Czech University of Life Sciences Prague

Faculty of Economics and Management

Department of Systems Engineering

Master's Thesis

Application of mathematical methods in decision making

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Economics and Management

DIPLOMA THESIS ASSIGNMENT

Zein Hammad

Systems Engineering and Informatics
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Thesis title

Aplication of mathematical methods in decision making

Objectives of thesis

The main goal of the thesis is to choose a suitable electric car for the selected company using multicriteria decision making (MCDM) methods.The partial goal is the formulation of decision criteria and the market segment search.

Methodology

The diploma thesis will deal with mathematical models for complex decision support. The main aim of the work is to select an electric car for the AGEMSYS Development s.r.o company according to the specified criteria.

The thesis will contain two main parts theoretical and practical. The theoretical part of the thesis will include basic concepts, definitions, and methods of multicriteria decision making and decision analysis. additionally, the part will introduce different methods to calculate the weight of the criteria.

After gaining theoretical knowledge, the practical part will focus on the selection of a suitable electric car from different models that are available in the Czech market. Some information about the company, history, and objectives will be introduced, furthermore, In this part, AHP method will be applied. The weight of the criteria will be calculated using Saaty's method and comparisons will be made by experts from the company. All the mentioned calculations will use data taken from the official website of each car model.

As a result, each alternative will get total utility and the best option will be with the highest utility. Then the table with ranked alternatives will present to the company to help and support the decision process.

The proposed extent of the thesis

50-60 pages

Keywords

Decision making, operational research, multiple criteria decision making

Recommended information sources

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Declaration

I declare that I have worked on my master's thesis titled "Application of mathematical methods in decision making" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the master's thesis, I declare that the thesis does not break any copyrights.

In Prague on 30/03/2023 ____________________________

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Application of mathematical methods in decision making

Abstract

This Diploma thesis deals with the application of mathematical models in decision-making. The main aim of the thesis is to choose a suitable electric car for AGEMSYS Development s.r.o and the partial goal is the formulation of a decision model along with a market segment search.

The theoretical part includes basic concepts of decision theory, the process of decision, types of decision problems, and the degree of certainty behind each decision type. The part also contains descriptions of different methods of multicriteria decision-making including ways to determine the weights of criteria and software used in decision support systems. Further, There is an overview of the trends in the field of electromobility in the Czech Republic and some information about the charging station infrastructure.

The practical part consists of the main steps of formulation of the decision-making model, there is an introduction of the selected company, its products, and goals, then the AHP method is applied to the selection of the electric car. Alternatives are selected from the Czech market and Information about the alternatives are gathered from official websites, moreover, the weights of criteria are determined using Saaty's method by one expert from the company. In conclusion, the alternatives are sorted according to the total utility and the result will be discussed with the company managers.

Keywords: Decision making, operational research, multiple criteria decision-making, AHP

Aplikace matematických metod při rozhodování

Abstrakt

Tato diplomová práce se zabývá aplikací matematických modelů při rozhodování. Hlavním cílem práce je vybrat vhodné elektrické auto pro společnost AGEMSYS Development s.r.o. a částečným cílem je formulace rozhodovacího modelu spolu s hledáním tržního segmentu.

Teoretická část zahrnuje základní koncepty teorie rozhodování, proces rozhodování, typy rozhodovacích problémů a míru jistoty za každým typem rozhodnutí. Část také obsahuje popisy různých metod multicriteriálního rozhodování včetně způsobů stanovení vah kritérií a softwaru používaného v systémech podpory rozhodování. Dále je zde přehled trendů v oblasti elektromobility v České republice a informace o infrastruktuře nabíjecích stanic.

Praktická část se skládá z hlavních kroků formulace rozhodovacího modelu, je zde představena vybraná společnost, její produkty a cíle, poté je použita metoda AHP pro výběr elektrického vozu. Alternativy jsou vybírány z českého trhu a informace o alternativách jsou získávány z oficiálních webových stránek, navíc jsou stanoveny váhy kritérií pomocí Saatyovy metody jedním expertem ze společnosti. V závěru jsou alternativy seřazeny podle celkové užitnosti a výsledek bude projednán s manažery společnosti.

Klíčová slova: Rozhodování, operační výzkum, vícekriteriální rozhodování, AHP

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1 Introduction

Decision-making is an inseparable part and daily activity in our life. Every person faces a situation where just one option has to be chosen, in some situations, the decisions can be easy as what to have for dinner or what to wear to school. However, some decisions can have a huge impact on our future, for example, choosing a job or high school, and such decisions must be carefully considered, as we can then bear the consequences for the rest of our lives.

Everyone wants to choose the best one from the offered options, thus maximizing their benefit, and the decision-making process helps them to do this. most often our intuition or our knowledge is enough for the solution, in other cases, we need a special approach, creativity, and knowledge of experts. Fortunately, throughout history, there are a lot of methods and ways that were developed to make the decision-making process a bit easier, one of the most common approaches is multicriteria decision-making.

Multicriteria decision-making solves problems in which several criteria are taken into account at the same time. The more criteria that are assessed, the more complex the problem and also its solution. The goal of multi-criteria decision-making models is to find a compromise variant that best suits the selected criteria.

In this thesis, the choice of an electric car for the selected company is solved as a case study. The issue of choosing an electric car is not at all simple these days. There is a wide range of these vehicles on the market from different companies, in addition to that, some important criteria have to be considered when buying electric vehicles, therefore, a suitable choice can result in financial savings and a good return on investment.

Selected multi-criteria decision-making methods will be applied to the possible variants and a suitable car will be recommended to the company management based on their requirements and preferences.

2 Objectives and Methodology

2.1 Objectives

The main goal of the thesis is to choose a suitable electric car for the selected company using multicriteria decision-making (MCDM) methods. The partial goal is the formulation of decision criteria and the market segment search.

2.2 Methodology

The diploma thesis will deal with mathematical models for complex decision support. The main aim of the work is to select an electric car for the AGEMSYS Development s.r.o company according to the specified criteria.

The thesis will contain two main parts theoretical and practical. The theoretical part of the thesis will include basic concepts, definitions, and methods of multicriteria decision-making and decision analysis. additionally, the part will introduce different methods to calculate the weight of the criteria.

After gaining theoretical knowledge, the practical part will focus on the selection of a suitable electric car from different models that are available in the Czech market. Some information about the company, history, and objectives will be introduced, furthermore, in this part, the AHP method will be applied. The weight of the criteria will be calculated using Saaty's method and comparisons will be made by experts from the company. All the mentioned calculations will use data taken from the official website of each car model. As a result, each alternative will get total utility and the best option will be with the highest utility. Then the table with ranked alternatives will present to the company to help and support the decision process.

3 Literature Review

3.1 Decision theory

Throughout history, the theory of decision has been divided into three main periods: the old period, the Pioneering period, and the Axiomatic period. Firstly, the old period started in ancient Greece. however, during this period, Greek did not recognize rational decisions from irrational ones. After Greek, there isn't any evidence that the following empires added anything to the theory. Then the Pioneering period began in 1654 when Blaise Pascal and Pierre de Fermat started working on and developing the probability theory. Another milestone in this period was the book published in 1662 known as "Port-Royal Logic", this book contains the first definition of the principle of maximizing expected value. The third major period is the Axiomatic, in this period, many attempts were made to axiomatize the definition of rational decision-making. The period has two milestones: the first one was a paper written in 1926 "Truth and Probability" by Frank Ramsey, in his paper, he proposed and explained a set of axioms for how rational decision-makers have to deal with uncertain prospects. During this period, the second milestone was Neumann and Morgenstern's book "Theory of Games and Economic Behavior" the first edition of the book dealt with decision-making under risk while the second one was about how people should make decisions among lotteries. (Peterson, 2009)

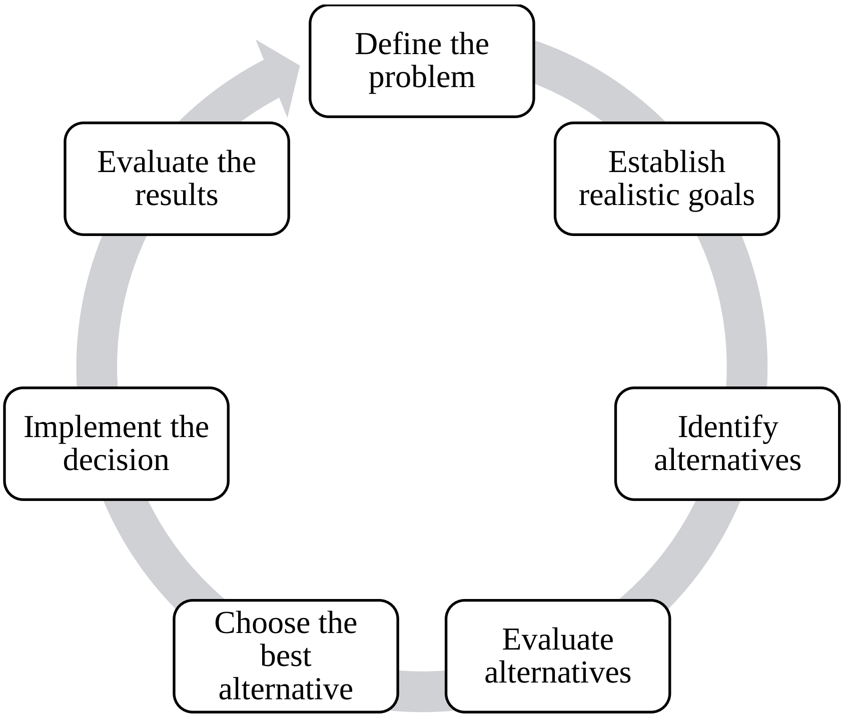
3.1.1 Decision-making process

According to (Motyčková & Štěpánková, 2014) we can generally define decision-making as a process in which we have to choose between various possible options, and this process aims to choose the best and most advantageous alternative.

