

The ANP method allows a more complete and comprehensive modeling of the problem, controlling and estimating all interconnections between elements (Crimi et al. 2019). The authors considered using AHP as a software to find shipment truck parking, but reconsidered it and used the ANP, since the nature of the variables involved could not be resolved hierarchically with AHP. In addition, this ANP structured analysis facilitates the dialogue and integration among the participants of a group, thereby enabling consensus to be reached, as can be seen in the work of Dano et al. (2019) about flooding in Malaysia. According to the author, the study demonstrated the robustness of the ANP decision method coupled with geolocation tools in the mapping of flooding susceptible points.

Lee et al. (2016) addressed in his study key factors for port management and made an analysis of the ports of Incheon in South Korea, and Bangkok in Thailand. Several criteria were used for analysis for both ANP and AHP techniques. The ANP demonstrated a more comprehensive modeling stability and, according to the author, it is the technique that presented the most consistent results. ANP was used to evaluate how specific business practices influence organizational performance, and how ANP methodology can be used as a mathematical method to collect and transform data from expert opinions (Ruano Pérez et al. 2018). The ANP is able to generalize the AHP approach, allowing mutual influence of any kind between the elements (Crimi et al. 2019). Moreover, for Yosritzal et al., (2019), ANP can be considered a more complete and scientific method than AHP, being the network structure more complex than the hierarchical structure. It can also be pointed out, as an advantage in this method, the calculation of the scale proportion, as well as the way to obtain the decisions, because while AHP is a choice, ANP is an influence (Yosritzal et al. 2019).

The ANP offers a differentiated condition for dealing with decisions without making assumptions about the independence of top-level elements from lower-level elements and about the independence of elements at one level. It also allows a more complex level interrelationship between the various levels of decision (Saaty 1990). The main advantage of using these methods comes from the fact that there are, in general, no decisions that are simultaneously optimal from all points of analysis, thus making the best selection and option possible (Vincke 1992). According to Behzadian et al. (2010), multi-criteria decision methods were also developed by the need to provide modern decision-making techniques that make use of advances in mathematical models and computational technology. Meyer (2003) prioritizes the importance and quantity of objective and subjective variables for decision-making and that simplification is the best way, also highlights that it is not necessary to measure the whole but to find the global variables that really matter and are efficient.

According to Cevriye and Didem (2007), some tools such as Super Decision or Excel among others provide options for creating and managing AHP and ANP models, entering their judgments, obtaining results, and performing sensitivity analyzes on results. When a problem arises, ANP can be a tool to find the best solution within the established criteria. Thus, ANP provides the decision maker with a more realistic definition of existing complex problems. In the literature, other studies and software related to ANP can be found such as the FDA, a free online multi-criteria decision tool that assists in decision making in cases where there are several decision makers. The main advantage of FDA tool is that it allows it to be used for crisp or fuzzy scenarios (Perzina et al 2018), for its use it is required internet, and a browser enables the protocol HTML and JavaScript.

A multichoice software was developed by the Central Institute of Economics and Mathematics of the Russian Academy of Science and has the option to solve the AHP and ANP (Milkova 2016). According to the author, the software has useful tools for exporting and viewing data. To use this software, it is necessary to download it, there is a version in English and Portuguese language. The SuperDecision software can apply AHP and ANP methods (Berdie et al. 2017). This software is available for download on Windows and Mac platforms. In the literature, it is the software that appears in greater use and for several applications, such as: for validation of new concept of automotive electric system (Tworek 2019), development of hydraulic oils for the new fuel-efficient hydraulic hybrid vehicles (Tang et al. 2018) and measuring of metallurgical supply chain resilience using fuzzy (Wicher et al. 2016).

## 4. Methodology and development

The software was developed using four procedures that were implemented according to the literature: a) structure the problem; b) perform the pairwise comparison; c) generate the super matrix and; d) present the best alternative. To illustrate the usage, a fictitious problem was modeled in the software. After the decision maker entered the criteria and alternatives into the software, the result was presented. To arrive at the result, the software performed a sequence of steps that are shown on Table 1.

