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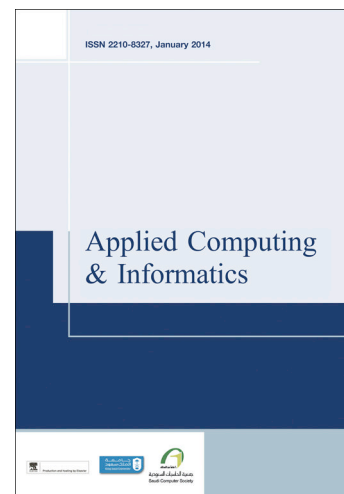
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# A Review on Multi-Criteria Decision-Making for Energy Efficiency in Automotive Engineering

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## Abstract

Governments around the world instituted guidelines for calculating energy efficiency of vehicles not only by models, but by the whole universe of new vehicles registered. This paper compiles Multi-criteria decision-making (MCDM) studies related to automotive industry. We applied a Systematic Literature Review on MCDM studies published until 2015 to identify patterns on MCDM applications to design vehicles more fuel efficient in order to achieve full compliance with energy efficiency guidelines (e.g., Inovar-Auto). From 339 papers, 45 papers have been identified as describing some MCDM technique and correlation to automotive industry. We classified the most common MCDM technique and application in the automotive industry. Integrated approaches were more usual than individual ones. Application of fuzzy methods to tackle uncertainties in the data was also observed. Despite the maturity in the use of MCDM in several areas of knowledge, and intensive use in the automotive industry, none of them are directly linked to car design for en-

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ergy efficiency. Analytic Hierarchy Process was identified as the common technique applied in the automotive industry.

*Keywords:* Multiple criteria analysis; Multi-criteria decision management; Energy efficiency.

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## 1. Introduction

Decision process can be defined as a set of actions and methods dynamically organized. This process is triggered by demand for action and it ends with a specific engagement execution [1]. Corporations have to choose the best option by aggregating outcomes of different stakeholders [2]. Although the decision-making problem could be constructed as more than one hierarchy with different criteria [3] to be solved, this process is still hard due to the following:

- They are non-repetitive, unprecedented and unique [2].
- Criteria may conflict itself, for example, customers want quality but they also want something not expensive. Conflicting criteria make the decision task tough [4, 5].
- Criteria such as fuel consumption can be objectively measured, commonly named as tangible criteria. Flexibility, quality, efficiency or future income, can not. This group is classified as intangible criteria. Intangible criteria cannot be converted into numeric or monetary values [6, 7].

As proposed by law [8], energy efficiency (EE) should not be calculated by models only, but by the whole universe of new vehicles registered. In

this scenario, the composition of vehicles sold in the market will have influence on profits of each automaker, since additional taxes are going to be applied for those automakers that do not achieve a specified target. Among all variables to be considered, one can highlight that analysis of manufacturing costs, customer value perception and market share, can be characterized as a multi-criteria decision-making problem. Due to the increasing competition, dynamic customer demands and regulatory laws, the scenario requires automakers to add energy efficiency items to practically the entire portfolio.

Starting from the pioneering works published in 1974, this paper overviewed research papers until October 2015, i.e., that is a period of 42 years of research. Applications of MCDM methods were categorized according to Behzadian [9], allowing the reader to understand the main applications of techniques, trends and opportunities for further investigations. This paper identifies 30 techniques or combinations of techniques self-described as MCDM.

The purpose of this paper is to review systematically the applications and techniques available to solve the problem of incorporate technologies of EE, keeping the balancing of manufacturing costs, customer value perception and market share.

The classification scheme for this review contains 339 papers from 33 journals since 1974, separated by application areas. This paper attempts to answer the following questions focused on automotive industry: Which methods were frequently used ? How rate of combined approaches instead of single method used? More accurate results when applying combined approaches. Or a specific method? Additionally, common SLR questions were also answered such as which countries, journals, year and authors have pub-

lished.

We organize this work as follows: In Section 2, we explain the background of research MCDM. In Section 3, we identify related work. Section 4 describes the details of methodology. Section 5 presents the results. In Section 6, the results are discussed. In Section 7, we conclude this work, pointing to future research.

## 2. Background

Multiple-criteria decision making (MCDM) is a sub-field of operations research [10, 9, 11, 12, 13, 14], concerned with designing mathematical and computational tools to support the subjective evaluation of performance criterion by decision [15, 16]. MCDM is a collection of methodologies to compare, select, or rank alternatives where multiple and conflicting criteria involve both tangible and intangible factors [17, 10]. MCDM has been used by decision makers according to their own preferences to choose one that met their goals, objectives, desires and values [18, 19]. MCDM has been used in the solution of real-world decision making problems [20]. The use of MCDM goes from autonomous drive [21] to assessment of Mars mission [22]. Part of applications are related to supplier selection and evaluation [23, 24, 25, 26, 27, 28, 29, 30, 31] and materials selection [32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43]. The application of MCDM methods have become easier for users and decision makers by improvement of computer techniques [44].

### *2.1. Multi-Objective and Multi-Attribute*

MCDM can be split in between Multi-Objective Decision Making (MODM) and Multi-Attribute Decision-Making (MADM) methods [11, 45, 46]. The

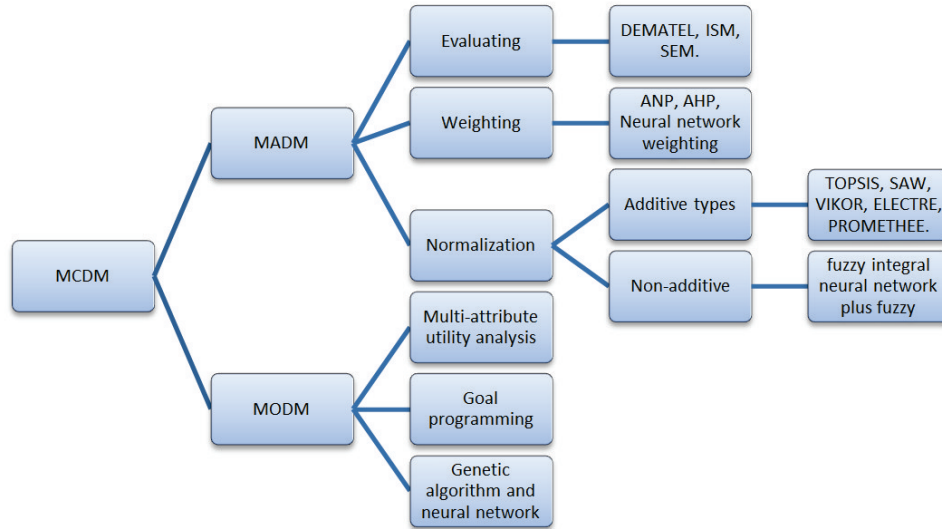


Figure 1: MCDM classification splitted in between MADM [10] and MODM [49].