(Peterson, 2009) identified two types of decision theory: Normative and descriptive. The normative approach offers a better understanding of the decision analysis, it is concerned with rational decisions and directly shows how people should make decisions, While the descriptive approach seeks to understand and explain how decisions actually are made, this approach assumes that rational decisions are made only to some extent, therefore, this theory is typical for cognitive sciences. (Peterson, 2009) further explained that both theories have some mutual points as they both say that decisions are influenced -to some extent- by the beliefs and thoughts of the decision-makers.

Any decision can be only rational, only right, or both. The focus and studies usually lie on rational decisions. In the rational model of decision-making, we follow a logical series of steps to solve our problems and make the right decision. These steps are explained by (Skinner, 2009) as follows:

Figure 1: Decision-making process



(Source: own work according to (Skinner, 2009))

3.1.2 Types of decision problems

In this complex world., the decision problems are largely diverse and decision-makers need to know well in which term the problem is defined, moreover, they have to be familiar with problems formulation and what they are deciding about (Roy, 1981) has identified four main types of decision problem formulation

- **Choice problem**

This type is very common in our life and always deals with the best option available. In this type, the goal is to compare the options amongst themselves in order to reduce as many as possible and retain the best single option.

- **Sorting problem**

We state this problem in terms of sorting the options into groups and categories according to their similar properties and behaviors, then this sorting helps us to take necessary action easily on the predefined group.

- **Ordering or ranking problem**

In this type, we arrange and order the options from best to worst by comparing them or using points, and this process is made according to selected criteria.

- **Description problem**

This formulation helps to describe the options, we state the problem in terms of the description and consequence of the actions.

Some additional problem types have been introduced also like the Elimination problem and Design problem. However, studies and research are usually made on the main four types mentioned above.

3.1.3 Decision-making analysis

Every decision model contains some essential elements: an alternatives list, states of nature with their probabilities, outcomes, and degree of certainty. These elements can be visualized in different graphical ways with some analysis tools, in other words, decision-makers can use them to make their decisions more effectively. Examples of these tools are decision trees and decision matrices

3.1.3.1 Decision matrix

(Gilboa, 2010) identified a Decision matrix as a method used for visualizing a decision model graphically, this matrix helps decision-makers to analyze and identify the outcome. The decision matrix (or table) contains M number raws of alternatives A we made our decision among them, N columns of states of nature (events), and each state has a probability of occurrence P. Outcomes O will be then happened according to both chosen alternatives and state of nature.

A full decision matrix (M*N) is shown below

Table 1: Decision matrix

	States of nature				
Alternatives	S_1 P_1	S_2 P_2	S_3 P_3	… …	S_N P_N
A_1	O_{11}	O_{12}	O_{13}	…	O_{1N}
A_2	O_{21}	O_{22}	O_{23}	…	O_{2N}
A_3	O_{31}	O_{32}	O_{33}	…	O_{3N}
…	…	…	…	…	…
A_M	O_{M1}	O_{M2}	O_{M3}	…	O_{MN}

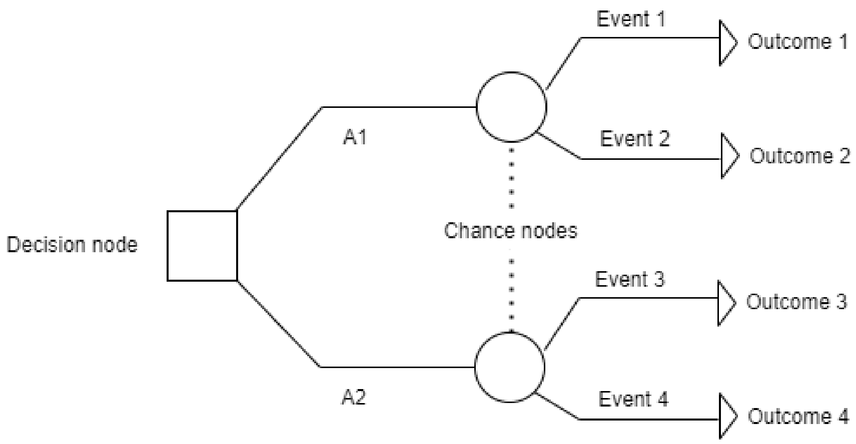
(Source: own work according to (Gilboa, 2010))

3.1.3.2 Decision tree

Another way to visualize a decision model effectively is the Decision tree. According to (Hui, 2015), we can define a decision tree as a support tool for making decisions that has a 2D tree graphic representation of the decisions, events, and expected outcomes. A decision tree has three types of nodes: Decision represented by squares, Chance by circles, and End by triangles.

The tree starts with a single Decision node, and from this node radiate some alternatives that end in a Chance node, then the tree ends with possible outcomes that come from chance nodes. (Davis & Yen, 1998)

Figure 2: Decisoion tree



(Source: own work according to (Hui, 2015))

We can convert all decision matrices into decision trees. However, some decision trees with more than one Chance node can not be turned into decision matrices.

3.1.4 Decision-making environment

In the decision-making model, “Degree of certainty” is a very important element, this element shows to what extent we are sure about future outcomes, moreover, it shows the degree and amount of knowledge we have about conditions that affect our decisions. Depending on the degree of certainty, we can categorize three main types of decision-making: decisions making under certainty, under risk, and under uncertainty. (French, 1986)

3.1.4.1 Decision-making under certainty

Decisions to make under certainty are quite easy because the conditions behind the decision-making process are completely known. Decision-makers have the knowledge and necessary information about alternatives, states of nature, and outcomes, moreover, they are able to choose the alternative that gives the most favorable outcome. (Bohanec, 2009)

3.1.4.2 Decision-making under risk

Risk arises in this type when decision-makers don't have sufficient information regarding the alternatives and states of nature. However, they can estimate the probability of occurrence for each outcome. These probabilities can be determined based on estimations from experts (subjective) or according to historical records. (Hui, 2015).

One approach to deal with decision-making under risk is to calculate the Expected Value (EV). Given that the probability of each state of nature is known, we can choose the alternative that gives us the highest expected value which is defined as the sum of the products of each outcome and the probability of the state of nature as follows:

$$\text{EV} = \sum_{j=1}^{N} (P_j \,.\, O_{ij}) \tag{1}$$

3.1.4.3 Decision-making under uncertainty

Most decisions today are made in this complex environment. According to (Arsham, 2001) conditions of uncertainty occur when the future environment is unpredictable. In this type, decision-makers don't have information regarding states of nature and expected outcomes nor they can assess the probability of occurrence. However, there are several approaches that help decision-makers to deal with uncertainty:

Maximax solution: or optimistic approach, the decision-maker chooses the alternative with the highest possible outcome.
Maximin solution: or pessimistic approach the decision-maker chooses the alternative whose outcome is the best between the worst outcomes.
Hurwicz a-criterion: the decision-maker is neither optimistic nor pessimistic but in the middle of two approaches. We use the optimism-pessimism index a(0.1) in this approach where a is near 1 when the decision-maker is more optimistic. The alternative A_I with the highest weighted average O_I is chosen

$$O_I = MAX\ [\ \alpha \,.\, MAX\ O_{ij} + (1-\alpha)\,.\, MIN\ O_{ij}\ ] \tag{2}$$

3.1.4.4 Decision-making under conflict- Game theory

In 1944, John Von Neumann and Oskar Morgenstern published “Theory of Games and Economic Behavior” which consider the cornerstone of Game theory. This is another important sub-field of the decision theory environment.

Game theory is applied to many areas of human activity from economics to political science and sociology, so it is not only a game but about conflicts between societies and people. This theory deals with interdependent decisions making under conflict situations where future outcomes of decisions and their probabilities depend on what other people do so one decision-maker doesn’t have full control over outcomes. The chess game is a good example of this theory. However, Prisoner’s Dilemma and the zero-sum game are the two most popular concepts used for explaining the theory. (Kelly, 2003)

3.1.5 Decision-making within organizations

Decision-makers throughout the different levels of the organization use the available information to make a wide range of decisions, some of these decisions fail and have a direct impact on the future of the organization. (Carpenter, et al., 2010) categorized the decision-making types within organizations according to their scope: Strategic decisions, tactical decisions, and operational decisions.

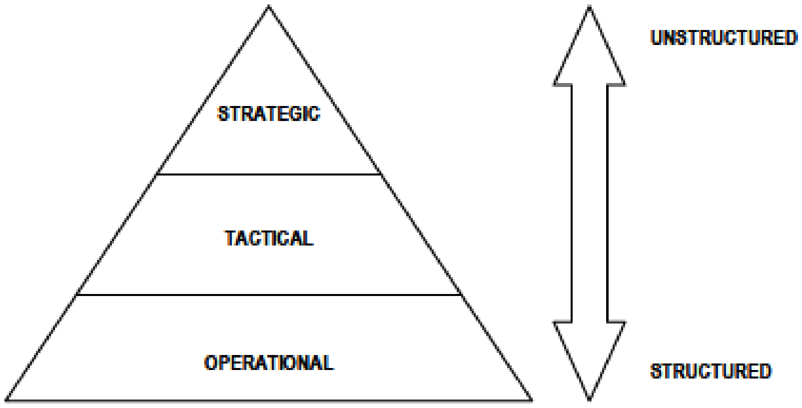
Firstly, Strategic decisions have a long-term impact on the entire organization, they are made by the upper level of management for setting the course of the enterprise. Usually, these decisions are complex and need business judgment.

Secondly, Tactical decisions: these types of decisions are related to the implementation of strategic decisions, they are made by middle managers and affect the organization for a limited time.

Finally, Operational decisions: these decisions are made every day by employees and lower-level management of the organization, they have a short-term impact and do not require much of business judgment.

