METHODOLOGY FOR SELECTING THE BEST STRATEGY TO PROVIDE FUEL TO A COLOMBIAN DEPARTMENT

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ABSTRACT: The Colombian Petroleum Company, ECOPETROL S.A., must select the best alternative to provide fuel during the next years to Nariño, a Colombian department located in the border with Ecuador. The decision has to be taken considering the implementation and operation costs associated to each alternative as well as other criteria related to the reliability in the transport of fuel such as the possibility of control and monitoring, and the time of transport. Since the problem involves some random variables, as well as quantitative and qualitative decision criteria, this paper addresses a structured decision analysis methodology that considers both type of decision criteria to select the best alternative supported in simulation and risk analysis models, and Analytic Hierarchy Process (AHP).

KEYWORDS: transport of fuel, Decision Analysis, Risk Analysis, MonteCarlo Simulation, Analytic Hierarchy Process.

1. INTRODUCTION

This paper presents the application of a decision methodology developed by Mario Castillo, Associate Professor of the Industrial Engineering Department, Universidad de los Andes, to assist ECOPETROL's Vice-President of Transport in making a decision as to the best alternative for procuring fuel to the Department of Nariño, located on the border with Ecuador. This a complex decision making problem considering its economic impact and the high level of uncertainty derived from the presence of variables such as the demand and diversion of fuel.

A general methodology for decision analysis [1] was used for solving the problem. With the assistance of this methodology, the problem was structured by defining the main elements, actors and variables, as well as the decision making criteria and the solution alternatives for it, as shown in Section 2. After structuring the problem, a specific analysis methodology was designed to solve the problem, which is described under Section 3. Section 4 presents the results obtained, and main conclusions and work recommendations are summarized under Section 5.

2. PROBLEM STRUCTURING

During the problem structuring, its main aspects, the actors participating or affected by the problem, the most relevant variables for the decision analysis, the criteria for evaluation and selection of the alternatives, and lastly, the group of alternatives to be considered in the analysis were identified.

Problem Description

The Polyducts Management has paid during the last years an significant annual amount of money, to cover fuel transportation compensation from the city of Yumbo to the city of Pasto, capital of the department of Nariño. During

the years 1999 through 2003 compensation payment increased as a result of the increase in the quotas assigned by the Ministry of Mines and Energy, as well as the annual increase in fuel rates. During these ten years, ECOPETROL S.A. has paid as compensation the amount of 157.000 million pesos; the magnitude of this amount has motivated ECOPETROL to evaluate other alternatives that may be more financially favorable to guarantee the supply to the Departament of Nariño.

Transport compensation makes the fuel price attractive to generate a technical smuggling, and instead of selling the product within the Nariño Department, it is sold in other near departments such as Valle del Cauca and Cauca. Consequently, fuel consumption per capita in the Department of Nariño has significantly increased without a justification since ECOPETROL started to pay the compensation.

Therefore, ECOPETROL S.A. has a justified interest in looking for the best way to transport the fuel between the cities of Yumbo and Pasto. The decision should be taken bearing in mind the various aspects involved in the problem, such as the financial, commercial, technical elements, the institutional image and the regulation, as well as the different stakeholders such as ECOPETROL, the company's union the Ministry of Mines, the Government and the groups on the fringes of the law. The great number of aspects and interactions among the stakeholders involved in the decision are reflected on a great number of variables relevant to the problem, such as the operating and maintenance costs, labor costs, additional investments, demand and diversion of fuel, among others.

Decision Criteria

Some of the aspects identified in the problem, generated the different relevant variables, while others were associated to the decision-making criteria. In order to evaluate the different alternatives for solving the described decision problem, the group of decision makers, integrated by engineers from ECOPETROL, experts in the different aspects of the problems, defined the following criteria for decision, under which the different alternatives would be evaluated:

- *Financial Performance:* Refers to the behavior of the different alternatives in terms of the Net Present Value of Expected Cost and variability of such net present value in the probabilistic model. Of course, it is understood that the lesser the expected cost the better the behavior of the alternative in this aspect.