Table 1. Steps for numerical solution using ANP.

| Step | Activity | Description |
|---|---|---|
| 1 | Sum the matrix column values | After the decision maker assigns the variables, the application assembles a matrix and sums the values of these matrices |
| 2 | Normalize array values | Based on the sum of the previous activity, the summed values are normalized so that they are between 0 (zero) and 1 (one) |
| 3 | Total values by matrix row | Perform the sum of the row of matrices of each criterion and alternative |
| 4 | Calculate the average of each matrix row | Calculate the average of each matrix row |
| 5 | Generate the percentage | To calculate the percentage, the application uses the values obtained in the previous activity and performs the multiplication by 100 (one hundred) |
| 6 | Generate the super matrix | The super matrix is generated using the values resulting from the previous step “generate the percentage” |
| 7 | Generate the boundary matrix | After assembling the super matrix, the application generates the limit matrix, which is built by successively multiplying matrices |
| 8 | Generate the network chart | Finally, the network graph is generated, showing the relationship between the alternatives and the criteria and indicating which is the best alternative |

In order to perform step 2 (normalization) we used equation 1 (Montgomery and Runger 2011). Where $rt_{ij}$ and $R_t$ are defined as non-normalized value of the relationship between elements i and $j$; $rt_{ij}^{N}$ corresponds to the normalized value that will replace $rt_{ij}$; in $R_t$; and $d$ is the column dimension of the matrix $R_t$. This normalization ensures that the sum of all elements for each column of the arrays ($R_1$, $R_2$ …) do not exceed 1.

$$rt_{ij}^{N} = \frac{rt_{ij}}{\sum_{k=1}^{d} rt_{kj}} \quad \text{(Equation 1)}$$

## 5. Implementation, modeling and evaluation

The methods that help in decision making are implemented through computer systems, which facilitate data analysis and present the results quickly in the form of tables and graphs, as well as allow import and export information. On the other hand, a software, in general, is likely to be flawed, sometimes featuring unintuitive designs and lacking functionality (Czekster et al. 2019). Therefore, some features such as simplicity and usability were taken into consideration in the development of ANSPI. The tool does not have a channel to send feedback. However, users will be able to interact with the authors through the email addresses that will be made available on the University website, on ANSPI download page. The Figure 2 represents the data structure used in the software development.

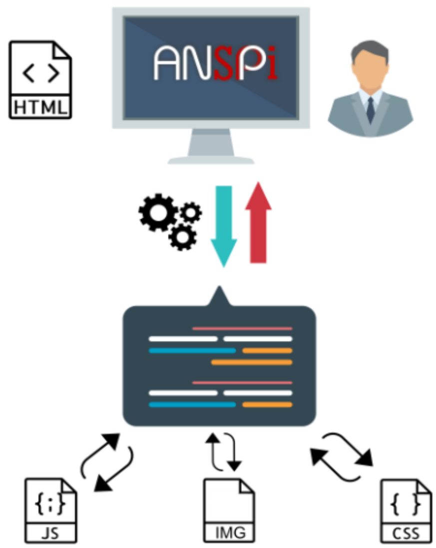


Figure 2. Operating structure of ANSPI software.

The software structure is divided into an HTML page that contains the interface. In the HTML you will find the call of the rules, which are in another file, encoded in the JavaScript (JS) language. In the next call, you will find the Cascading Style Sheets (CSS) writing file that is being used in HTML. Finally, the images (IMG) contained in the software are in a folder that is called by HTML. To use the tool the user will need a browser to download. However, the application will run locally, so no internet access will be required for operation. The application will occupy around 2MB in disk space. The software must be run on devices with HTML support and a browser to run the application. Figure 3 presents the ANSPI home screen.