goal in MADM problems is to design the best alternative, considering the evaluation of the whole set of attributes which are hard to quantify, incommensurable or incomparable [11, 47]. In MODM, alternatives are not predetermined, but instead a set of objective functions is optimized, subject to a set of constraints, with a number of alternatives effectively infinite. The most satisfactory and efficient solution is the goal. In this solution, it is not possible to improve the performance of any objective without degrading the performance of others [11, 48].

[10] split MADM into three classes, [49] proposed a categorization for MODM in three classes. Figure 1 mix both these proposals. [11] offering two possible classifications:

- By method: deterministic, stochastic and fuzzy methods;

- By the type of data employed,: quantitative, qualitative or mixed.

[50] classify methods in:

- Outranking approaches (ELECTRE, PROMETHEE);
- Additive methods (linear additive model, AHP and the Multi-Attribute Utility Theory);
- Multiple Objective Programming (Multi-Objective Lineal Programming);

[51] classify methods in single or combined. Single models are sub-divided in Mathematics, Single Model and Artificial Intelligence. Mathematics methods include, for example, AHP, Linear Programming (LP) and Goal Programming (GP).

## 2.2. Analytic Hierarchy Process

AHP is a powerful technique which supports decision making in a multi-attribute environment [3, 52]. It allows the creation of an understandable hierarchical model by the decomposition of complex problems [53]. Smaller parts of the problem can be handled by human information processing capabilities more than the entire problem [54]. AHP is based on pairwise comparisons of criteria to establish the weights and alternatives to evaluate performance [55]. Consistency across judgments can be evaluated and improved[56]. Advantages of AHP include:

- Ability to capture both quantitative and qualitative attributes in a simple manner [57, 3, 58, 49];
- Popularity [59, 60, 28, 11, 61, 62, 24, 63, 64, 65];

- Simplicity in implementing and interpreting [66, 67];
- Capability in handling sparse or poor quality data [58];
- Consistency test to ensure judgments quality [53].

AHP has the drawback of including the potential internal inconsistency, the questionable theoretical foundation of the rigid scale [68]. Inconsistency can increase when the process contains a number of criteria that exceeds the human short-term memory [69]. The process can also be affected due to time taken to complete the experts' judgments [70]. For [49], it can only compare a limited number of decision alternatives, which is usually not greater than 15. To deal with the uncertainty and ambiguity, AHP could be combined with fuzzy logic [24, 71, 72, 73, 74, 75, 76]. The use of Delphi method combined with an appropriate selection and a relevant number of decision criteria for pairwise comparisons can also address this drawback [77]. AHP is also combined with other methods: such as Simple Additive Weighting (SAW), Grey Relational Analysis (GRA), ANP. There are studies that combine both approaches such as fuzzy logic and Simple Additive Weighting (SAW) in order to reduce this drawback [78].

### 2.3. Fuzzy Numbers

Pairwise comparison is the foundation for MCDM methods. Pairwise comparison is a rate between two options. In Saaty's original proposal, a rigid scale is used to measure this relation. A fuzzy approach uses a less rigid scale to define the strength in which one option dominates other [79]. To ensure the proper reflection of expert's judgments by making reference to the



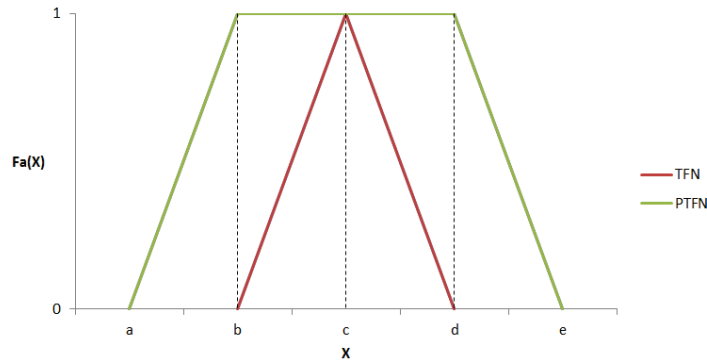


Figure 2: Positive trapezoidal fuzzy number and triangular fuzzy number.

uncertainty, fuzzy numbers are used to integrate linguistic assessments [80]. Fuzzy numbers are a common approach to represent mathematically the human uncertainty and vagueness in pairwise comparison [24]. They help experts to express approximate ratio instead of exactness [79].

The membership function represents this ratio in equation  $f_a(x) \in [0, 1]$ . A positive trapezoidal fuzzy number (PTFN)  $n$  can be defined as  $(n_1, n_2, n_3, n_4)$  if  $n_2 = n_3$ , then  $n$  is called a triangular fuzzy number (TFN) [81, 79]. Figure 2 shows a graphical representation of this function. The membership function for TFN and PTFN can be seen in Equations 1 and 2 respectively. Mathematical approaches are used to convert a fuzzy number in a set of weights for one judgment, which allows fuzzy to be combined with methods such as TOPSIS [82, 83, 84, 85, 77, 28, 14], AHP [74, 72, 71, 24, 73, 75, 76], ANP [86, 4], VIKOR [87, 38, 88], DEMATEL [27, 89, 90].

$$f_a(x) = \begin{cases} 0 & : x < a, x > c \\ \frac{x-a}{b-a} & : a \leq x \leq b \\ \frac{c-x}{c-b} & : b \leq x \leq c \end{cases} \quad (1)$$

$$f_a(x) = \begin{cases} 0 & : x > a \\ \frac{x-a}{b-a} & : a \leq x \leq b \\ 1 & : b \leq x \leq c \\ \frac{d-x}{d-c} & : c \leq x \leq d \\ 0 & : x > d \end{cases} \quad (2)$$

### 3. Related Work

Table 1 presents work of researchers that focus on MCDM method specifically or focused on particular field of interest.