- *Reliability:* Corresponds to the probability to satisfy the demand for liquid fuel of the Department of Nariño, upon implementation of the different alternatives. Comprises the following aspects:

  - *Possibility of Control:* understood as the possibility born by each procurement alternative to ensure that the fuel being delivered at the final point of the alternative is servicing the actual demand; that is, that there is no diversion for other reasons different from the department's consumption of fuel.
  - *Time for Transportation Storage Point – Final Point:* Represents the time required by ECOPETROL to transport the fuel from the storage center to the final delivery point of fuel for each alternative. It is assumed that a shorter transportation time represents a greater reliability.
  - *Road Infrastructure:* Refers to the quality of the infrastructure of the transportation means used by each alternative to deliver the fuel to the delivery point associated to each alternative.
  - *Logistic and Operating Complexity:* Refers to the complexity of the logistic organization necessary for the implementation of each of the alternatives by ECOPETROL. Comprises possible problems in the operation and contracting associated with each of the alternatives in regards to ECOPETROL'S responsibilities.

Decision Alternatives

Following are the alternatives initially identified by ECOPETROL S.A:

- A1: To contract a fleet of tank cars for transportation of fuel between Yumbo and the gas stations in the Department of Nariño with a quota assigned.

- A2: To contract a fleet of tank cars for transportation of fuel between the city of Yumbo and the city of San Juan de Pasto, where a stock center will be built for the reception, storage and distribution of fuel.

- A3: To transport the fuel by sea from Cartagena to Tumaco, building a provision plant in Tumaco where fuel is delivered to retail dealers.

- A4: To transport the fuel by sea from Buenaventura to Tumaco, building a provision plant in Tumaco where fuel is delivered to retail dealers.

- A5: To continue with present system, taking into consideration the implementation of control systems.

- A6: To build a polyduct to transport fuel between the cities of Yumbo and San Juan de Pasto, where a stock center will be built for the reception, storage and distribution of fuel.

3. METHODOLOGY FOR THE ANALYSIS OF ALTERNATIVES

Following is the description of the specific methodology of three steps shown in Figure 1, which was designed for the selection and final evaluation of the alternatives for provision of fuel to the Department of Nariño. In regards to the general methodology shown in Figure 1, the specific methodology that is shown here would correspond to what appears as model definition in the general methodology.

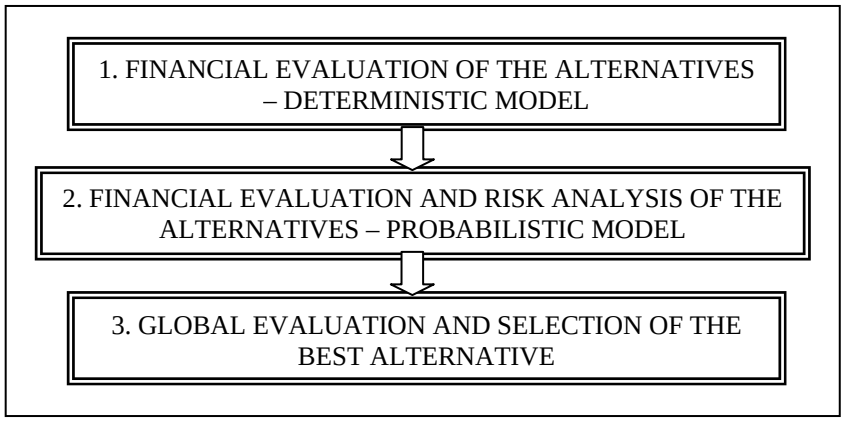

Figure 1: Methodology for the Analysis of Alternatives

Step 1: Financial Evaluation of the Alternatives – Deterministic Model

Based on the information available in ECOPETROL regarding the relevant variables for the financial evaluation of alternatives, and starting from the estimates that the work team considered as more reliable and robust about the Nariño Department demand, a first financial evaluation of the group of identified alternatives was carried out. .

Step 2: Financial Evaluation and Risk Analysis of the Alternatives – Probabilistic Model

Starting from the deterministic model mentioned before, the random behavior of the demand variable was incorporated to the analysis, which represents the main source of uncertainty of the problem. A probabilistic model was structured and the financial evaluation of the different alternatives was carried out based on this model, as well as the description and evaluation of the risk associated with each of them.

MonteCarlo simulation models were used during this stage as well as the Crystal Ball software package.

Step 3: Global Evaluation and Selection of the Best Alternative

Based on the results of the model prepared during former stage and using the decision making criteria agreed with ECOPETROL, a final decision model was created to make the final evaluation of the alternatives. This evaluation raised a timing of the alternatives in respect of the global performance, bearing in mind the decision making criteria established by the decision makers group. This analysis was performed based on a decision methodology known as

the Analytical Hierarchy Process, which allows for the incorporation of quantitative and qualitative aspects to the decision making analysis.