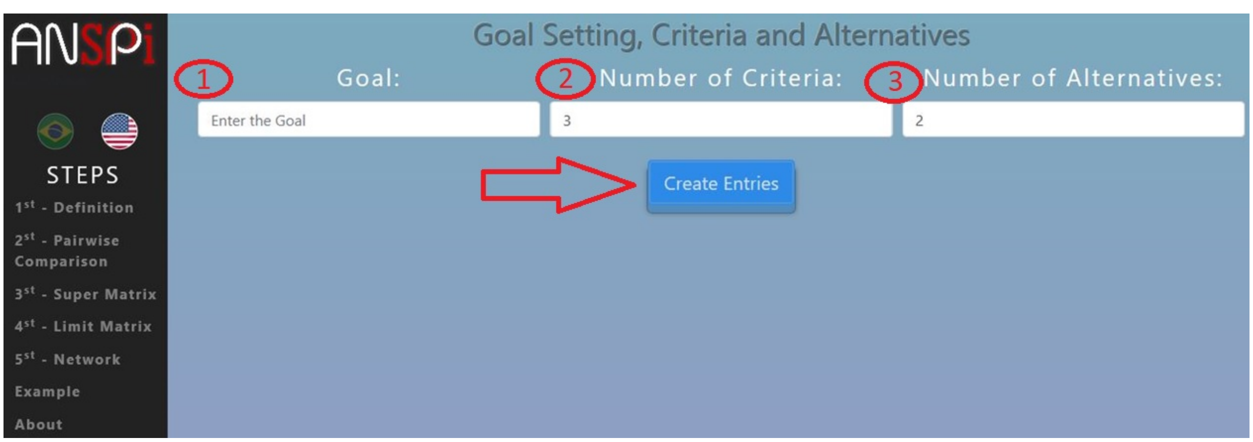


Figure 3. ANSPI general screen - Variable definition.

The menu on the left of the screen presents the steps that the software uses to perform the operation. To do this, the decision maker must first click on definition and enter the parameters of the problem to be solved: the goal, the number of criteria, and the number of alternatives to create the entries. After performing this procedure, it is necessary to enter the criteria and alternatives, as illustrated in Figure 4. In the example, we simulate the selection of a car.

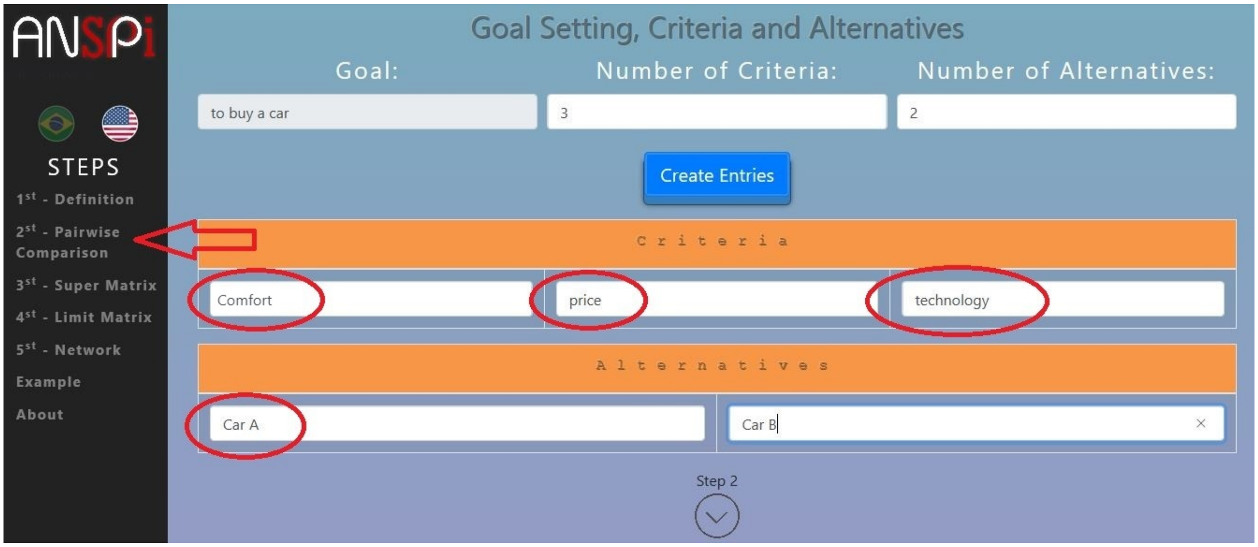


Figure 4. ANSPI intermediate screen - step 1 - definition of variables.