Table 1: Related Work

Author	Topic	Period	Papers	Findings
[65]	MCDM review concerning design and operation of urban passenger transport systems	between 1982 and 2014 (up to May)	86	AHP popularity. The number of papers increased from 2000, with a surprising small amount of publications between 2003 and 2006. From the total number of papers published in these 30+ years, 48.86% were published between 1982 and 2007, while 51.14% were published during the last 6 years (between 2008 and 2014).
[9]	Review focused on TOPSIS applications	Between 2010 and 2012	266	Among numerous MCDM methods, TOPSIS continues to work across different application areas.

Continued on next page

Table 1 – continued from previous page

Author	Topic	Period	Papers	Findings
[49]	Review about material screening and choosing methods	Until 2009	95	TOPSIS, ELECTRE and AHP have been the most popular state of the art methods in material choosing.
[59]	Identify MCDM approaches for green supplier evaluation and selection	from 1996 to 2011	33	AHP is the most widely MCDM method and also for green supplier evaluation and selection. Single technique is more common than integrated approach. Interestingly, many of the identified papers, twenty five papers (77.77%) are still utilizing a single technique in their analysis. Eight papers (22.22%) utilized an integrated approach, with the objective of trying to achieve a more realistic application given the complexities of a real-world decision process.
Continued on next page				

Table 1 – continued from previous page

Author	Topic	Period	Papers	Findings
[91]	Environmentally conscious manufacturing and product recovery (ECMPRO)	between 1996 and 2014	190	Increase in the number of publications concerning the use of MCDM techniques in recent years. MCDA is more popular than MODM in ECMPRO. Among the most frequent used techniques, one can find AHP. Significant increase in the number of publications in recent years.
[92]	MCDM review concerning bioenergy sector	from 2000 to 2010	57	Optimization methods are most popular with methods choosing between few alternatives being used in 44% of reviewed papers and methods choosing between many alternatives being used in 28%. The most popular application area was to technology selection with 27% of reviewed papers followed by policy decisions with 18%.

### 3.1. Maritime and aviation related work

The researchers also identified related work in Maritime transportation field. Regarding maritime industry EE, lowering fuel consumption of ships has gained a great deal of attention due to environmental and economic concerns. According to [93] the potential for fuel economy in shipping ranging between 25% to 75% is possible by using existing technology and practices and technical improvements in the design of new ships.

International Maritime Organization (IMO) proposed the Energy Efficiency Design Index (EEDI) and it was made mandatory for new ships in the Ship Energy Efficiency Management Plan *SEEMP* [94]. Maritime researches considerations included the purpose of selection and assessment ([95, 96, 97], a Fuzzy-AHP approach to prioritize the weight of each measure [98], Auto pilot adjustment decreases by 0.5–3% of fuel consumption [93] and the selection of alternative energy sources for shipping in order to effectively mitigate the problems of energy consumption and environmental problems [99].

Regarding aviation, where fuel consumption is one of the major operating cost, it can amount to approximately 20% of its overall operating cost [100, 101]. Air Transport Association (IATA) sets an average improvement in fuel efficiency of 1.5% per year from 2009 to 2020, and a reduction in CO<sub>2</sub> emissions by 50% by 2050, related to 2005 levels [102]. The selection of the most sustainable aviation fuel is similar to the selection of marine fuel [103]. In both cases EE is related to fleet management or fuel selection considering it is not related to personal use.

#### 4. Research Design

SLRs are organized reviews based on clear search strategy to ensure rigor, completeness and repeatability of the process. The process consists of identifying, evaluating and interpreting available work relevant to a particular question [104]. This SLR comprehends two steps. Firstly, a Bibliometric Study was conducted to create understanding around this theme. Second, papers were reviewed to understand MCDM techniques used by automotive industry giving specific attention to energy efficiency. MCDM applications were identified and classified according to table 2.

Table 2: Classification of papers application

Shortname	Fullname
1- Supply	1- Supply Chain Management and Logistics
2- Design	2- Design, Engineering and Manufacturing Systems
3- Business	3- Business and Marketing Management
4- Health	4- Health, Safety and Environment Management
5- Human	5- Human Resources Management
6- Energy	6- Energy Management
7- Chemical	7- Chemical Engineering
8- Water	8- Water Resources Management
9- Other	9- Other topics

Searching in one database and in titles for MCDM or multi-criteria, we got more than 12.000 results. Reviews use one of the following strategies: limiting the application of MCDM technique to specific field [59, 105, 65, 11, 92],

others limiting by the MCDM method [13, 9, 10]; or limiting by both [49]. Since one of the main purposes is to compare MCDM methods, this study narrows the results limiting the subject to automotive industry.

The procedure of systematic review includes the following steps: planning, defining research questions, searching databases, discussion of validity, data extraction, and synthesis of the results [104]. The next subsections describe these steps.

#### *4.1. Planning*

We developed a review protocol at the beginning of the systematic review, to assure that the research is undertaken as planned and not driven by researcher expectations. The protocol includes research background, the research questions, search strategy, study selection criteria and procedures, quality assessment, data extraction, and data synthesis strategies. The research questions and article identification strategies are described in the following subsections.

#### *4.2. Research questions*

Specifying the research questions is an representative part of any systematic review [104]. The present paper attempts to answer the following questions:

- **RQ1:** Which are the MCDM methods frequently applied to automotive industry?
- **RQ2:** How rate of combined approaches instead of single method is used?



- **RQ3:** What are the frequent applications of MCDM ?
- **RQ4:** How has fuzzy logic been used to deal with uncertainty?

The main objective of RQ1 and RQ2 is to understand which are the common methods and their combinations. RQ3 gets a picture of papers scenarios, their authors and journals. In order to group the papers application we applied a categorization proposal according to Table 2.