A continuous interaction with the office of ECOPETROL's Vice-Presidency of Transport and its Work Team was present during each of the stages, so that every progress attained in the analysis of the problems was validated by the company.

4. ANALYSIS OF RESULTS

The following results were obtained after applying the methodology described above aimed at determining the best alternative:

Results Step 1: Initial Financial Evaluation of the Alternatives - Deterministic Model

In order to create the deterministic model, a model was prepared in Excel to calculate the Net Present Value (NPV) of costs for the six alternatives defined for a 10 year period.

On the other hand, and taking into account that the fuel demand in the Department of Nariño was the problem's most important variable, the different scenarios for the behavior of this variable were addressed. First of all, five scenarios associated with sustained annual growth of -3%, -2%, 0%, 2% and 3% for the next 10 years were approached, which we called E1, E2, E3, E4 y E5, respectively. Then, another scenario (E6) was created, corresponding to ECOPETROL's forecast of demand. Finally, and taking into consideration that the company believes that a percentage of the demand is possibly being deviated to unlawful activities, a last scenario (E7) was created, which separates in two components the Department of Nariño demand, as follows:

- *Explained Demand:* is the demand destined to regular activities of the department, such as consumption of vehicles and industries.
- *Unexplained Demand:* is the demand destined to unlawful activities and thus, cannot be explained as resulting from the level of development and the economic activity of the department.

In order to establish the percentage of the demand that can be considered as unexplained, we assume that the per capita consumption of Nariño must be similar to the average per capita consumption of the country. At the present time, the per capita consumption of Nariño is 10% above the per capita consumption of the country, and thus it can be concluded that 10% of Nariño's present consumption per capita represents the unexplained demand.

After the unexplained demand was defined for present alternative (A5), the ECOPETROL's team established the percentage of the unexplained demand for the other alternatives, comparing the control possibilities on each of them with those of present alternative. In this sense, the magnitude of the unexplained demand will depend on the possibility born by each supply alternative to guarantee that the fuel that is being delivered at the final point of the alternative is covering the real demand, that is, that there is no diversion for other purposes different from the department's consumption of fuel. Results are shown on Table 1.

Alternative	Unexplained Demand (%)	Unexplained Demand (BDC)
1.- To use tank cars up to the stations	4%	164.0
2.- To build a storage center in Pasto	6%	246.0
3.- To transport the product by sea from Cartagena to Tumaco	11%	451.0
4.- To transport the product by sea from Buenaventura to Tumaco	11%	451.0
5.- To continue with present system (using control systems)	11%	451.0
6.- Polyduct Yumbo – Pasto	0%	0.0

Table 1: Unexplained demand

Using the Excel spreadsheet prepared by ECOPETROL to calculate the NPV of each of the alternatives, an analysis of the behavior of such NPVs was analyzed under the different demand scenarios. Alternative A6 presented a NPV

of cost above the $300.000 (US $150 millions), which is, by far, above that of the other alternatives. For this reason, this alternative was excluded from the analysis that will be presented hereinafter.

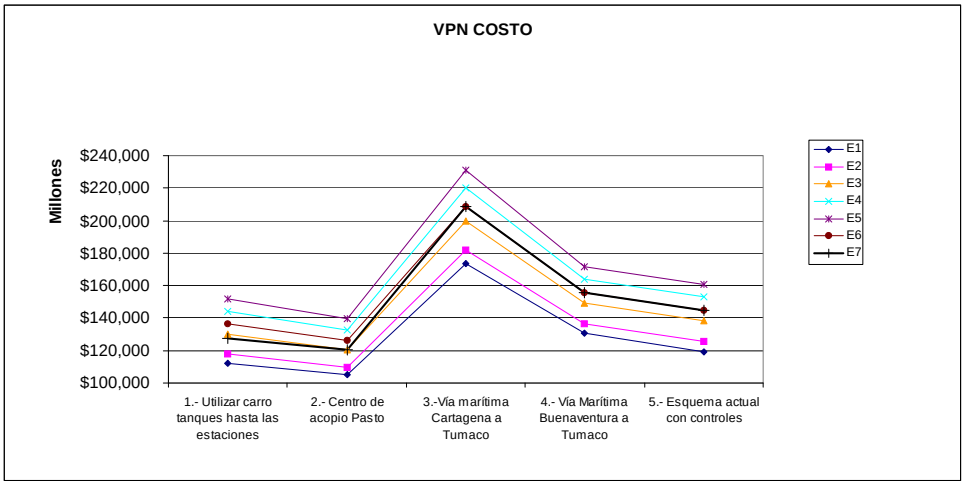

Figure 2: NPV's of Alternatives under the Deterministic Scenarios of Demand

Analyzing the behavior of the alternatives under the different scenarios, as shown in Figure 2, it can be observed that although the demand has certain impact on the cost of the different alternatives (the difference can be around 30.000 million for the demand extremes evaluated), the order of the alternatives is kept independent from the scenario of the demand under consideration. The alternatives with a better financial behavior are A1 and A2 with a cost between 10 and 30 thousand million pesos as compared to alternatives A4 and A5. Alternative A3 has a much higher cost than the other alternatives.