Other types of decisions are based on the level of structure, whether decisions are well defined and can be considered repetitive (Bohanec, 2009)

Figure 3: Decision types in organizations



(Source: (Bohanec, 2009))

3.2 Multicriteria decision-making

(Dodgson, et al., 2009) defined multicriteria decision-making MCDM (also known as multicriteria decision analysis MCDA) is an approach and method used in different types of decision-making problems where there are a set of alternatives and a set of weighted criteria according to which we prioritize, rank, or choose from the alternatives.

The practice of multicriteria decision-making analysis is old in history. A human being has always tried to analyze criteria in order to choose the best alternative. (Thakkar, 2021) stated some important milestones related to multicriteria decision-making: the earliest root was an approach adopted by Benjamin Franklin in 1772, he worked on a simple paper system that had two various types of arguments on both sides so he could evaluate these arguments and eventually have only one argument, this approach was called “Moral Algebra”.

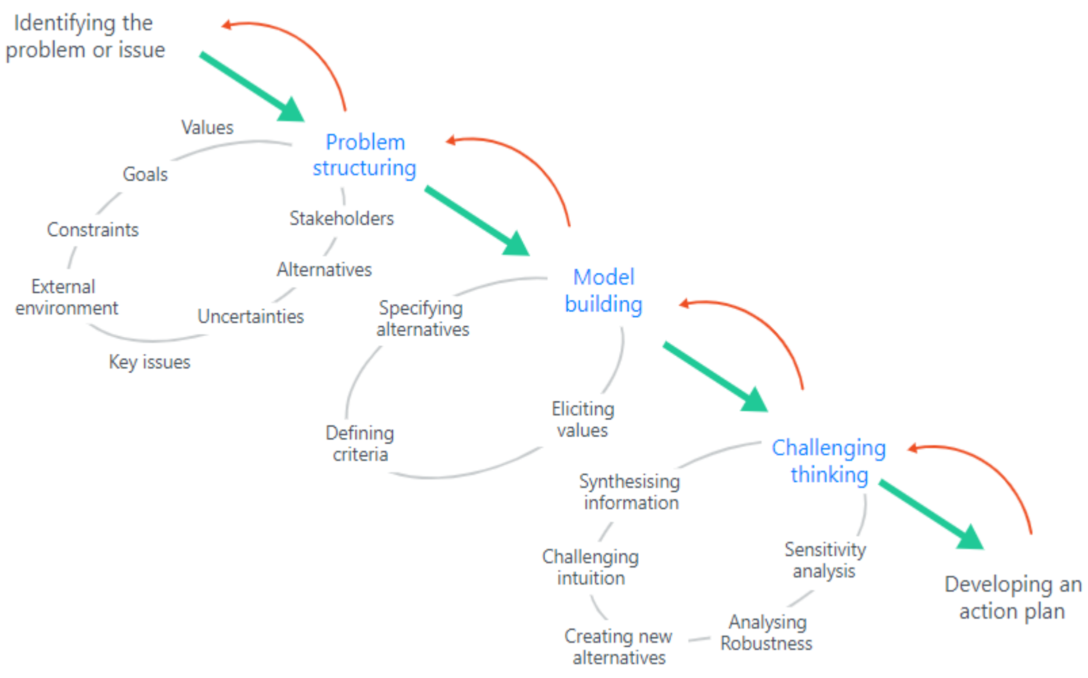
Then in the late 18th century, the Condorcet paradox (known also as the voting system) was developed by the Marquis de Condorcet for dealing with voting problems where there are many candidates and the one who wins in a head-to-head against each other candidates is selected.

In the 19th century, there was a rapid development in the Multicriteria decision-making theory, Firstly, in 1951 Kuhn and Tucker developed Nonlinear programming for selecting the optimal solution. After this important milestone, there was an extension of Linear Programming by Charnes, Cooper, and Ferguson, who in 1955 formulated the Goal programming technique. Since then, a lot of techniques were developed like ELECTRE IN the 1960s proposed by Bernard Roy, AHP, and ANP in the 1970s developed by Saaty.

3.2.1 Multicriteria decision-making model

The figure below shows the process of MCDA starting from identifying the problem and ending with developing an action plan. Each stage has some cycle feedback and is sometimes supported by computer software.

Figure 4: The process of MCDA



(Source: (Belton & Stewart, 2002))

Although the models of MCDA are various and diverse, they all share some mutual characteristics (Hwang & Yoon, 1981) identified them as follows:

a) Alternatives: can be defined as different decision-making possibilities, they are assumed to be finite and logically achievable, moreover, they must be selected in a way they can be evaluated later with criteria.

(Brožová & Houška, 2014) differentiated the following types:

- **Dominated**: in the case of the maximization criterion, this alternative acquires better values than the alternative with which it is compared for all evaluated criteria
- **Pareto or effective**: is the one that is not dominated by any alternative.
- **Ideal alternative**: achieves the best value in all evaluation criteria, it is mostly a hypothetical alternative.
- **Basal alternative**: represents an alternative that has the worst values in all criteria, it can be a hypothetical or even a real alternative.
- **Compromise alternative**: is the most advantageous variant of all permissible variants, it is recommended for implementation.

all the compromise alternatives are non-dominated

b) **Criteria:** Each MCDM model is associated with a set of criteria used to evaluate alternatives. The number of criteria must be acceptable, moreover, they must cover all aspects of the selection and must be independent.

(Munier, 2011) categorized criteria :

- **Quantitative criteria**: values of alternatives according to such criteria constitute objectively measurable data,

- **Qualitative criteria**: the values of alternatives according to these criteria cannot be measured objectively, they are subjective and in this case, different scoring scales or relative ranking are used
- **Minimization criteria**: find alternatives with the lowest possible criteria values
- **Maximization criteria**: find alternatives with the highest possible values

c) **Conflict among criteria**: different criteria represent different viewpoints in the evaluation of alternatives so they may conflict with each other, for example, the conflict between cost and profit.

d) **weights of criteria**: all the MCDM models require assigning weights to criteria. These weights are from an interval {0,1} expressing the relative importance of this criteria compared to others and the sum of all weights is equal to one.

after the evaluation of the variants -according to the criteria- is made, the MCDM model can be represented in a clear criterion matrix Y (similar to the decision matrix). The elements of the matrix indicate the evaluation of alternatives A according to criteria C with weights W.

Table 2: Criteria matrix

	States of nature				
Alternatives	C_1 W_1	C_2 W_2	C_3 W_3	… …	C_N W_N
A_1	a_{11}	a_{12}	a_{13}	…	a_{1N}
A_2	a_{21}	a_{22}	a_{23}	…	a_{2N}
A_3	a_{31}	a_{32}	a_{33}	…	a_{3N}
…	…	…	…	…	…
A_M	a_{M1}	a_{M2}	a_{M3}	…	a_{MN}

(Source: own work according to (Triantaphyllou, et al., 1998))

3.2.2 Classification of multicriteria decision-making

Multicriteria decision-making can be classified into two main categories: Multi-objective decision-making MODM and Multi-attribute decision-making MADM.

3.2.2.1 Multi-objectives decision-making

MODM deals with design problems where criteria are defined by objectives, in this type, there are a set of conflicting objectives and a set of constraints, in other words, objectives are clearly explicitly defined along with constraints, however, attributes are implicitly defined. In terms of alternatives, in MODM there are a large number of alternative and feasible solutions, moreover, the methods in MODM always evaluate the conflict between the objectives and try to find the optimal solution.

(Tzeng & Huang, 2011) mentioned some problems and difficulties in this method, two problems related to trade-off and scale problems. The trad-off problem occurs because the final optimal solution has to be transformed into a weighted objective, hence, the trade-off information between the objectives must be obtained and identified first. The second problem is the scaling problem where the dimension increases over capacity.

Some methods that deal with decision problems in continuous space are Linear and Goal programming, LINMAP, and Lexicographic

3.2.2.2 Multi-attribute decision-making

The problem is described in terms of selection in discrete decision spaces. Attributes are explicitly defined and usually, the number of alternatives is small and limited. During the evaluation, the process of final selection is done by attribute comparison.

According to (Hwang & Yoon, 1981) there are two main models of MADM based on attribute information processing: Non-Compensatory and Compensatory

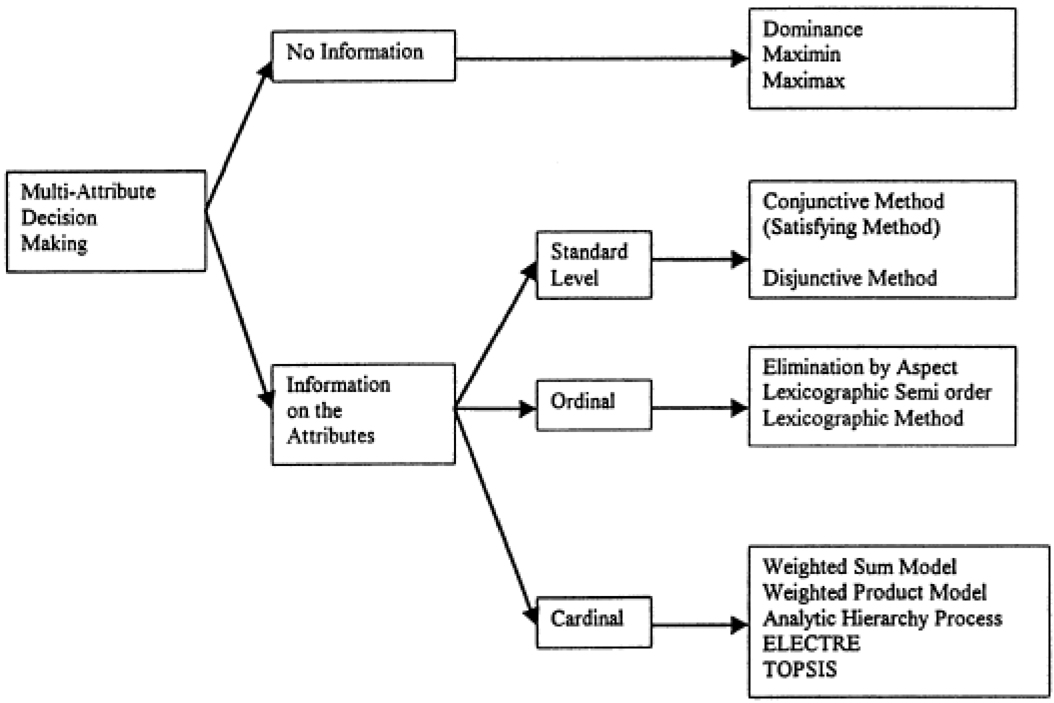
- **Non-compensatory**: in this model, there are no tradeoffs between attributes, each attribute represents itself only so any disadvantage in one attribute can't be substituted by any advantage from another attribute. Here the comparisons between attributes are made on one by one basis.