#### *4.3. Research strategy and search process*

We considered only indexed journals and papers written in English. Usage of indexed journals is a common strategy [106]. No additional filter related to type of publication was done in the initial step, so books were included. Searches were conducted in four electronic databases: Science Direct, Emerald, IEEE Xplorer, Springer. In the searches, we used the same conceptual search string. It resulted in 215 results from Science Direct, 113 from Springer, 20 from IEEE Explorer and 4 from Emerald, totalizing 352 results. This study uses the following search string : ("Multi-criteria decision-making") OR ("multiple-criteria decision analysis") OR ("MADM") OR ("MODM") AND ("vehicle" or "vehicular" or "automotive") AND ("fuel" or "emission"). Synonyms, abbreviations, and alternative spellings were created in order to cover relevant topics as suggested by [104]. The search string filters papers that treat MCDM and have a link to EE in automotive industry at the same time. After removing duplicated papers, 339 papers remained. After removing the papers that are out of the inclusion criteria, 45 papers remained to be analyzed. Both authors conducted the analyses and conclusions about the final selected papers. Inclusion and exclusion criteria are

explained as follows.

The inclusion criteria are:

- Academic papers published on journals or conferences;
- Papers related to MCDM and to automotive industry, at the same time;
- Papers that have clear concepts about MCDM;
- Papers written in English;
- Studies published until September 22 of 2015;
- Papers that have explicitly mentioned MCDM method or combination of methods.

The exclusion criteria are:

- Duplicate papers found on digital libraries;
- Books, thesis, editorials, prefaces, article summaries, interviews, news, reviews, correspondence, discussions, comments, reader's letters and summaries of tutorials, workshops, panels, and poster session;
- Papers written in other languages than English;
- Studies available only as abstracts.

#### *4.4. Threats to Validity*

The approaches below follows [104] guidelines. We adopted precautions in order to avoid that relevant papers have not been left out. Firstly, since

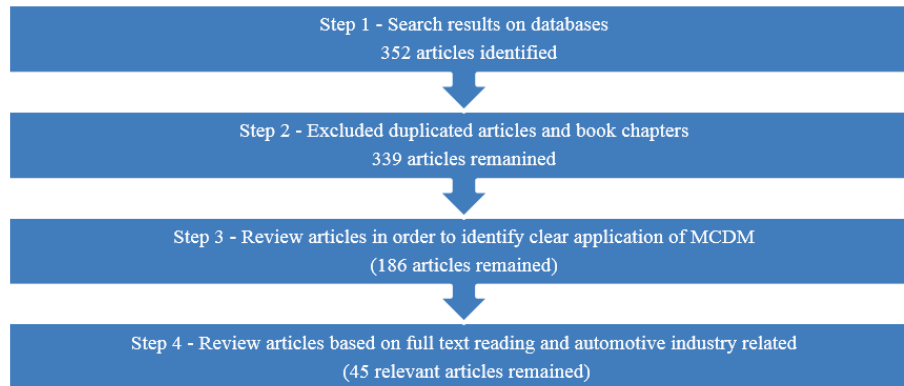


Figure 3: Step by step of research process.

there is some ambiguity in the English language, we used different terminology in the search in order to cover as much related terms as possible. Search included documents keywords, title, and abstract according to [107]. Secondly, search was carried out in well-known journals and proceedings which are included in the electronic databases examined. ScienceDirect has over than 3,800 journals [108], Springer has over than 2,500 journals [109], Emerald 593 journals [110] and IEE Xplorer more than 3,9 million of items [111]. To avoid limitations of search in one or two databases [107], we included four databases in the search. Thirdly, in order to avoid papers from being rejected incorrectly, the selection process included specific questions. Figure 3 summarizes this process.

The following measures have been taken to improve the validity of the research and to minimize the number of missed papers. The inclusion and exclusion criteria at every step were explicitly defined and reviewed by the

authors. Clear criteria were adopted to allow the correct paper categorization and also to assure quality of analyzed papers such as:

- Is the correlation to automotive industry clear?
- Is it clear what techniques were used to construct each model?
- Is it clear how the accuracy is measured?
- Are the indicators/criteria defined?
- Are the linguistic terms defined?
- Is the ranking defined?

#### *4.5. Data extraction and synthesis*

After identification of the relevant papers, we extracted the following data: the source (journal or conference), title, authors, publication year, MCDM methods and a basic evaluation of applied technique such as accuracy, criteria, indicators, ranking and linguistic terms if applicable. The data extracted from each paper were maintained through the whole review process. Based on the criteria for classifying the papers, all papers were reviewed.

Further criteria for classifying the papers were defined and discussed by the research team, based on what information was available in the papers. When there was uncertainty about the classification of the studies, the authors discussed the issue until consensus was reached. The data synthesis was specified in the review protocol from the beginning of the systematic review.

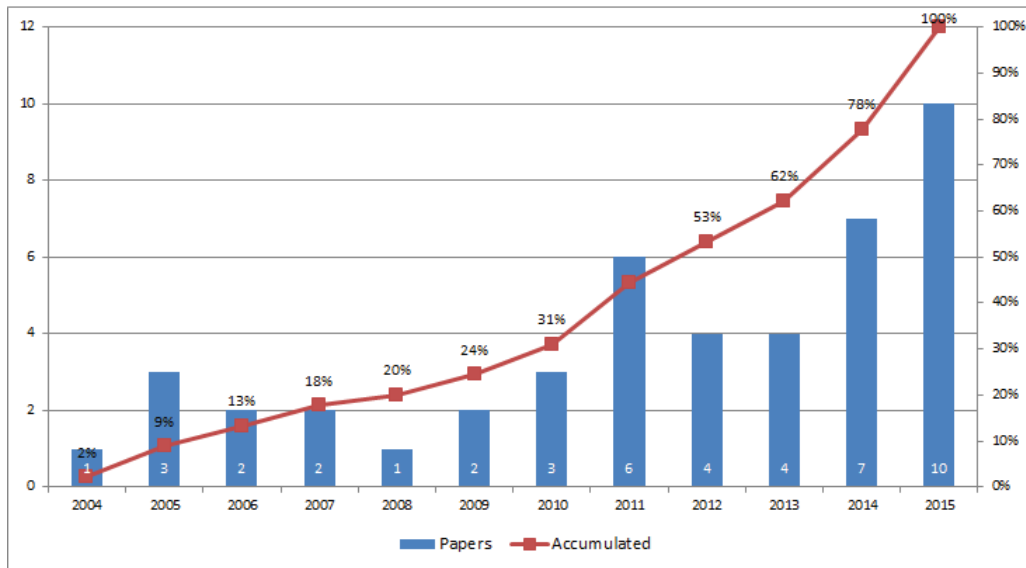


Figure 4: Published papers by year related to MCDM and automotive industry.