Results Step 2: Financial Evaluation and Risk Analysis of the Alternatives– Probabilistic Model

Starting from the deterministic model created during former stage, the random behavior of the fuel demand variables was incorporated to the analysis. A probabilistic model was structured and used as the base to perform the financial appraisal of the different alternatives and the description and assessment of risk associated with each of them. Different scenarios were defined for this model, starting from the possible behaviors of the random variables which represented the main sources of problem's uncertainty aimed at analyzing the alternatives behavior in the different scenarios. During this stage, MonteCarlo simulation models were used as well as the software package.

In order to model the demand as a random variable, in the first place for the explained demand, starting from ECOPETROL's base scenario, the variation was modeled on the annual growth as a normal random variable, with a mean equal to the growth value corresponding to ECOPETROL's scenario and standard deviation of 1%. In addition and based on the available historic series, it was also estimated that co-relation among demands of consecutive years was around 0.9.

For the unexplained demand, the percentages defined in former stage for each alternative were defined as random triangular variables with the following parameters:

Alternative	Minimum Value	Most probable Value	Maximum Value
1.- To use tank cars up to the stations	2%	4%	4%
2.- To build a storage center in Pasto	4%	6%	6%
3.- To transport the product by sea from Cartagena to Tumaco	6%	11%	11%
4.- To transport the product by sea from Buenaventura to Tumaco	6%	11%	11%
5.- To continue with present system (using control systems)	6%	11%	11%

Table 2: Parameters for Unexplained Demand

For valuation of risk associated with the NPV of cost of each of the alternatives, the standard deviation from the standard expected value of the NPV of each of the alternatives was taken into account, but the Value at Risk (VaR) concept, defined as the maximum loss that can be obtained in respect of a target cost under certain level of reliability, was used as the principal measure of risk for the different alternatives. In this case, the NPV of the cost of alternative A2, which represents the most economical alternative, was taken as the target cost.

Figure 3 presents a summary of the alternatives' behavior, taking into account both, the expected value of cost NPV and the risk, represented by the VaR.

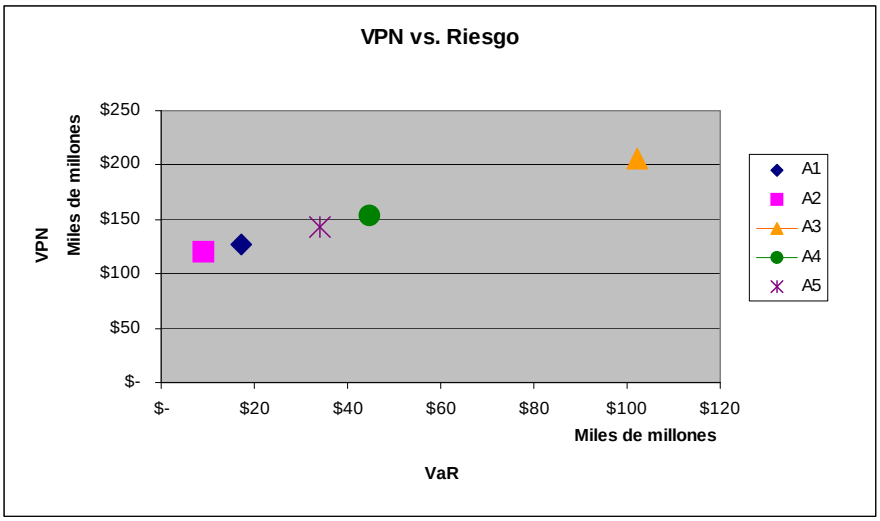

Figure 3: NPV vs VaR for the Five Alternatives

Figure 3 shows that when analyzing both, the NPV and the risk, alternatives A1 and A2 show a better performance than the other alternatives, confirming the results obtained with the deterministic model.