- **Compensatory Model:** the tradeoffs between attributes are permitted, any change in one attribute can be offset by another attribute. This model can be divided into :

  Scoring model: the alternative with the highest score is selected or the one with maximum utility.
  Compromising model: the model depends on the best and worst available solutions between available alternatives and then selects the one which is closest to the ideal.
  Concordance model: this model is difficult to deal with compared to scoring and compromising models. The evaluation is made with a concordance measure.

The figure below shows the different methods for multi-attribute decision-making MADM

Figure 5: MADM method



(Source: (Hwang & Yoon, 1981))

3.2.3 Methods for determining weights of criteria

determining the weights of individual criteria is the cornerstone for multicriteria analysis of variants. (Klicnarová, 2010) stated that weights numerically express the importance of individual criteria. the more important the criterion is for the contracting authority, the more weight it has. The methods for determining the weights of the criteria are very subjective, they differ in their demands on the information needed or the complexity of their implementation.

Table 3: Methods for determining weights of criteria

Information about preferences between criteria		
None	Ordinal	Cardinal
Method of equal weights	Ranking method	Scoring method
Entropy method	Fuller method	Saaty method

(Source: own work)

3.2.3.1 Method of equal weights

(Odu, 2019) stated that the method of equal weights is used in case of information about the preference of individual criteria can't be obtained, or the decision-maker can't decide for himself which of the entered criteria is more important than the others, therefore, it is not possible to organize the criteria, nor to assign numerical weights to them, through which the importance for the decision could be determined. Therefore, equal weight will be assigned to all criteria and the sum of the weights should be equal to 1, the weight of each criterion will be 1/n, where n indicates the number of criteria.

3.2.3.2 Entropy method

This method was proposed by Claude Shannon in 1984. The entropy concept has been widely employed to measure the uncertainty in the information in terms of probability.

The method evaluates value by measuring the degree of disorder in the system, the higher the difference between the measured value, the higher the degree of disorder, and more information can be obtained., therefore, a higher weight should be assigned. (Zhu, et al., 2020)

The procedure for determining weights is carried out in three steps, first, we start with the normalization of the decision matrix (i= 1,2,…m; j= 1,2,..,n)

(Zhu, et al., 2020) showed the steps as follows:

The standardized value P_{ij} is calculated:

$$P_{ij} = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} \tag{3}$$

Then the entropy value E_i of the i-th is defined:

$$E_i = -\frac{\sum_{j=1}^{n} P_{ij} * \ln P_{ij}}{\ln n} \tag{4}$$

The range of the entropy value is [0,1], the larger the value the greater the differentiation, ln n is used to guarantee that.

The last step is the calculation method of weight

$$W_i = \frac{1 - E_i}{\sum_{i=1}^{m} (1 - E_i)} \tag{5}$$

3.2.3.3 Ranking method

This method is based on ordinal information about the preference of individual criteria., the ranking method is used to determine the weights of the criteria mainly when the evaluation of criteria is done by many decision-makers. Each one ranks the criteria according to their importance. The most important criterion is rated n points (n is the number of criteria), and the second most important n-1 points so eventually the criterion with the least important gets only 1 point. In case some criteria have equal importance, they will receive points according to the average ranking.

Determining the weight of each of the criteria is calculated by summing up the points obtained from the experts and dividing it by the total number of points that the experts distributed among all the criteria. This guarantees that the sum of the weights of all criteria is equal to 1. (Klicnarová, 2010)

$$w_j = \frac{b_j}{\sum_{j=1}^{n} b_j} \tag{6}$$

3.2.3.4 Fuller method

Fuller's method consists of a pairwise comparison of individual criteria, Comparisons can be made in the so-called Fuller's triangle, in which all possible two-element combinations of criteria are captured. For each pair, experts circle the criterion they consider more important. (Ramík & Tošenovský, 2013)

$$N = \binom{n}{2} = \frac{n(n-1)}{2} \tag{7}$$

Where n is the number of compared criteria.

One point is assigned to the more important criterion. The weight of the i-th criterion is then calculated according to the formula.

$$w_j = \frac{n_j}{N} \tag{8}$$

$j = 1, 2, \dots, n$

where n_j is the sum of points assigned to the j-th criterion in pairwise comparisons.

3.2.3.5 Scoring method

The method is similar to the ranking method, but unlike the ranking method requires cardinal information about the preferences of individual criteria. The method is among the simplest methods requiring cardinal information. It is about assigning points from a specified scale to each criterion. The scale can have any range, but it is common to use a scale of 1 – 10. where the more points, the more preferred the criterion. The advantage is that it is possible to assign the same number of points to several criteria. The criteria weights are then calculated in the same way as for the relationship ranking method. (Thakkar, 2021)

$$w_j = \frac{b_j}{\sum_{j=1}^{n} b_j} \tag{9}$$

Where b_j is the number of points assigned to the j-th criterion, and n is the number of criteria.

3.2.3.6 Saaty method

It is a common method for determining weights by just one expert and is further used in this thesis. (Saaty , 1994) stated that this technique uses a quantitative pairwise comparison. A scale of 1-9 is used for the evaluation and by using this scale, individual pairwise comparisons are made.

The simplified form of this scale contains only the values 1, 3, 5, 7, 9, and intermediate levels can also be used, which are the values 2, 4, 6, 8. Even values are used when it is necessary to determine preferences more precisely.

Table 4: Saaty's scale

Intensity of importance	Definition
1	Equal importance
2	Weak
3	Moderate importance
4	Moderate plus
5	Strong importance
6	Strong plus
7	Very strong
8	Very, very strong
9	Extreme importance

(Source: own work according to (Saaty & Vargas, 2001))

The expert compares all pairs of criteria and writes the strength of preference into the Saaty matrix S. The matrix S must always be square, so it has a size $n \times n$. It determines the intensity of the importance of the i-th criterion over the j-th criterion. If the criteria are equal in meaning in the i-th row of the i-th column, this preference is written as sij=1. Otherwise, i.e. when the j-th criterion is preferred over the i-team, the intensity of the importance is recorded using the inverse value.

Figure 6: Saaty matrix

$$\begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & \cdots & 1 \end{bmatrix}$$

(Source: (Saaty , 1994))

It is important to verify the consistency of the Saaty matrix – Is, we verify the consistency of the Saaty matrix according to the formula:

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{10}$$

$$CR = \frac{CI}{RI} \tag{11}$$

where λmax is the largest eigenvalue of the Saaty matrix and n is the number of criteria. The Saaty matrix is sufficiently consistent if CR < 0.1. If this number were higher than 0.1, it is necessary to requalify this matrix.

if the Saaty matrix is consistent, the geometric mean of the numbers is calculated for each criterion according to the formula

$$b_i = \sqrt[n]{\prod_{j-1}^{n} s_{ij}} \tag{12}$$

The weights are then calculated using the normalization of bi values, according to the formula:

$$\omega_j = \frac{b_i}{\sum_{i=1}^{n} b_i} \tag{13}$$

3.2.4 Multicriteria decision-making methods

The method of MCDM are divided according to the types of information among the criteria, some methods require cardinal or ordinal information on the criteria to be used, and other types of methods deal with the aspiration level of the criteria (nominal information) (ŠUBRT & kol, 2011)

3.2.4.1 Methods based on aspiration level

According to (ŠUBRT & kol, 2011). These methods require knowledge of the aspirational level of the criteria. Variants in these methods are categorized into two types according to the information about the aspirational level: variants refer to them as "bad", ineffective, or "unaccepted" variants, and variants that have better criterion values refer to them as "good", effective, or "accepted" variants.

Conjunctive and Disjunctive method

If we denote the aspirational level of the criteria as z = (z1, z2, z3 …, zn), where n is the number of criteria and y_{ij} is the value of the j-th criterion for the i-th variant. we determine the set of acceptable variants so that, in the case of the conjunctive method, we accept only variants that meet all aspirational levels

$$M = \{ a_i \mid y_{ij} \geq z_j \ for\ all\ j = 1, \ldots, n \} \tag{14}$$

And in the case of the disjunctive method:

$$M = \{ a_i \mid y_{ij} \geq z_j \ for\ at\ least\ j = 1, \ldots, n \} \tag{15}$$

Where z_j is the minimum required evaluation of the variant according to the j-th criterion (aspirational level of criterion j).

3.2.4.2 Methods based on ordinal information

Ordinal information expresses the order of criteria according to importance or the order of variants according to how they are evaluated by the criterion.

Lexicographic method

This method requires that the attributes be ranked according to their importance by the decision-maker, the lexicographic method uses an ordinal type of information, and it is based on assumption that the criterion is the only important thing for choosing a compromise variant. Only the most important criterion is used to select a compromise alternative. If more than one alternative achieves the best evaluation according to this criterion, the criterion values of the alternatives are compared using the second most important criterion. Other criteria can be gradually used until a compromise option is selected. (Triantaphyllou, 2000).

ORESTE method

(Alinezhad & Khalili, 2019) stated that the ORESTE method uses ordinal information about variants and criteria, it was proposed by Marc Roubens in 1980. The input data for the method is organized data about criteria and variants. In this method the distance of each variant according to each criterion from the fictitious origin is determined, then the variants are arranged according to certain rules and a preference analysis is performed for each pair of variants.