## 5. Results

We identified frequent methods to solve decision making problems related to automotive industry. We also classified publications per year, author, and journal. Papers found were categorized according to [9]. Considering the number of publications by year according to Figure 4, the number of publications increases. Figure 5 depicts MCDM applications by country. Australia has major publications followed by Iran, India and China.

Considering journals and reviews, [112] is the most active with 5 publications followed by [113] with 3. Considering just the energy management group [112] and [114] are the most active journals with 3 publications each one.

Evaluation of authors data according to ideas created by [115] shows that

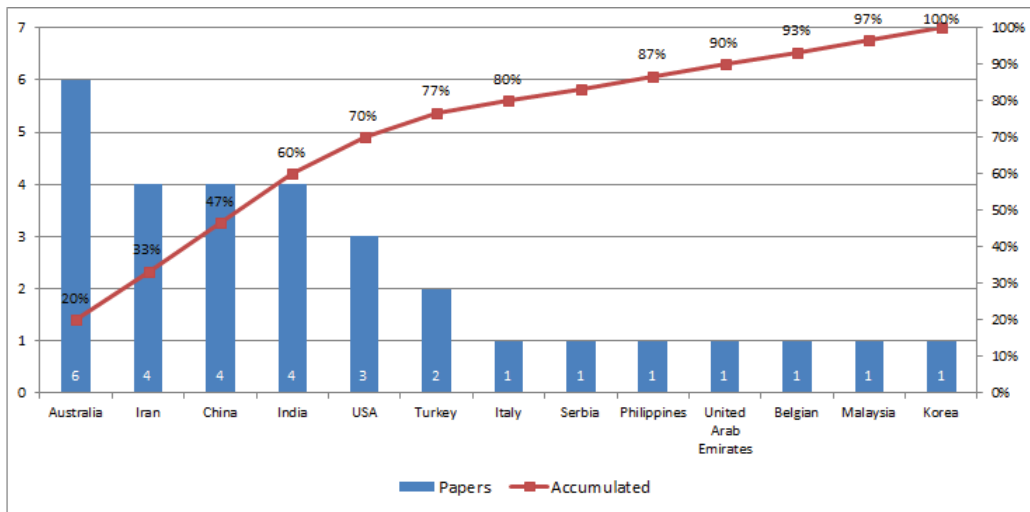


Figure 5: Published papers by country related to MCDM and automotive industry.

a small number of authors produces more than one document. In the set of papers selected at this search, 10 authors published more than 1 document. At the top 5 researcher Ayoko (7 publications)[116, 117, 118, 119, 120, 121, 122], followed by 2 other members with 6 publications and other 2 with 5 publications according to figure 6. Those researchers that published more than one paper, usually do that about the same MCDM methods.

### 5.1. An Overall Analysis of co-authorship network

We focus on the co-authored publications. This was achieved by Excel to extract a list of co-authors and R scripts to calculate network measures and generate graphs for author-author network. An author-author network (co-authorship), which is associated to a set of connections between authors [123].

In order to reproduce the steps used in the SLR we run a network ana-

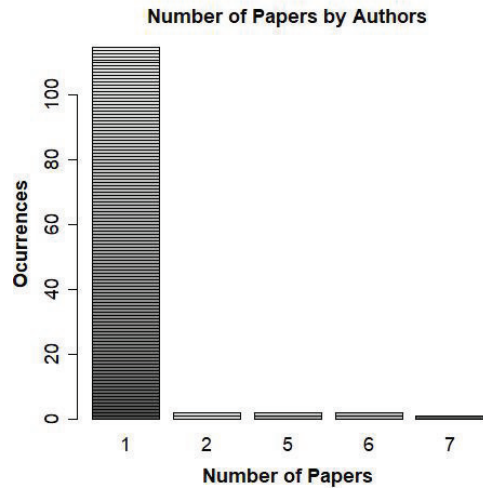


Figure 6: Number of papers published by authors.

lyzes through three different data sets each one for a specific step of SLR. We started with the 339 unique papers found out in step 2 and then 186 which clearly identified a MCDM application in the step 3 and finally the 45 remaining in step 4 which are related to automotive topic. These steps are shown in figure 3. The distribution of authors by each article is shown in figure 7.

the network of authors is showed in figure 10

Network Density Analysis Density refers to the connections between authors. If every node is directly connected to every other node, we have a complete graph. The density of a graph is defined as the number of links divided by the number of vertices in a complete graph with the same number of nodes. And the research has proven that the density of the network affects the dissemination of knowledge and information. The greater the density, the

