# Multicriteria Decision Making: A Case Study in the Automobile Industry

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**Abstract**

Multi-criteria decision analysis (MCDA) has been one of the fastest-growing areas of operations research during the last decades. The academic attention devoted to MCDA motivated the development of a great variety of approaches and methods within the field. These methods distinguish themselves in terms of procedures, theoretical assumptions and type of decision addressed. This diversity poses challenges to the process of selecting the most suited method for a specific real-world decision problem. In this paper we present a case study in a real-world decision problem arising in the painting sector of an automobile plant. We tackle the problem by resorting to the well-known AHP method and to the MCDA method proposed by Pereira and Fontes (2012) (MMASSI). By relying on two, rather than one, MCDA methods we expect to improve the confidence and robustness of the obtained results. The contributions of this paper are twofold: first, we intend to investigate the contrasts and similarities of the results obtained by distinct MCDA approaches (AHP and MMASSI); secondly, we expect to enrich the literature of the field with a real-world MCDA case study on a complex decision making problem since there is a paucity of applied research work addressing real decision problems faced by organizations.

**Keywords:** *AHP, Decision Making, Multicriteria Decision Analysis, Multicriteria Methodology, Automobile Industry.*

## 1 Introduction

In recent years, the increasing competitiveness of the global market, as well as the burst of the so-called *Global Financial Crisis*, forced companies to rethink their processes so as to rise the levels of efficiency, responsiveness and flexibility. In such contexts, resorting to MCDA to assist in strategic decision problems can turn out to be a decisive step towards achieving these goals.

MCDA is a formal quantitative approach, which purpose is to aid the decision making process, by fostering in decision makers (DM) the development of a structured thinking about the decision problem at hand. The main motivation behind the development of this research field is strongly related to the recognition that human judgments can be limited, distorted and prone to bias, especially when faced with problems that require the processing and analysis of large amounts of complex information (Dodgson et al., 2000). MCDA is a problem solving methodology that organizes and synthesizes the information regarding a given decision problem in a way that provides the decision maker with a coherent overall view of the problem. MCDA methods assist DM in the process of identifying the most preferred action(s), from a set of possible alternative actions (explicitly or implicitly defined), when there are multiple, complex, incommensurable and often conflicting objectives (e.g. maximize quality and minimize costs), measured in terms of different evaluation criteria. The alternative actions distinguish themselves by the extent to which they achieve the objectives and none of these alternatives will be the best at achieving all objectives (Dodgson et al., 2000). By explicitly assessing the performance of different alternative actions, based on the integration of objective measurement with subjective value judgment, MCDA techniques unavoidably lead to more efficient and more informed decisions. The goal of MCDA is not to prescribe the "best" decision to be chosen but to help decision makers select a single alternative, or a short-list of good alternatives, that best fit their needs and is coherent with their preferences and general understanding of the problem (Brito et al., 2010). Usually, this alternative corresponds to the best compromise solution rather than to an optimal solution.

Both the academic attention devoted to the field of MCDA and the widespread application of its methods in real-world decision problems, is a reflection of the advantages of MCDA approaches in aiding decision making. Bearing this in mind, in this work we aim at presenting a case study on a real-world decision problem arising in the painting sector of one of Toyota's plants, using the well-known AHP method (Saaty, 1990) and the MCDA method proposed by Pereira and Fontes (2012) (MMASSI). The contributions of this paper are twofold: first, we intend to investigate the contrasts and similarities of the results obtained by distinct MCDA approaches (AHP and MMASSI); secondly, we expect to enrich the literature of the field with a real-world MCDA application on a complex decision-making problem since, according to Roy (1999) and Dooley et al. (2009), there is a paucity of applied research work addressing real decision problems faced by organizations.

The remainder of this document is organized as follows. Section 2 describes the MCDA methods used in this work, namely, AHP and MMASSI. Section 3 presents and details the application of these methods to a real-world decision-making problem regarding the painting sector of one of Toyota's plants. Section 4 concludes the paper.