The first step is to make the position matrix where the alternatives are ranked based on the attributes, then we calculate the block distance of each alternative:

$$d\left(0, A_{ij}\right) = a.r_{ij}\ (a) + (1-a)r_j \quad (16)$$

a represents the succession rate, r_{ij} is the value of the position matrix of i-th alternative in j-th attribute

then the calculated values are placed in the block distance matrix, the final step is to make a pairwise comparison of block distances, dij values are arranged from the smallest to the largest, evaluated by rank and then written into the new matrix R = (rij). For every alternative i is calculated value r_i:

$$R_i = \sum_{j=1}^{n} R_{ij} \quad (17)$$

3.2.4.3 Methods based on cardinal information

Cardinal information is quantitative, in the case of a preference for criteria we work with weights and most of the methods deal with cardinal information.

In this type of method there are three basic approaches to variant evaluation according to (Triantaphyllou, 2000):

- Minimization of the distance from the ideal variant
- Utility function
- Evaluation of the preferential relationship

TOPSIS

(The technique for order of preference by similarity to ideal solution) (Tzeng & Huang, 2011) stated that TOPSIS was developed by scientists Ching-Lai Hwang and Yoon in 1981 and further developed in 1987 and 1993. It is one of the many methods based on cardinal information, it states that the best alternative should have the shortest geometric distance from the ideal and the longest distance from the basal alternative.

According to (Tzeng & Huang, 2011) first, it is necessary to convert minimization criteria to maximization criteria:

$$y'_{ij} = -y_{ij} \tag{18}$$

The matrix of values of alternatives R needs to be normalized according to the formula

$$r_{ij} = \frac{y_{ij}}{\sum_1^n y_{ij}} \tag{19}$$

Weights are assigned to the criteria according to their importance. υ_{ij} (where j = 1, 2, … n)

Then, the weighted normalized matrix is calculated as below:

$$w_{ij} = \upsilon_{ij} * r_{ij} \tag{20}$$

The next step is to determine the ideal alternative (h1,…, hm) and basal alternative (d1,…, dm), and the distance of each alternative from the ideal and basal is calculated:

From ideal:

$$d_i^+ = \sqrt{\sum_1^n (w_{ij} - h_j)^2} \tag{21}$$

From basal:

$$d_i^- = \sqrt{\sum_1^n (w_{ij} - d_j)^2} \quad (22)$$

The last step is to calculate the relative closeness to the ideal alternative:

$$C_i^* = \frac{d_i^-}{d_i^+ + d_i^-} \quad (23)$$

Where C_i^* is between 0 and 1, the bigger the C_i^* the better then the alternatives are arranged in descending order according to the value of C_i^*.

Weighted sum approach

(ŠUBRT & kol, 2011) stated that the utility function assigns a utility expressed as a real number to each decision alternative, this total utility of each alternative can be determined based on knowledge of criteria weights and partial utility functions of individual criteria.

In general, the value of the partial utility function is equal to 1 for the best alternative according to criterion j and 0 for the worst one. Depending on how the utility changes with the increasing value of the criterion, we distinguish between linear, progressive, and degressive utility functions

The weighted sum approach is based on maximizing the linear utility function with a scale of 0 to 1, we determine the ideal alternative H with the evaluation (h1,h2,...,hn) and the basal alternative D with the evaluation (d1, d2,...,dn). then a standardized matrix R is created

$$r_{ij} = \frac{y_{ij} - d_j}{h_j - d_j} \quad (24)$$

After the transformation, the basal alternative is given 0 and the ideal is given 1. The total utility of each alternative is calculated:

$$u_i(a_i) = \sum_{j=1}^n r_{ij} * v_j \quad (25)$$

Finally, all the alternatives are ranked according to the utilities.

ELECTRE

ELimination Et Choix Traduisant la REalit´e (elimination and choice expressing reality) belongs to outranking method family. It was introduced in the middle of the 60s by the father of the outranking methods B.Roy and his team at SEMA company. (Triantaphyllou, et al., 1998)

The ELECTRE method is based on a pairwise comparison between alternatives according to each one of the criteria separately.

(Ishizaka & Nemery, 2013) stated that The ELECTRE method is suitable to use with more than two criteria and at least one of these conditions:

- The criteria are measured and expressed in different units
- The compensation effect between criteria is not to be tolerated
- Indifference and preference thresholds are required

The typical process of the method can be described according to (Roy, et al., 1966):

Step 1. Normalizing the decision matrix to transform to dimensionless comparable units:

$$x_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{M} a_{ij}^2}} \tag{26}$$

Where M is the number of alternatives, x_{ij} is the new measure of i-th alternative according to j-th criterion

Step 2. Assigning weights to the normalized decision matrix Y=X.W.

Step 3. Determine the Concordance and Discordance sets for alternatives A_k and A_l

Concordance set: $C_{kl} = \{ j$, such that: $y_{kj} \geq y_{lj} \}$

Discordance set: $D_{kl} = \{ j$, such that: $y_{kj} < y_{lj} \}$

Step 4. Construct the matrices, where C_{kl} represents the sum of weights of criteria in the concordance set

$$C_{kl} = \sum W_j \tag{27}$$

While D_{kl} expresses the degree to which the alternative A_k is worse than A_l

$$D_{kl} = \frac{\max\left|y_{kj} - y_{lj}\right| \ j \in D_{kl}}{\max\left|y_{kj} - y_{lj}\right|} \tag{28}$$

Step 5. Determine the concordance and discordance dominance matrices.

Threshold $\underline{C}$ is the average concordance index :

$$\underline{C} = \frac{1}{M(M-1)} * \sum_{k=1}^{M} \sum_{l=1}^{M} C_{kl} \tag{29}$$

Where dominance matrix F is 1 if $C_{kl} \geq \underline{C}$ and 0 otherwise.

Threshold $\underline{D}$:

$$\underline{D} = \frac{1}{M(M-1)} * \sum_{k=1}^{M} \sum_{l=1}^{M} D_{kl} \tag{30}$$

Discordance dominance matrix G is 1 if $D_{kl} \geq \underline{D}$ and 0 otherwise.

Step 6. Determine the aggregate dominance matrix

$$E_{kl} = G_{kl} * F_{kl} \tag{31}$$

Step 7. it depends on the ELECTRE level (ELECTRE I is for the choice problem, ELECTRE II, III, and IV are usually for the ranking problem) the less favorable alternatives are eliminated from the final matrix.

AHP

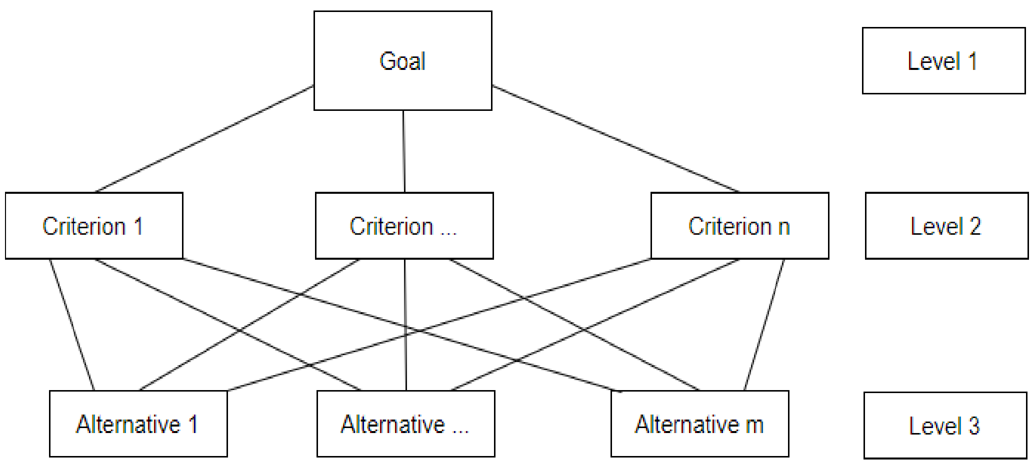
The AHP (Analytic Hierarchy Process) method was designed by prof. Saaty in 1980. This method provides a framework for making effective decisions in complex decision-making situations, helping to simplify and speed up the decision-making process.

AHP is a method of simplifying a complex unstructured situation by creating a hierarchical system. At each level of the hierarchical structure, Saaty's quantitative pairwise comparison method is used. Through the subjective evaluation of the pairwise comparison, we assign quantitative characteristics to the individual components that express their importance.

The method can be used for any type of information about preferential relationships between model components. The only condition is that the decision-maker can determine the intensity of preference between all pairs of compared components from this information. (Saaty , 1994)

the hierarchical structure is a linear structure that contains several levels. These levels are arranged from general to specific. The more general the elements are in relation to a given decision problem, the higher they occupy in the relevant hierarchy and vice versa. At the top level of the hierarchy, there is only one element or evaluation target, and this element can be assigned a value of one, which is distributed among the elements at the second level. Similarly, the value of each element is divided at the next lower levels of the hierarchy until we get the evaluation of the lowest level.

Figure 7: hierarchical structure of AHP



(Source: own work according to (Saaty , 1994))

This method contains a lot of pairwise comparisons, and it is necessary to check the consistency in the matrix. This process involves a few steps :

Step.1: multiply each column of the matrix by the corresponding weight.

Step.2: calculate the eigenvector λ

$$\lambda = \frac{x}{c} \tag{32}$$

Step.3: calculate the average λ_{avg}

$$\lambda\text{avg} = \left|\frac{\sum \lambda_i}{n}\right| \tag{33}$$

Step.4: calculate CI the consistency index

$$CI = \left|\frac{\lambda\text{avg} - \text{n}}{n-1}\right| \tag{34}$$

Step.5: if the (CI/RI) is large than 0.10 there is no consistency and it is necessary to revise the comparisons.