After entering the parameters, the decision maker should click comparison in the menu as indicated in Figure 5. The software will generate the comparison matrix, where the decision maker must indicate the values for the criteria and alternatives. Importantly, the values of the diagonals will always be 1 (one), because according to the literature, a variable when compared with itself must have the value 1 (one) in the matrix.

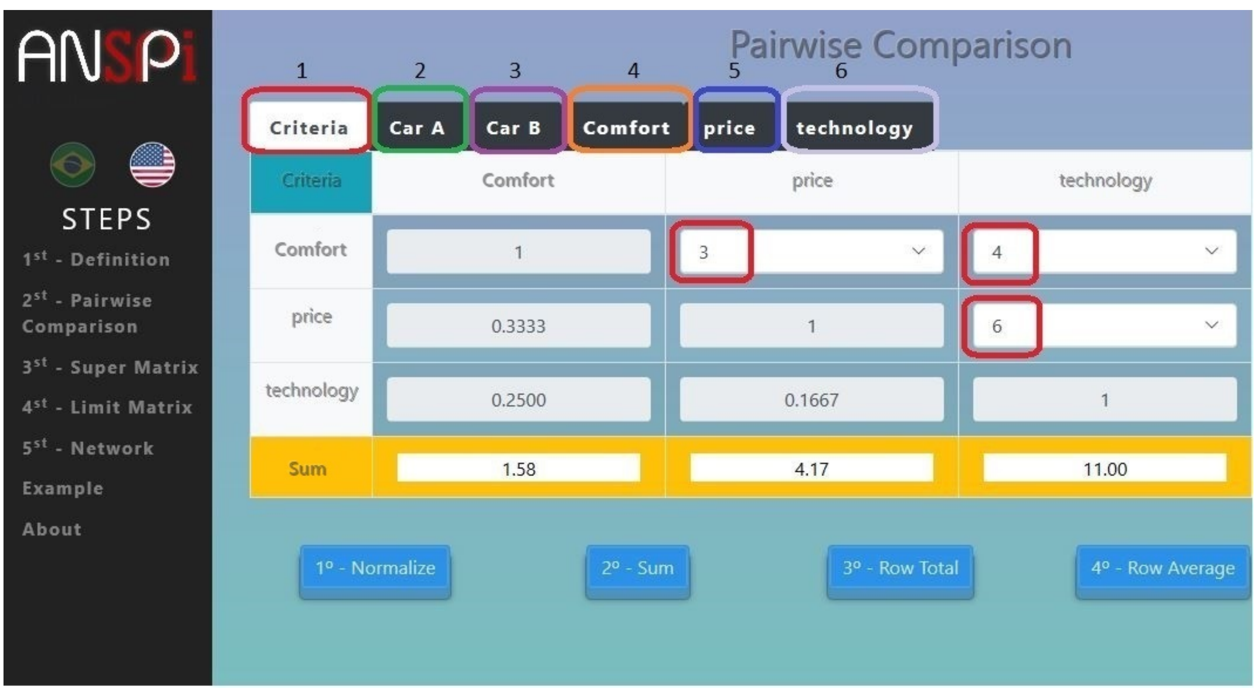


Figure 5. ANSPI intermediate screen - step 1 - pairwise comparison.

Figure 5 illustrates the attribution of values for the criteria, where the decision maker assigned the value 3 (three) on price versus comfort comparison, 4 (four) on technology versus comfort comparison, and 6 (six) on technology comparison relative to the price. Then, the values for alternative A, alternative B and the price, comfort and consumption criteria were assigned. In order to perform this procedure, it is necessary to normalize, sum, generate the total, the average and the percentage per line of the matrix. Figure 6 shows the sequence of what should be done.