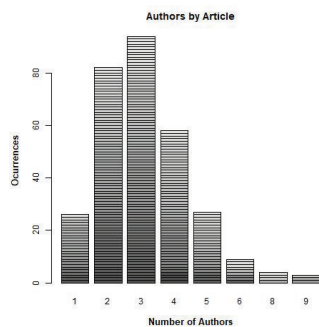


Figure 7: 339 Papers analyzed

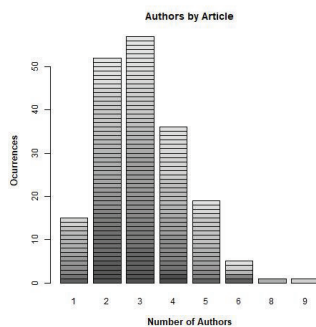


Figure 8: 186 Papers analyzed

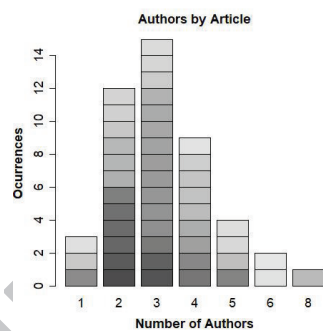


Figure 9: 45 Papers analyzed

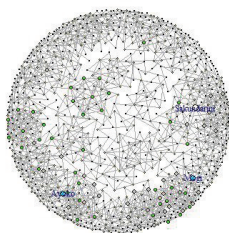


Figure 10: 339 Papers

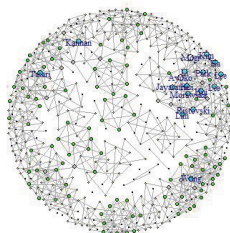


Figure 11: 186 Papers

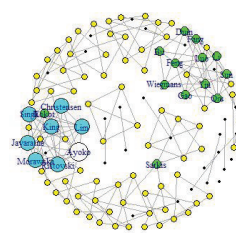


Figure 12: 45 Papers



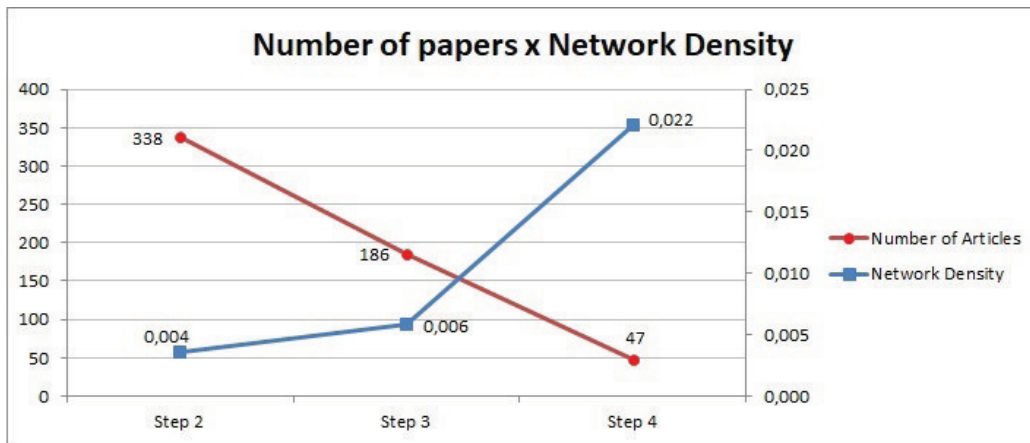


Figure 13: Number of papers in each research step X network density.

more conducive to the sharing and dissemination of knowledge

According to the results of network density analysis, the network density of the coauthors is 0.02212448 which is greater than 0.0084 found by [124] using 5,808 papers from China authors. Results can be found in table 3. This can be seen in figure 13.

It proves that the collaboration among the core authors is not tight. At the same time, it also shows that in the field of management, there is still much space for scientific collaboration.

**Degree Centrality:** Degree centrality is simply the degree of a vertex, which can be measured by the number of nodes directly connected to it. We can conclude that the highest degree is Ayoko, the absolute degree is 10 points. That means, Ayoko once published with 10 authors within our 47 papers network.

Betweenness is a measure which measures the extent to which a particular node lies between the various other nodes of the network. Betweenness

centrality is defined as the ratio of the number of shortest paths (between all pairs of nodes) that pass through a given node divided by the total number of shortest paths

Table 3: Degree of centrality

Author	Degree centrality	Betweenness	Betweenness Centrality
Ayoko, Godwin A.	10	16.6	0.002249
Lim, McKenzie C. H.	8	0.6	0.000081
Jayaratne, E. Rohan	8	0.6	0.000081
Morawska, Lidia	8	0.6	0.000081
Ristovski, Zoran D.	8	0.6	0.000081
Sarkis, Joseph	4	4.0	0.000542

### 5.2. MCDM Methods

Figure 14 shows absolute frequency of MCDM methods founded in selected papers. Between the main groups of MCDM, MADM is by far most common with 91% of papers against 9% of MODM. The number of methods is greater than documents analyzed since it is the usual combination of methods. **Answering RQ1**, our analysis shows that AHP (12 occurrences) is the most popular method in this context, followed by PROMETHEE (8 times which 6 from Australia). This is coherent with the increasing popularity of the PROMETHEE in different activities [125].

If we consider all 186 papers analyzed, where the method application is clear and consistent, we still conclude that the most popular method is AHP (19,5%) followed by TOPSIS (12,4%), F-AHP (7,38%), PROMETHEE (7,1%) and F-TOPSIS(4%). AHP is still considered most popular of MCDM

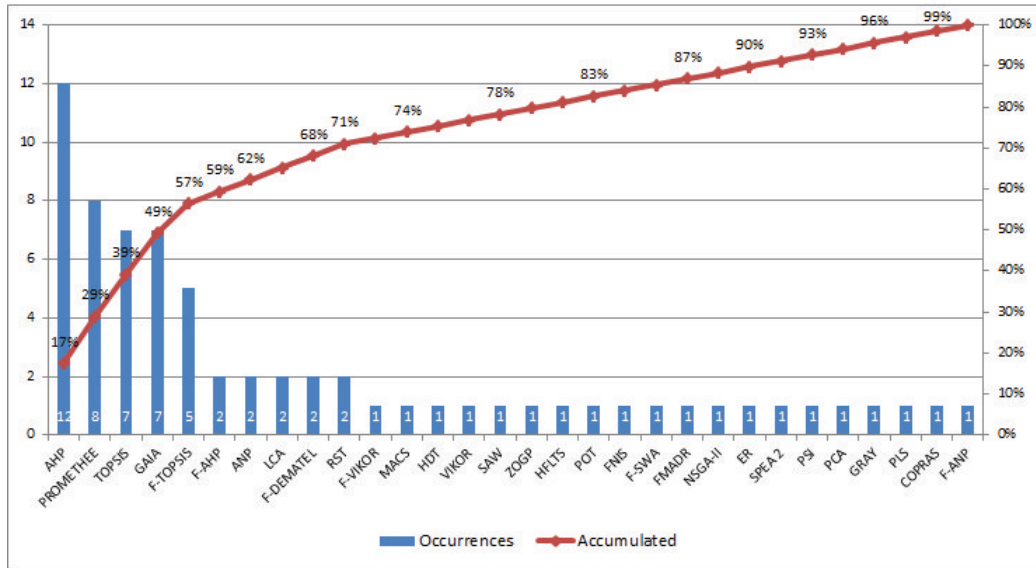


Figure 14: MCDM methods occurrences in analyzed papers.

methods [11, 28, 64, 63, 59, 60], the most applied for transport projects evaluation [62, 11, 60], for supplier evaluation [24], for green supplier evaluation [59] and for solid waste management [61]. [57] found DEA as the most popular individual approach for supplier selection. However, integrated AHP approaches are prevalent [57]. TOPSIS and AHP are the most frequent decision-making methods [126]. TOPSIS is, as well, one of the most well-known and widely accepted methods for MCDM [127]. Fuzzy was the most common alternative proposition, present in 17% of analyzed methods. This number is also coherent with Vinod's (2015) numbers between 10% and 15% [24].