Results Step 3: Evaluation and Selection of the Best Alternative

For final selection of the best alternative an analytical hierarchy process was built taking into consideration the financial performance, measured according to the results for each former stage, such as reliability, explained through various sub-elements. The AHP illustrated in Figure 10 was structured in this manner. For appraisal of this last stage, the alternative A3 was excluded (to transport the product by sea from Buenaventura to Tumaco) because it is clearly dominated by the other alternatives from a financial point of view, and neither did it represented any advantage in the qualitative aspects.

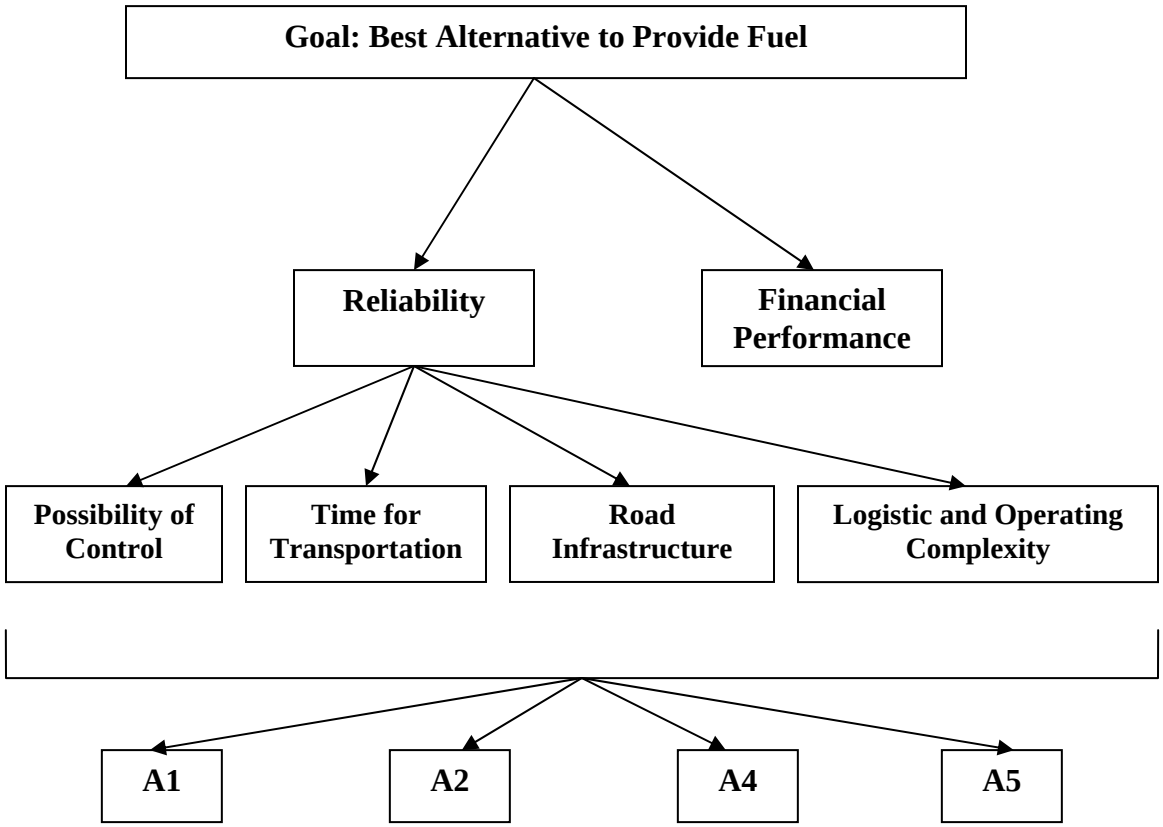

Figure 4: AHP with the Decision Criteria

Based on the hierarchy of Figure 4, pairwise comparison matrices were prepared for the criteria, as well as for the alternatives in respect of the different criteria. Various meetings with ECOPETROL's experts were held for the preparation of the matrices; the experts arrived to a consensus regarding the weights of each of the matrices.

Based on this model, a weight was obtained for each of the criteria, as well as the global rating of the alternatives. These results are depicted in Figures 5 and 6. It is observed that the alternative with the best aggregate performance is A2, as it is the best financially speaking and the second in reliability. Alternative A5 is the second best, in the aggregate, as it is the best in reliability, although its financial performance is not good.