# 2 MCDA methods

Although several methods have been proposed over the years, here we only describe the AHP and MMASSI, since these are the ones used in our study.

## 2.1 AHP

One of the most prevalent and popular approaches for MCDA is AHP. This method was developed by Saaty (1990) and its basic idea is to convert the DM's subjective assessments of relative importance into a set of overall scores and weights that reflect the DM's preferences. AHP is based on three principles: first, structure of the decision problem;

second, comparative judgment of the alternatives and the criteria, in the form of pairwise comparisons; third, synthesis of the priorities.

The main reasons behind the wide applicability of AHP are: its simplicity, since it does not involve cumbersome Mathematics; the relative ease with which it handles multiple criteria; its great flexibility, being able to effectively deal with both qualitative and quantitative data; and the ease of understanding (Kahraman et al., 2003). Besides, the consistency verification operation of AHP can act as a feedback mechanism for the DM to review and revise their judgments, thus preventing inconsistencies (Ho et al., 2009). However, despite these advantages, the drawbacks of AHP instigated a controversial debate among MCDA academics that raises doubts about the underlying theoretical foundations of the method. As pointed out by Goodwin and Wright (2004), the major concerns are related to the rank reversal problem and the potential inconsistency of the nine-point scale proposed by Saaty (1990). These lead us to use another method so that a more confident evaluation and analysis can be provided to the DM.

## 2.2 MMASSI

As said before, in here we perform a comparison of the results yielded by the well-known AHP method and the ones provided by MMASSI Pereira and Fontes (2012). This way, we are able to increase the level of confidence on the yielded results, by removing some of the constraints associated to the use of a single method. The underpinnings of MMASSI rely on existing normative methods, which were developed along the lines of the American school of thought. This methodology was originally devised to aid the decision support process involving a group of decision makers. However, to fit the scope of our research, we will adapt it to a single-decision maker (or a consensual group of them). MMASSI distinguishes from previously proposed MCDA methodologies in the sense that (a) it provides the DM with a pre-defined set of criteria that tries to generally cover all the relevant criteria in the field of application (b) it does not explicitly requires the presence of a facilitator, or analyst, to guide the DM throughout the decision process, since it is implemented in an user-friendly and self-explanatory software (c) it uses a continuous scale with two reference levels and thus no normalization of the valuations is required.

MMASSI methodology encompasses a set of sequential steps that guide the DM through the several stages of a multi-criteria decision process. MMASSI begins by presenting the DM with a pre-defined set of criteria, along with their descriptions and suggestions on how to measure them. These criteria are chosen based on the *a priori* study of the decision context and subsequent identification of the features that are consensually considered relevant within its scope. This provisional family of criteria works as a starting point to guide the DM through the criteria selection. Nevertheless, it is the DM who defines and assesses the suggested criteria according to the following range of properties: completeness, redundancy, mutual independence and operationality (Seydel, 2006). In order to generate the final set of criteria, the DM can refine the starting set by removing, or modifying, or adding new criteria. After validating the criteria set, a set of alternatives is provided by the DM, or the analyst if one is involved, to the MMASSI system. The following stage comprises the employment of a weighting elicitation technique, namely the swing-weight procedure proposed by Winterfeldt and Edwards (1986), that sets up the relative criteria weights according to the preferences manifested by the DM. A fixed continuous scale with seven semantic levels with two references is presented to the DM so as to set up the ground values based on which he/she assesses each considered alternative against each selected criterion. The construction of this scale was based on earlier work by Bana e Costa and

Vansnick (1999). Having defined the criteria, the possible courses of action and a continuous semantic scale, in the next phase the DM appraises each alternative by allotting a semantic level to each criterion. The last step of MMASSI involves the computation of an overall score for each alternative, according to an additive aggregation model, and the subsequent ranking of the alternatives. Similarly to AHP method, the alternative ranked first is associated to the largest overall score and corresponds to the most preferred alternative.