After checking for consistency, the matrix is computed for pairwise comparison of alternatives and criteria as well based on which criteria weights are determined. The sum of weights must be 1.

Finally, the best alternative is determined according to the synthetic utility values.

$$u(X_i) = max \sum_{i=1}^{m} \omega_j . w_{ij} \tag{35}$$

3.2.5 Software support for multicriteria decision-making

MCDM methods have seen rapid theoretical development in the last years, Many Companies and suppliers have developed different software programs to help in solving decision problems. During the decision-making process-especially in the last stages- there are big advantages to supporting the decision with software, it facilitates the correction of errors during the initial calculation, gives alternative ways of weights input, helps with graphing the outcomes, moreover, it gives some automation to the process of analysis.

3.2.5.1 PRIME

This program was created by a team from the system analysis laboratory at Helsinki University of Technology based on a pairwise comparison of variants according to all criteria. The main aim of this software is to help with discrete choice problems, it permits the entry of input data and deals with both ordinal and cardinal information. However, working on the software is not easy and needs some practice. (Belton & Stewart, 2002).

3.2.5.2 Expert Choice

Program Expert Choice from Expert Choice Inc was founded in the 1980s to help companies and individuals make better decisions. The software is based on the AHP method for discrete choice problems, it helps with making the comparison, prioritizing, checking for consistency, and graphing the scores. (Belton & Stewart, 2002)

3.2.5.3 M-MACBETH

M-MACBETH supports the MACBETH technique, it is a Powerful software aimed to deal with both quantitative and qualitative criteria using pairwise comparison. This software includes tools to facilitate complex evaluation and the process of weighting criteria and scoring options. A free trial can be downloaded from the website. (Ishizaka & Nemery, 2013)

3.2.5.4 Smart Picker Pro

This software was created to support the PROMETHEE technique, similarly to D-Sight or Decision Lab, this software enables the decision-makers to do the sensitivity analysis and what-if analysis which is helpful to deal with risk situations. The software has user-friendly smart tools for visualizing the outcomes in graphical ways. (Ishizaka & Nemery, 2013)

3.2.5.5 V.I.S.A

V.I.S.A stands for Visual Interactive Sensitivity Analysis, it is a windows-based software of Multicriteria decision analysis developed by SIMUL8 Corporation Ltd. The software is suitable for individual and group decision-making with multiple criteria, it documents all stages in process of decision and shows the reasons behind the outcome.

3.3 Trends in the field of Electromobility

In recent years, there was a growing trend in the development of electromobility. The high carbon emissions of cars with internal combustion force the world to look for more ecological and long-term sustainable options for driving cars. Whether electric cars have a future and whether they will one day replace conventional cars is highly controversial, but every year it is more realistic.

Electric cars include all vehicles that are powered by electricity, first type is BEV (Battery Electric Vehicle) which does not have an internal combustion engine and is powered only by electric motors, the second type is HEV (Hybrid Electric Vehicle) has both internal combustion and electric motor, the battery here is charged by an internal combustion engine. The last type is PHEV (Plug-in Hybrid Electric Vehicle) is just like HEV but with the possibility of charging the battery from the network. (Durant, 2014)

There are many reasons why people should invest in modern electric car technology, but there are also some disadvantages that a potential customer should consider before purchasing an electric car. Advantages include, for example, lower exhaust emissions, low maintenance, low running costs, no noise, and more. On the other hand, the short range, charging time, and battery replacement can be disadvantages for consumers.

There are several ways to charge an electric car. It can be charged in home sockets, the only drawback is the charging time, as this method is slower, but on the other hand more affordable. An AC (alternative current) outlet is recommended, which is already installed in most households. Charging at home can be done also with a so-called wall box charging station which makes the process of charging faster and more efficient. Another option Public charging stations can be found usually in many places, e.g. in business and shopping centers or garages of larger companies, In many cases, fast chargers and superchargers can also be found in publicly accessible, they use DC (direct current) which is way faster than AC. (Durant, 2014)

3.3.1 Electromobility in the Czech Republic.

The number of electric cars on European roads has been growing in recent years. In the Czech Republic, this trend is not so noticeable yet and the development of electromobility is slower than in other countries, due to the fact that cars with an internal combustion engines and fuel are not heavily taxed. However, The demand for electromobility in the Czech Republic is growing, In addition to the development of electromobility in passenger transport (HEV, PHEV, and BEV), the number of electric buses is also growing.

The graph shows the number of new EVs including HEV, PHEV, and BEV. (doprava, 2022)

Figure 8: Number of new EV registration 2011-2022

(Source: (doprava, 2022))

The data are from 2011 to 2022, the HEV types were registered the most in the period till 2018. However, after 2018 there was an increase in the number of BEVs and PHEVs, the total number of BEV cars during this period is the most among the types with 11,906 which is about 42.95%, PHEV with 9,241 33.34%, and then HEV with 6,571 23.71%. the graph illustrates the growing interest in the BEV after 2019 there was an increase of almost 331% in the registration of new BEVs.

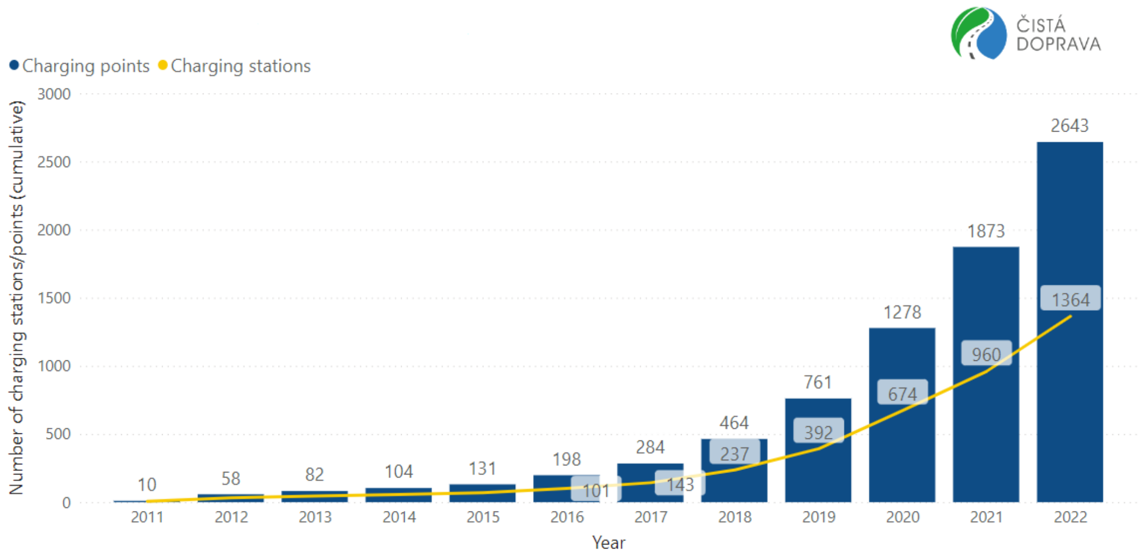
As one of the goals in the fight against climate change, the EU has set itself carbon neutrality by 2050 and to end internal combustion engines in 2035. Such a plan will pave the way to increase the number of EVs significantly in the EU including the Czech Republic. (euractiv, 2022).

3.3.2 The infrastructure of charging stations in the Czech Republic

The development of charging station infrastructure is a very important factor in shaping public perception of electromobility technology. Building an infrastructure of charging stations is a necessary prerequisite for the development of electromobility because without building the infrastructure, the willingness of consumers to buy an electric car will be very low.

Now in the Czech Republic, there are 2643 charging points in 1,364 charging stations, about half of them 50.29 % have both types of AC and DC, 45.5% only AC, and 4.21% only DC. (doprava, 2022)

Figure 9: Total charging points and stations in the CZ



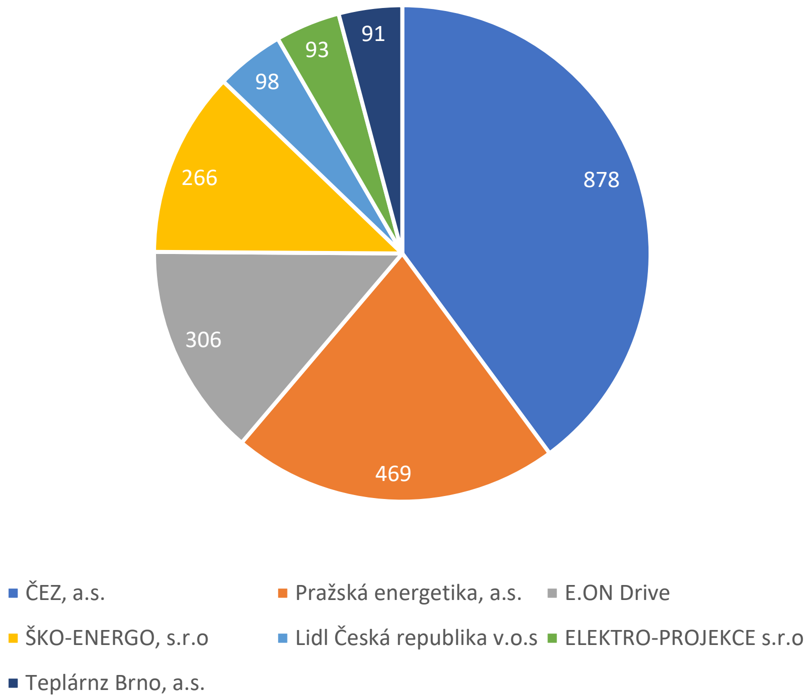
(Source: (doprava, 2022))

The graph shows the increase in the total number of charging stations number after 2018 and that makes sense since the number of electric cars increased after 2018 as well.

The capital city of Prague has the highest number of charging stations with 510 then Brno 217, Mlada Boleslav 171, and Ostrava 96.