Figure 5: Weight of the Criteria

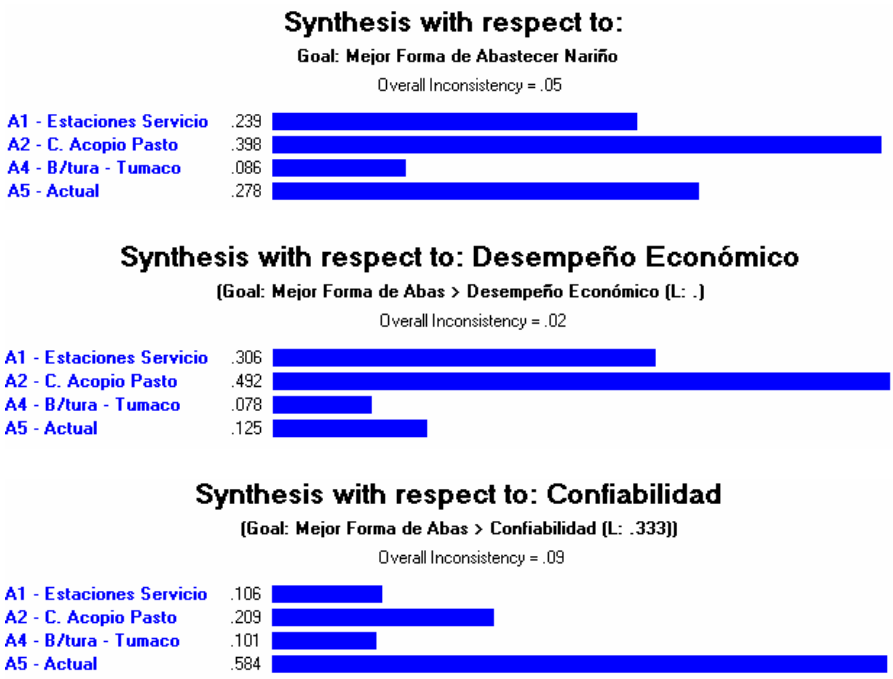

Figure 6: Results of the Five Alternatives

Furthermore, a sensitivity analysis was carried out aimed at observing the impact of the weight changes for decision criteria of first level (Financial Performance and Reliability) in the sequencing of the alternatives, and the conclusion was that the sequencing is very robust before rational changes in such weights. More precisely, the results that have been presented were obtained based on the weights of the Reliability and Financial Performance elements assigned by ECOPETROL of .33 and .67, respectively. If such weights were the same, for example, 5 and 5, the two best alternatives, A2 and A5, would be equal with the same aggregate performance. In order for Alternative A5 to exceed the global performance of A2 it would be necessary for the Reliability element to exceed the Financial Performance element. The other two alternatives, A1 and A4, exceeded the two former ones only before extreme changes in weights of the two elements mentioned before, which would not be rational.

Summarizing the results of this last step of the analysis methodology for the alternatives, it can be concluded that as the evaluation criteria agreed with ECOPETROL's group of decision makers was taken into account, alternative A2 (To build a storage center in Pasto) presents the best global performance, followed by Alternative A5 (to continue with present system using control systems) and A1 (to use tank cars up to the stations).

5. CONCLUSIONS

Considering the methodology developed to select the best strategy for the provision of fuel to the Department of Nariño and the results obtained, we arrived to the following conclusions:

1. The alternatives with the best financial behavior are A1 and A2 with an expected cost under 20 and 30 thousand million pesos as compared to alternatives A4 and A5.

2. Although the demand has certain impact on the cost of the different alternatives (it can reach a difference of around 30 thousand millions for the demand extremes evaluated), the order of the alternatives is kept regardless of the demand scenario considered.

3. Only two great aspects were taken into consideration in the Global Qualitative Model: the Reliability and Financial Performance of the Alternatives. The alternatives with a better behavior in Reliability are A5 (0.584) and A2 (0.209).

4. The alternative with a better global performance taking into account Reliability and Financial Performance is alternative A2 (0.398), followed by alternative A5 (0.278). The worst in global performance was A4 (0.086).

5. Taking into account possible changes in ECOPETROL's stock structure, although the alternative with a better performance, both financially and globally is A2 (Supply Center in Pasto), for the implementation of the final decision to be adopted, ECOPETROL will have to evaluate whether to make the investment demanded by the alternative A2, or whether to maintain present compensation until more precise information is available concerning the future of the regulation presently in force that requires the compensation.

6. The work submitted in this paper shows the importance of the formal application of methodologies and decision analysis models in the evaluation of decisions with high impact in public and private companies, and the considerable savings that this type of analysis can represent for a company.

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