# 3 Case Study: Evaluation of Vehicle Painting Plans

The automobile industry has been one of hardest hit by the global financial downturn, which reflected in a sharp fall on industry sales. Due to this reason, the automobile plant where we carried out our case study is producing below capacity. Under such adverse circumstances, the management of the plant felt the need to optimize its processes. Since the painting process is (a) one of the most complex activities in automobile manufacturing, (b) a bottleneck in this specific plant, and (c) responsible for the highest costs (e.g. the painting sector costs represent a fraction of, approximately, 70% of the total expenditures of the entire plant), the management plant considered this sector to be the most critical to conduct a MCDA. In this section we describe the decision problem under consideration, explain how the case study was carried out and present the obtained results.

## 3.1 Problem description

The target of our case study is one of the plants of Toyota, located in Ovar, Portugal. The main function of this plant is to perform the welding, painting and final assembly of a specific automotive model. The management is interested in optimizing the painting process, which is a bottleneck of the plant. The only way to improve this process is by optimizing the vehicle *painting plans*. These painting plans are defined as a combination of a vehicle model, which can be *simple* or *mixed*, with the number of distinct colors used to paint the vehicles, in a given day. Given this, the purpose of this case study is, on the one hand, to illustrate the potential of the application of MCDA for solving a complex decision making problem in the painting sector of an automobile plant; on the other hand, to provide the DM with an evaluation of the aforementioned painting plans, as well as with information about the most preferred plan.

## 3.2 Data Gathering

The application of MCDA to this decision problem involved the operations manager of the plant and the painting sector team (henceforth *decision maker*, or simply DM). Albeit there are several people involved in the decision making process, they act as if they were a *single decision maker*, since the given answers represent the consensual views and preferences of both the manager and the painting sector team. A number of face-to-face meetings with the DM were convened, so as to understand the decision context and gather information regarding the decision problem, the alternatives and the relevant criteria.

As mentioned before, the goal of the DM is to optimize the painting sector of the plant through the optimization of the vehicle painting plans. The portfolio of alternatives was determined by identifying the most frequent painting plans based on daily historical data of the plant. The analyzed data referred to a time span of six months (June 2012 to December 2012). Using this procedure we identified eight alternatives, which will be referred to, in this paper, as PP-A (Painting Plan A), PP-B, PP-C, PP-D, PP-E, PP-F, PP-G and PP-H. These alternatives were validated by the DM and are described in Table 1.

The next step was the selection of the relevant set of criteria to be used to appraise each one the alternatives. Four quantitative criteria were considered after a brainstorming session with the DM, namely: the *quality index*, the *energy consumption*, the *paint consumption* and the *quantity of painted vehicles*. The *quality index* (QI) is given by the average number of defects per painted vehicle and, as the name implies, is a proxy for the quality of the performed painting. *Energy consumption* (EC) includes both the electricity and the gas consumption of the painting sector and is measured in kilowatts-hour (kWh). In turn, *paint consumption* (PC) reflects the direct cost of painting the vehicles (in terms of materials), being given by the average ink liters used to paint a given vehicle. The last criterion is the *quantity of painted vehicles* (QPV) per day. More detailed information regarding these criteria is given in Table 1.

## 3.3 Elicitation of criteria weights

After structuring the decision problem at hand, the DM was asked to assess the relative importance of the identified criteria based on two different procedures: pairwise comparisons and swing-weight procedure of Winterfeldt and Edwards (1986). The former is used in the AHP method, whereas the latter is used in the MMASSI methodology.

**AHP:** According to AHP, the assignment of weights to the chosen criteria is performed by asking the DM to form an individual pairwise comparison matrix using the nine-point intensity scale proposed by Saaty (1990). In this pairwise comparison matrix, the four criteria are compared against each other in terms of their relative importance, or contribution, to the main goal of the decision problem. The obtained weights are provided in Table 1. Based on the AHP results, the *quality index* was deemed the most important criterion ($w_{QI} = 60.6\%$) for the evaluation of the painting plans, followed by *energy consumption* ($w_{EC} = 23\%$) and *paint consumption* ($w_{PC} = 12.6\%$). The least important criterion is the *quantity of painted vehicles*, which was assigned a relative importance of merely 3.9%.