**Answering RQ2**, our analysis shows that combined approaches are more frequent than single methods. The rate of integrated approaches (62,2%) are greater than individual approaches (37,8%). Since there is no distin-

guished superiority of one MCDM technique over the others, it is difficult to determine the best decision making method for a given scenario regardless of approach [128, 57]. Integrated approaches seem to be a solution to surpass weaknesses. This procedure explains why Fuzzy commonly fulfills the uncertainty gap. **Answering RQ4**, where the information is deficient, intangibility, arising from human qualitative judgments, uncertainties, vagueness or preferences available are subjective and imprecise, fuzzy logic is required [38, 14, 27]. Another usual approach for fuzzy is to avoid rigid scale. Authors used seven linguistics terms to assess the level of the performance criteria with TFN [85], gray numbers [5] and PTFN [129, 38]. Despite one occurrence of TFN combined with eleven linguistics terms [27]. We observed in our research that five linguistics terms with TFN with six cases are used frequently [71, 5, 24, 130, 90, 75]. This integrated approach also helps to eliminate the disadvantages of AHP [24]. Those cases where the optimal alternative should not have the worse performance in some criteria are usually solved by integrated approaches. In these cases, AHP is used for obtaining the weights of attributes and TOPSIS is responsible for calculating the ratings and ranking the alternatives [21, 64, 26, 131]. Figure 15 shows absolute frequency of MCDM method or combination found out in analyzed papers. PROMETHEE and GAIA (6 times) overcome the combination of AHP and TOPSIS (4 times) found out in selected papers, in **response to RQ2**. Considering grouped methods, FUZZY becomes even more popular as variation achieves 20%.

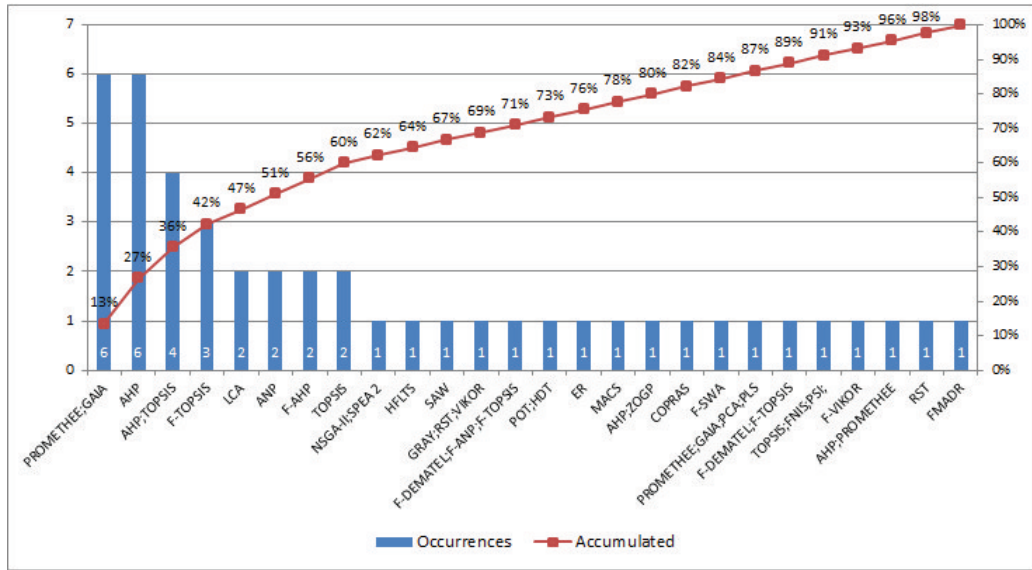


Figure 15: MCDM methods combined in analyzed papers.

### 5.3. MCDM Application

**Answering RQ3**, this research analyzed the application of MCDM technique in selected papers to understand the most frequent applications. We categorized them in 9 groups as proposed by [9]. As expected, the main group was Design, Engineering and Manufacturing systems (cf. Figure 16).

Considering the link between the five categories of application and MCDM methods the results are present in Figure 17, most applications that combined method PROMETHEE and GAIA are related to Health and Environment. TOPSIS can fit requirements of different areas [9], as well as AHP, since they were found in four of nine proposed areas within our research scope. Among numerous MCDA/MCDM methods developed to solve real-world decision problems, TOPSIS continues to work satisfactorily across different application areas [9]. TOPSIS is the most frequent method applied in Supply chain

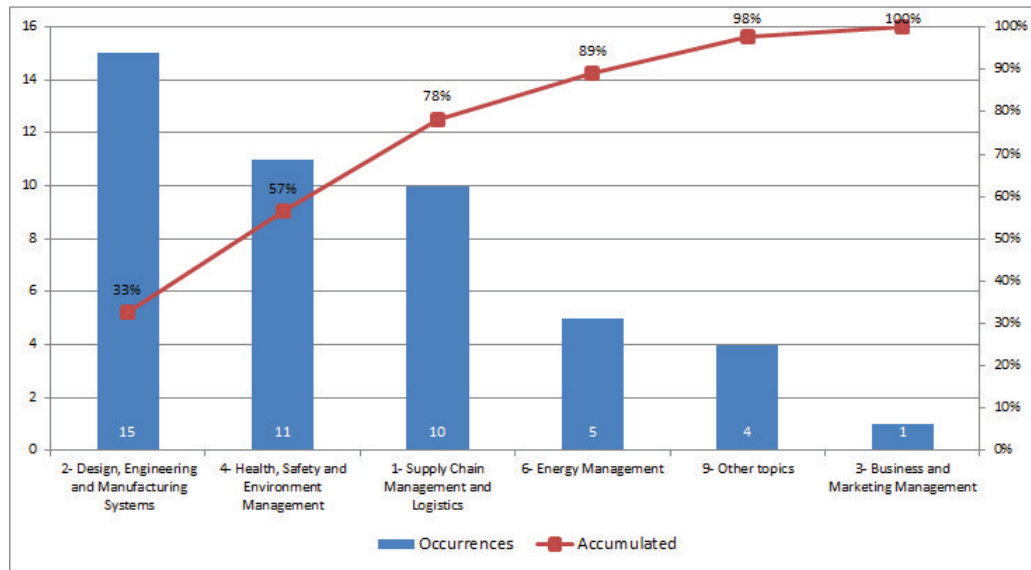


Figure 16: Applications of MCDM methods in analyzed papers.