The chart below shows the biggest operators of charging points in the Czech Republic, ČEZ has the largest network of charging points with 878 almost 34%, the second operator is Pražská energetika which operates 469 of the total public station points in the country, and the third place goes to E.on Drive with 306 stations.

Figure 10: Number of charging points by the station operator



(Source: own work according to (doprava, 2022))

4 Practical part

4.1 Company description

Basic information about the company:

Business name:	AGEMSYS Development s.r.o
Company ID number:	09657118
Date of registration:	05/11/2020
Headquarters:	Rybna 716/24 11000 Praha, Czech Republic
Founder:	Peter Szenasy
Legal form:	Společnost s ručením omezeným (with limited liability)

AGEMSYS Development (Advance Green Energy Mobility Systems) was established on 05/11/2020 in Prague with a partner relationship with EPDOR s.r.o in the Czech Republic.

EPDOR group consists of companies sharing the same vision, EPDOR France, EPDOR international, AGEMSYS, and SENSOWATCH. Each of these companies provides special services in the field of energy and innovative technologies.

AGEMSYS Development consists of a group of technical and economic experts, it provides comprehensive products in the field of renewable energy and electromobility.

The main scope of AGEMSYS Development:

- To develop and apply smart solutions in the field of green energy and electromobility.
- To increase energy efficiency and maximize the use of technological products.
- To reduce carbon emissions and support electromobility infrastructure.

Since its first day, the company has had the vision to boost the trend of electric vehicles in the Czech Republic. Currently, the company has different products in the Czech market. The e2-mobility bundle product enables charging electric cars from renewable sources at home, in addition, the company offers a green parking solution to install photovoltaic panels and charging stations in the parking areas.

Thanks to these products, the company became one of the leading companies in the field of electromobility and green energy in the Czech Republic.

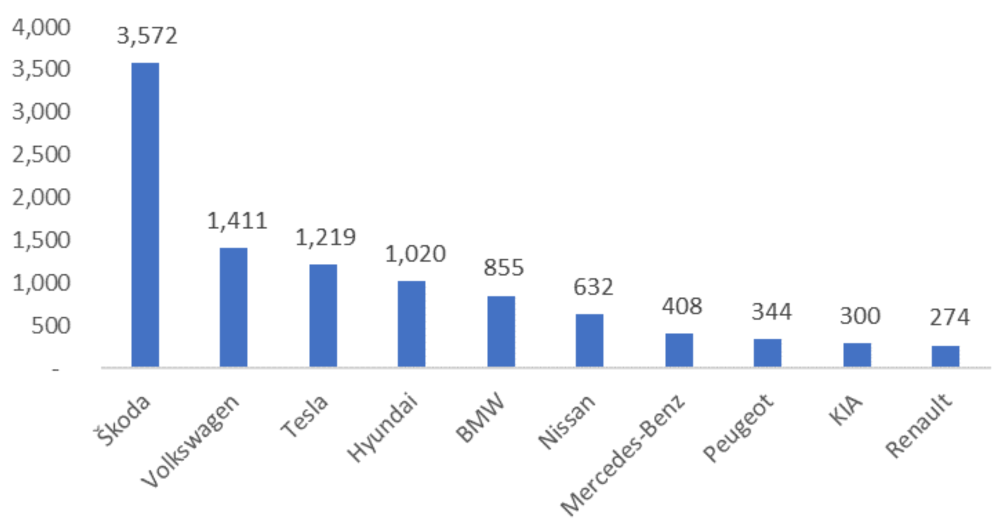
4.2 Formulation of the Decision-making model

The company has been developing and testing its products in a way that can be effective and efficient in the market, Therefore, a decision was made by the managers to have a photovoltaic power plant with charging station infrastructure in the company's building.

Different scenarios were calculated for different types of EV (Electric Vehicle) drivers with different driving ranges so the car can be recharged at home without any problem. The company now is dealing with a choice problem, they are searching for a suitable and available EV in the Czech market, this car will be used for business trips as well as to test to what extent the product is effective.

The selection of the car takes into consideration many factors. Looking at the Czech market in previous years, considering the new EV registrations by brand and model from 2005 to 2022 from the Transport Research Centre.

Figure 11:Number of EV registration (2005-2022)



(Source: own work according to (doprava, 2022))

The figure shows the most sold cars in the Czech Republic. The best-selling electric car brand for this period is Skoda, the second best-selling is Volkswagen, and the third is Tesla, Hyundai, and BMW have the next two places.

Regarding the number of kilometers traveled daily, the driving pattern in the company shows that the current car is used for business trips which can range from a few kilometers in Prague to more than 250 km across the Czech Republic.

After consideration of these facts by the company's management, they decide to buy a new EV. However, the process manager has some basic requirements:

- The car must be available easily in the Czech market from the best-selling list with 4 seat minimum. This will make the choice more realistic and increase the efficiency of the testing process.
- It has a range of at least 275 km because the car may be used on a business trip out of Prague and the number of charging stations on road in the Czech Republic is still not sufficient
- Costs 1,500,000 CZK maximum, to make a good return on investment so the EV can be a good economic choice. Within this range, the electric car can be more affordable with cheaper maintenance and service costs.
- Takes less than 8 hours to be fully charged, so the car can be recharged in the company’s building in the worst scenario (with a wall box charging station 22k or 11kw)
- Charging type 2 (Mennekes – IEC 62196) so charging at home can be possible using charging power up to 22kW with charging point 3-phase 32A. Another requirement regarding the charging process is the car must be able to take rapid or ultra charging power, these types of charging stations are public and they can help while the car is used for a business trip.

4.2.1 Decision criteria

In cooperation with the process manager of AGEMSYS Mr. Tomaš Lovecký, a total of six criteria were selected that best represent the requirements and demands of the company. All criteria are quantitative with their units. Regarding the battery warranty, electric cars in the market have usually 8 years or 160,00 km, in addition, the service cost depends on the owner and the packages that the company provides so we don’t consider these criteria in our situation.

a) **C_1 Price [CZK]:** the price of electric vehicles is usually higher than petrol cars but with cheaper running costs, the price in the Czech market is between 500,000 CZK to more than 3,000,000 for the newest version. In our calculation, the price is up to 1,500,000 CZK. the high price of electric cars is usually because of the expensive lithium batteries

b) **C_2 Range [Km]:** minimum range required is 275 km, the range can be from 230 km and up to 500 km depending not only on the capacity of the battery and consumption of the car, but also on several conditions like the style of driving, weather, and the route condition. Usually, the range is calculated based on WLTP ratings (worldwide harmonized light vehicles 57% city routes, 25% intercity routes, 18% highway routes) it is used in the EU and is 80-90% accurate when it is compared to real tests

c) **C_3 Safety[%]:** it is an important criterion when considering buying an electric car, in the calculation, the data are taken from euroncap, the verified website for testing cars in the EU, safety rating contains adult occupant, child occupant, vulnerable road users, and safety assistants. This total rate will be the average of these factors.

d) **C_4 Battery capacity [kWh]:** the average net capacity was around 40 kWh but now it can be up to 100 kWh, the capacity has a direct impact on the range higher capacity means a higher range and of course means a higher price. Some electric cars have the same capacity but different ranges because the consumption [kWh/km] can be different from one car to another exactly like petrol cars

e) **C_5 Charging time [Hours]:** charging time must be 8 hours maximum with a 22kW or 11kW wall box charging station. In general, the time can be less or more depending on the battery capacity and the power of the charging station used (public or ultra-speed public). Cars with the same capacity may have different charging rates and speeds and that affects the charging time.

f) **C_6 Consumption [Wh/km]:** Since the electric car doesn't use fuel, the consumption is expressed in Watt-hour per kilometer which means how many Watt-hour are needed to drive a kilometer. Consumption can be an important factor to calculate the range of an electric car because it depends also on the style of the driver

4.2.2 Alternatives

Based on the requirements of the company and after discussing the situation with the process manager Mr. Lovecký and the financial manager Ms. Novotná, a list of seven electric cars was selected. All the data are collected from the official websites:

- Official websites of each car in the Czech Republic.
- Ev-database provides real-world data.

4.2.2.1 Renault zoe

Figure 12: Renault zoe

(Source: https://www.renault.cz/elektricke-vozy/zoe.html)

In June 2019 Renault announced a new Zoe hatchback, 4 087 × 1 787 × 1 562 mm, 1 502 kg with a 52 kWh battery, CCS fast charging, and an onboard charger with a power of up to 22 kW. It came with everything a small modern fully electric car should have, standard equipment includes keyless entry, Apple CarPlay, Android Auto, two USB ports, smartphone mirroring, and other accessories. (Renault.cz, 2022)

Table 5: Specifications of Renault Zoe

Renault zoe	
C_1 Price	1,027,000 CZK
C_2 Range	370 km
C_3 Safety	50%
C_4 Battery capacity	52 kWh
C_5 Charging time	4.5 hours
C_6 Consumption	177 Wh/km

(Source: own work according to (Renault.cz, 2022))

4.2.2.2 BMW i3

Figure 13: BMW i3

(Source: https://www.bmw.cz/cs/index.html)

One of the first mass-production electric cars announced by BMW, a B-segment high-roof hatchback car 4 011 × 1 775 × 1 598 mm 1 320 kg. the car has a rear engine and rear-wheel drive with 4 seats. The drive unit is tuned to 125 kW and has a torque of 250 Nm with acceleration from zero to 100 km/h in 7.3 seconds, so the driver can benefit from the immediate onset of power transmitted to the wheels. (BMW.cz, 2022)

Table 6: Specifications of BMW i3

BMW i3	
C_1 Price	1,049,100 CZK
C_2 Range	330 km
C_3 Safety	69.75%
C_4 Battery capacity	42.2 kWh
C_5 Charging time	5.5 hours
C_6 Consumption	161 Wh/km

(Source: own work according to (BMW.cz, 2022))