A pairwise comparison matrix is of acceptable consistency if the corresponding *Consistency Ratio* (CR) is $CR < 0.1$ (Saaty, 1990). Since we obtained $CR = 0.066 < 0.1$, the DM has been consistent in his judgments and, thus, the obtained criteria weights can be used in the decision making process.

Table 1: Performance Matrix. The best values observed for each criterion are underlined.

| **Criteria** | **QI** | **EC** | **PC** | **QPV** |
|---|---|---|---|---|
| Unit | # Defects | kWh | Ink liters | # Vehicles |
| Max/Min | Min | Min | Min | Max |
| Weights AHP | 0.606 | 0.23 | 0.126 | 0.039 |
| Weights MMASSI | 0.588 | 0.235 | 0.118 | 0.059 |
| **PP-A** (Simple + 1 Color) | 3.45 | 87 | 2.02 | 15 |
| **PP-B** (Simple + 2 Colors) | 2.1 | 66 | 1.85 | 14 |
| **PP-C** (Simple + 3 Colors) | <u>1.6</u> | 60 | 1.59 | <u>30</u> |
| **PP-D** (Simple + 4 Colors) | 3.2 | 79 | 1.87 | 15 |
| **PP-E** (Mixed + 1 Color) | 2.1 | 81 | <u>1.55</u> | 11 |
| **PP-F** (Mixed + 2 Colors) | 3.0 | 73 | 1.58 | 21 |
| **PP-G** (Mixed + 3 Colors) | 2.8 | 72 | 1.64 | 16 |
| **PP-H** (Mixed + 4 Colors) | 2.5 | <u>53</u> | 1.56 | 15 |

**MMASSI:** Contrary to AHP, which relies on pairwise comparisons, the MMASSI method resorts to the swing-weight procedure to derive criteria weights. According to this procedure, the DM should first identify the most important criterion, which will be assigned a score of 100, and then successively allot scores (lower than 100) to the second, third and fourth most important criteria. The given scores should reflect the DM's order and magnitude of preference and are further normalized so as to obtain the criteria weights. The resulting criteria weights are given in Table 1. Similarly to AHP, in MMASSI *quality index* is also the criterion with the highest priority, with an influence of 58.8%, followed by the *energy consumption* ($w_{EC} = 23.5\%$), *paint consumption* ($w_{PC} = 11.8\%$) and *quantity of painted vehicles* ($w_{QPV} = 5.9\%$).

## 3.4 Evaluation and Ranking of the Alternatives

In this stage, the alternative painting plans are appraised by the DM in terms of their contribution to the previously stated criteria. To obtain this information, we have asked the DM to provide a numerical evaluation of the relative performance of each alternative painting plan for each considered criterion. These numerical evaluations are expressed using the scale adopted by each MCDA approach. To assist the DM in this stage, we constructed a *performance matrix* by aggregating the daily data gathered by the painting sector, for a period of six months. This matrix provides objective information regarding the performance of each alternative on each relevant criterion, and served as a basis for the DM's evaluation. Upon completion of this stage, the alternatives' overall score is computed based on an aggregation procedure that takes into account, not only the alternatives' performance evaluation provided by the DM, but also the criteria weights. The final ranking is generated by sorting the alternatives in decreasing order of these overall scores.