and Logistic field [9, 10]. We grouped methods with only one application. The use of Fuzzy techniques is also common for Supply Chain Management and Logistics.

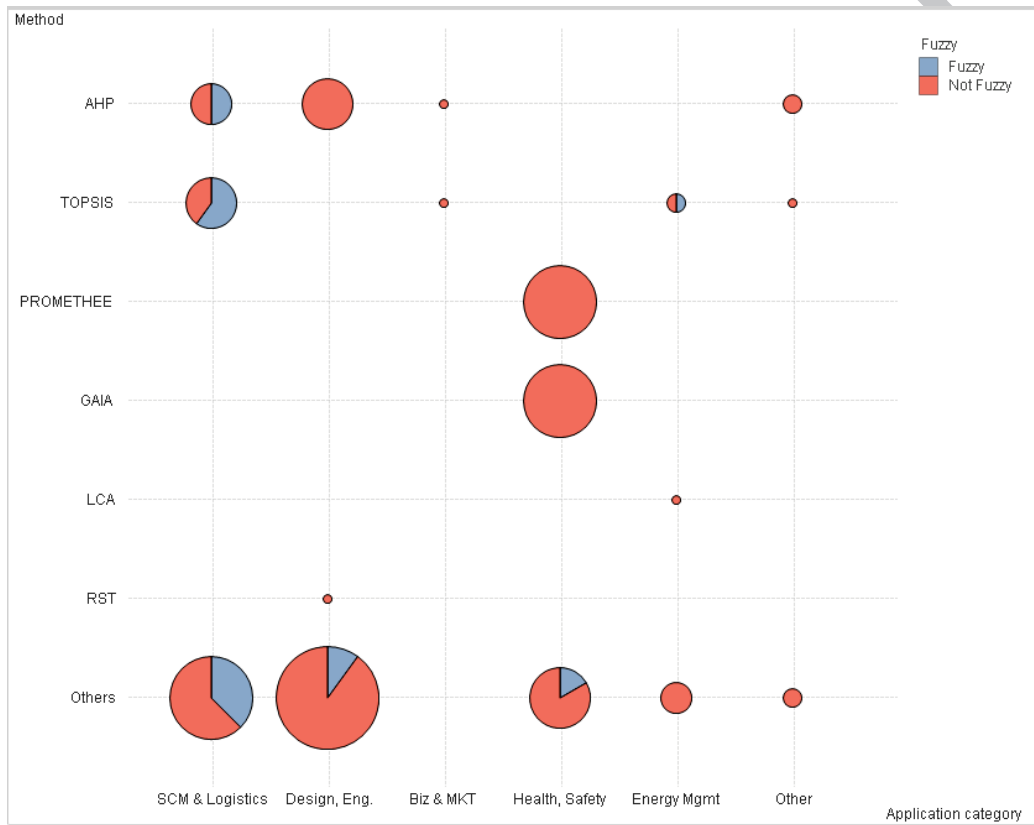


Figure 17: Applications of MCDM techniques in analyzed papers.

## 6. Discussion

In general, MCDM techniques are popular and applied in different applications and fields, considering the number of different journals that bring papers related to MCDM subject. The number of methods, combinations and variations show that a common standard was understood, at the same time researchers are trying to enhance decision-making processes to the next level. In this direction, there is an increasing tendency to combine fuzzy logic techniques with other MCDM methods to deal with uncertainty and vagueness inherent in decision-making processes, especially those with large number of stakeholders involved.

In spite of the popularity and applicability of the same methods, there is no killer approach. However, correcting criteria and alternatives structure is a relevant step. Since methods rely on experts to assist criteria, a process of identifying inconsistencies is important. This could be one of the reasons for AHP popularity.

Methods specialization was also perceived, as researchers seemed to have their preferred methods that are basis for variations or are applied in different problems. This can explain why it is common to have reviews and applications about one method instead of comparisons between methods.

Improve EE of automobiles is a complex problem due to effects of this changes in customers perception. It is necessary assist this process of increase EE at same time customer's attraction to vehicles is kept. MCDM can be used to assist this task in automotive industry.



## 7. Conclusion

This paper carried out a unique literature review to classify MCDM techniques with focus on automotive industries. The review categorized 45 scholarly papers from 33 journals until October 2015 into 5 application areas. We classified them by publication year, publication journal, country of application. We found that MCDM techniques have been successfully applied to a wide range of applications in automotive industry. The methods in engineering design are the most frequent, followed by environment and supply chain. We observed that AHP was the most consistent technique followed by PROMETHEE. Integrated approaches were more usual than individual ones. Application of fuzzy methods to tackle uncertainty was also observed [127, 24, 85, 38, 14, 132, 27, 90, 74].

There is a gap on the use of MCDM for automotive design focused in EE, although a review of the published literature on automotive industry analyzed here indicates greater applicability of MCDM methods for dealing with complex decision-making in automotive sectors with different subjects and terms. None of them focused on EE from automakers point of view. Although there are papers for fleet selection [5, 133, 74] and fuel selection [134, 135, 17, 129, 136] none of them focused on supporting a rational decision on which features should be adopted on each vehicle in order to enhance EE. The methods have been widely used to handle multiple, conflicting criteria even though increasing popularity and applicability of these methods beyond 2010 indicate a paradigm shift in MCDM approaches. It is clear that application of MCDM on automotive design for EE is an option and should be object of future researches.

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