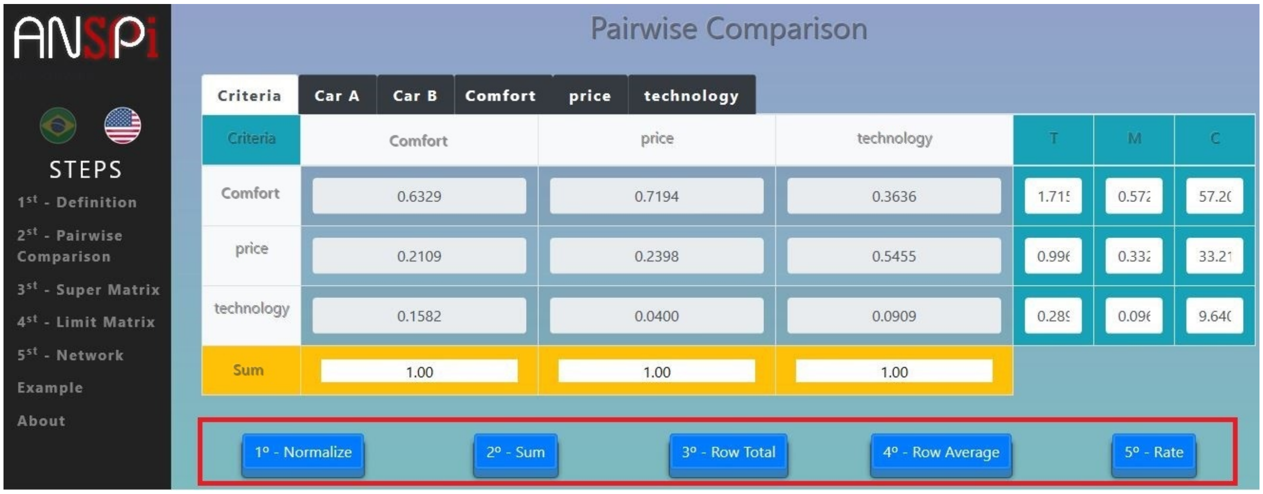


Figure 6. ANSPI Intermediate Screen - Step 1 - Normalize, Sum, and Generate Line Totals.

The next step is the super matrix generation. For that, the decision maker must click on super matrix on the left menu. Figure 7 illustrates the super matrix of the problem.


Figure 7. ANSPI Intermediate Screen - Step 2 - Super Matrix.

Once the above matrix has been generated, the boundary matrix must be generated. Just follow the same procedure as the previous step, but now by clicking limit matrix on the left menu. The boundary matrix is represented in Figure 8.

Limit Matrix

Create Limit Matrix

| Limit Matrix | to buy a car | Comfort | price | technology | Car A | Car B |
|---|---|---|---|---|---|---|
| to buy a car | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Comfort | 0.0 | 25.0 | 25.0 | 25.0 | 0.0 | 0.0 |
| price | 0.0 | 29.0 | 29.0 | 29.0 | 0.0 | 0.0 |
| technology | 0.0 | 45.0 | 45.0 | 45.0 | 0.0 | 0.0 |
| Car A | Ranking 59.0 | 0.0 | 0.0 | 0.0 | 59.0 | 59.0 |
| Car B | Ranking 41.0 | 0.0 | 0.0 | 0.0 | 41.0 | 41.0 |

Figure 8. ANSPI intermediate screen - step 3 - boundary matrix generation.

In order to facilitate interpretation of the result, it is possible to generate the network graph (step 4) by clicking on the network option on the menu. Figure 9 exemplifies the result of the problem (buy car) modeled on ANSPI. According to the chart the best alternative is car A.