Table 2: Final rankings yielded by AHP and MMASSI methods. The overall scores range from 0 to 100, with a higher score representing a higher level of preference.

| AHP Ranking | AHP Overall Score | MMASSI Ranking | MMASSI Overall Score |
|---|---|---|---|
| PP-C | 88.29 | PP-C | 64.64 |
| PP-H | 49.53 | PP-E | 51.05 |
| PP-E | 49.08 | PP-B | 33.69 |
| PP-B | 46.92 | PP-H | 28.09 |
| PP-F | 21.9 | PP-G | 22.95 |
| PP-G | 21.71 | PP-F | 21.72 |
| PP-D | 9.09 | PP-D | 12.96 |
| PP-A | 5.16 | PP-A | 8.72 |

**AHP:** In this step, the DM is asked to appraise the alternatives by performing separate pairwise comparisons for the set of alternatives in each criterion. This elicitation process is based on a set of questions of the general form: "How much more does alternative 1 contributes to the achievement of criterion A than alternative 2?". The corresponding verbal answers of the DM are written down and subsequently codified into the nine-point intensity scale of AHP. These relative performance scores constitute one of the inputs of a weighting and summing step that yields the final result of AHP.

**MMASSI:** Regarding MMASSI, the DM was first asked to set, for each criterion, the mandatory reference levels (*neutral* and *better* levels) of MMASSI fixed scale. The established *neutral* levels were: $QI = 1.8$, $EC = 27$, $PC = 1.79$ and $QPV = 12$. For the *better* level, we obtained $QI = 1.6$, $EC = 21$, $PC = 1.66$ and $QPV = 21$. Taking into account these two reference levels, the DM appraises the set of alternatives, on each criterion, by assigning one of the following semantic levels to each alternative: Much Worse, Worse, Slightly Worse, Neutral, Slightly Better, Better or Much Better. In this MCDA step, the major differences between AHP and MMASSI are the following: (a) in contrast with AHP, MMASSI does not rely on pairwise comparisons, since each alternative is only assessed in terms of its contribution to each criterion; (b) instead of using the potentially inconsistent nine-point semantic scale of AHP, MMASSI relies on a fixed interval scale that is fully defined by the DM.

#### 3.4.1 Comparison of Results

After performing these evaluations, the alternatives were ranked based on a global indicator of preference. From the analysis of Table 2, we deduce that the most preferred alternative is PP-C, since it ranks first in both AHP and MMASSI final rankings. Thus, the panting plan with highest relative merit is the one involving the painting of simple vehicles with three different colors. From the business viewpoint, this result means that PP-C is the painting plan which contributes the most to the painting process optimization. In order to compare the similarity of the rankings returned by the two methods, we compute Kendall's tau rank correlation coefficient, denoted as $\tau$ $(-1 \leq \tau \leq 1)$. The obtained value, $\tau = 0.79$, indicates the existence of a significant rank correlation between the AHP and MMASSI final rankings, which means that both methods yield quite similar results.

### 3.5 Sensitivity Analysis

Since some steps of the MCDA process can be permeated by subjectivity and uncertainty, we validated our results by performing a sensitivity analysis in order to determine how the final ranking of alternatives changes under different criteria weighting schemes. The results for both AHP and MMASSI have shown that changes in the relative criteria weights did not make any impact on both the top and the bottom of the ranking, although some position shifts were observed in the intermediate ranking levels.

## 4 Conclusions

In this paper, we present a case study on the application of MCDA to assist the management of an automobile plant in the process of evaluating the relative merits of alternative painting plans, so as to optimize the painting sector. This problem is of great relevance for the company, since the painting sector is a bottleneck of the manufacturing process of the plant. Being aware that MCDA methods are prone to subjectivity and uncertainty, we resorted to two MCDA methods, namely the well-known AHP and the MCDA method proposed by Pereira and Fontes (2012) (MMASSI), in order to increase the reliability and robustness of the obtained results.

According to DM's point of view, MMASSI method proved to be more swift during the preference elicitation stage. This is partly explained by the use of a continuous, rather than semantic, scale and by the requirement of a lower number of evaluations, when compared to AHP. Nevertheless, AHP proved to be more advantageous than MMASSI for structuring the decision problem. The application of the MCDA methodology encouraged fruitful discussions and a deeper analysis of the problem peculiarities among the team, which helped determine the right key performance indicators and the corresponding target values for the painting sector. Regarding the MCDA results, the management found them satisfactory and intends to use the final rankings to enhance the weekly planning of the painting sector.

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