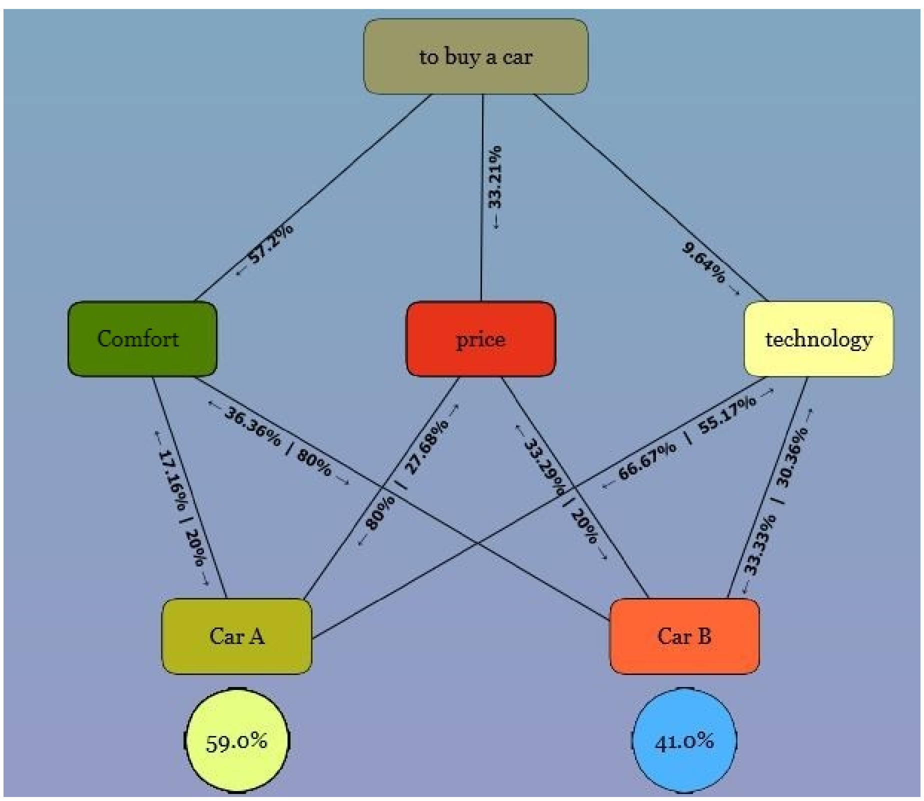


Figure 9. ANSPI Final Screen - Step 4 - Network Chart.

When modeling the problem, it is possible to realize that the software is a user-friendly tool, intuitive and fast to solve. These features are extremely important as users are sometimes unfamiliar with technology and do not have time to understand how a software works.

## 6. Conclusion

This article points out the advantages of using the ANP method as an improvement to the AHP method, favoring a more efficient decision making. It considers all the most relevant criteria and alternatives on a scalar basis and as a network, not just hierarchically, such as AHP. Therefore, the ANSPI software is developed with a fully web and multiplatform interface. This tool was developed to assist decision makers in identifying and selecting more assertive options through the Analytical Network Process multi-criteria decision method. Its interface is simple, intuitive and user-friendly to allow easy data entry, whether by researchers or professionals who want to use the software to support decision making. The technique used makes it possible to rigorously structure and drive decisions for complex problems by calculating the best alternatives from multiple criteria.

The results show that the tool is reliable and robust, since from the insertion of criteria, weights and alternatives the software performs all steps and calculations of the ANP technique, considering the interdependencies between elements and structuring a networked system. In addition, it demonstrates a response speed in the order of hundredths of a second, which guarantees it a great performance. All its development was based on simplicity, always thinking about usability, but covering all the ANP requirements.

The tool is expected to be used by decision makers to build decision models and achieve the benefits offered. An extension for Fuzzy Analytic Network Process calculations, and incorporation of a level of sub criteria to extend the network and assist in solving even broader problems, is also considered to be part of the tool. Another proposal for the software extension is the development of reports to extract each step of technique results. Finally, it is also believed that the results and discussions presented in this article have expanded the knowledge of multi-criteria decision methods, especially ANP with the developed software, and can serve as a scientific basis for future work.

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