4.2.2.3 KIA e-Niro

Figure 14: KIA e-Niro

(Source: https://www.kia.com/cz/modely/niro-ev/objevte/)

The e-Niro electric car from KIA is one of the best electric cars on the market, a family SUV 4 375 × 1 805 × 1 608 mm 1 812 kg with 5 seats. The Kia E-Niro has a distinctive blue interior and redesigned 17-inch alloy wheels, it comes with an electric motor that provides up to 150 kW of power with a rear engine style. Thanks to the electric motor and its high torque, the car is one of the fastest cars in its category. (KIA.cz, 2022)

Table 7: Specifications of KIA e-Niro

KIA e-Niro	
C_1 Price	1,169,980 CZK
C_2 Range	455 km
C_3 Safety	77.5%
C_4 Battery capacity	64 kWh
C_5 Charging time	7 hours
C_6 Consumption	164 Wh/km

(Source: own work according to (KIA.cz, 2022))

4.2.2.4 Škoda ENYAQ iv60

Figure 15: Škoda ENYAQ iv60

(Source: https://www.skoda-auto.cz/modely/enyaq/enyaq-iv)

ENYAQ iV is a crossover SUV electric car manufactured by Škoda Auto. It is the first Škoda car using the MEB platform. The best-selling electric car on the Czech market has a 132 kW electric motor and 310 Nm. The dimensions of the car are 4 648 × 1 877 × 1 618 mm 1 812 kg with 5 seats. The car comes with three-zone Climatronic automatic air conditioning, a multifunctional leather steering wheel, KESSY keyless locking and starting, a DAB tuner, SmartLink, and LED headlights. (Škoda.cz, 2022)

Table 8: Specifications of Škoda ENYAQ iv60

Škoda ENYAQ iv60	
C_1 Price	1,179,900 CZK
C_2 Range	415 km
C_3 Safety	84%
C_4 Battery capacity	60 kWh
C_5 Charging time	6 hours
C_6 Consumption	160 Wh/km

(Source: own work according to (Škoda.cz, 2022))

4.2.2.5 Hyundai KONA EV Style

Figure 16: Hyundai KONA EV Style

(Source: https://www.hyundai.com/cz/modely/kona-electric/technologie.html)

The second all-electric car from Hyundai KONA comes with a sportier look while still maintaining the adventurous SUV style. This version has 4 205 × 1 800 × 1 570 mm 1 610 kg with seats for 5 people. The pair of large displays in the new KONA Electric model combines state-of-the-art connectivity with an elegant design. The car also comes with an Anti-lock braking system ABS + electronic brake force distribution EBD + brake assistant BA + hill start assistant HAC+ESC. (Hyundai.cz, 2022)

Table 9: Specifications of Hyundai KONA EV Style

Hyundai KONA EV Style	
C_1 Price	959,990 CZK
C_2 Range	310 km
C_3 Safety	73.5%
C_4 Battery capacity	40 kWh
C_5 Charging time	6.5 hours
C_6 Consumption	157 Wh/km

(Source: own work according to (Hyundai.cz, 2022))

4.2.2.6 Tesla Model 3

Figure 17: Tesla Model 3

(Source: https://www.tesla.com/cs_cz/model3/design#overview)

One of the most popular electric cars in the world, the Tesla Model 3 is the first mass-produced car that can be charged up to 255 kW. The car has a long range and motor with 208 kW that gives the car acceleration from 0 to 100 km/h in less than 6 seconds. Tesla Model 3 is one of the luxury electric cars on the market with dimensions 4 694 × 1 849 × 1 443 mm. The standard version comes with a gigantic 15-inch widescreen touchscreen through which everything can be controlled. (Tesla.cz, 2022)

Table 10: Specifications of Tesla Model 3

Tesla Model 3	
C_1 Price	1,369,990 CZK
C_2 Range	495 km
C_3 Safety	87.5%
C_4 Battery capacity	60 kWh
C_5 Charging time	6.5 hours
C_6 Consumption	157 Wh/km

(Source: own work according to (Tesla.cz, 2022))

4.2.2.7 Volkswagen ID.3 GO

Figure 18: Volkswagen ID 3 GO

(Source: https://www.volkswagen.cz/modely/id3)

Volkswagen's first electric car built on the MEB platform is a hot topic in the automotive industry, the car is one of the best-selling cars around the world and in the Czech Republic. the car comes with 4 261 × 1 809 × 1 568 mm 1812 kg. This version of the car comes with a 150 kW motor with 310 Nm, in addition, the car has Rear wheel driver style, and 18 steel wheels with decorative plastic covers. One of the best things about this car is the intelligent lighting system with the voice assistant. (Volkswagen.cz, 2022)

Table 11: Specifications of Volkswagen ID 3 GO

Volkswagen ID 3 GO	
C_1 Price	1,228,900 CZK
C_2 Range	415 km
C_3 Safety	83.75%
C_4 Battery capacity	58 kWh
C_5 Charging time	6.5 hours
C_6 Consumption	156 Wh/km

(Source: own work according to (Volkswagen.cz, 2022))

4.2.3 Decision matrix

Table 12: Decision matrix

	Price	Range	Safety	Battery capacity	Charging time	Consumption
	Min	Max	Max	Max	Min	Min
Renault zoe	1,027,000	370	50	52	4.5	177
BMW I3	1,049,100	330	69.75	42.2	5.5	161
KIA e-Niro	1,169,980	455	77.5	64	7	164
Skoda ENYAQ	1,179,900	412	84	60	6	160
Hyundai KONA	959,990	310	73.5	40	6.5	157
Tesla Model 3	1,369,990	495	87.5	60	6.5	157
Volkswagen ID.3 GO	1,228,900	415	83.75	58	6.5	156

(Source: own work)

4.3 Decision-making process

To deal with the choice problem in the decision-making process, we will use the AHP method and Saaty's scale to determine the weights of each criterion, this method as we mentioned in the theoretical part depending on the quantitative pairwise comparison.

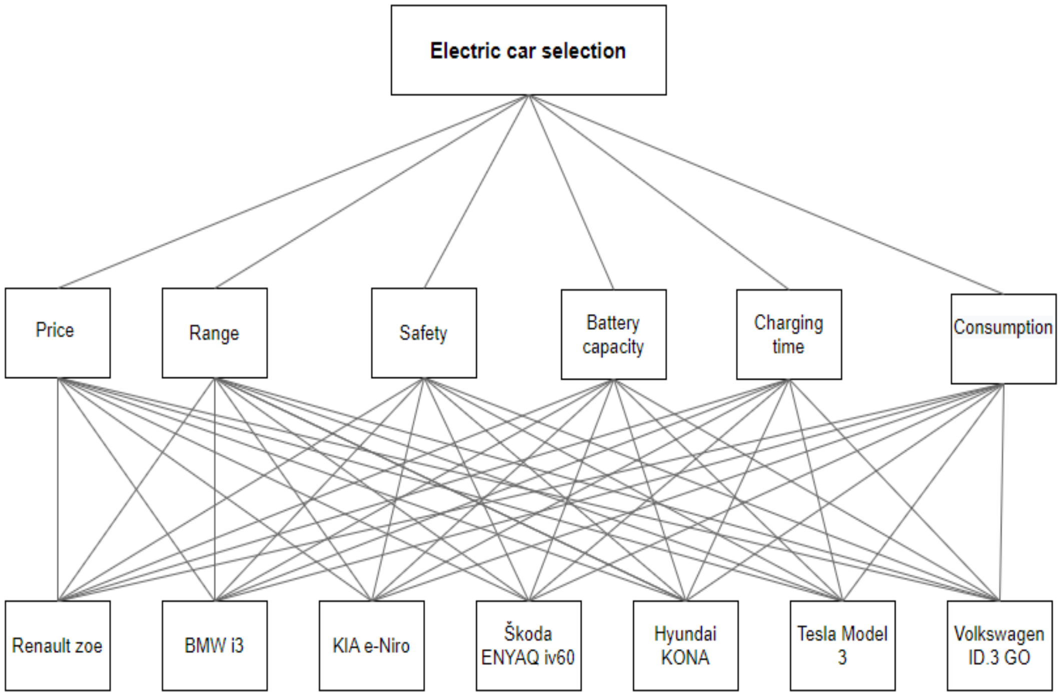
The whole situation is illustrated below using the electric car selection hierarchy. The hierarchy also shows individual levels of multi-criteria decision-making:

• level 1 – the aim of the decision: EV selection

• level 2 – evaluation criteria: 6 quantitative criteria

• level 3 – alternatives: 7 electric cars

Figure 19: Hierarchy of EV selection



(Source: own work)

4.3.1 Calculation of weights by the Saaty method

This method of determining criteria weights is used when one expert evaluates them. In this model, the comparison will be made by the process manager Mr. Lovecký, It is a method of quantitative pairwise comparison of criteria, where a 9-point scale (1,3,5,7,9) is used and it is also possible to use intermediate levels (values 2,4,6,8). The values are then entered into the Saaty matrix.

Table 13: Saaty matrix for criteria

	Price	Range	Safety	Battery capacity	Charging time	Consumption
Price	1.00	2.00	2.00	2.00	3.00	5.00
Range	0.50	1.00	2.00	2.00	3.00	3.00
Safety	0.50	0.50	1.00	2.00	2.00	3.00
Battery capacity	0.50	0.50	0.50	1.00	2.00	2.00
Charging time	0.33	0.33	0.50	0.50	1.00	2.00
Consumption	0.20	0.33	0.33	0.50	0.50	1.00

(Source: own work according to Mr. Lovecky)

It's necessary to check for consistency, according to equation (10).

$$\text{CI} = \frac{\lambda_{max} - n}{n-1} \quad \text{where n = 6,}$$

CI = 0.0745 and then calculate the random consistency index RI which for n=6 is 1.2.

From equation (11) we calculate

$CR = \frac{CI}{RI}$ = 0.0564 CR < 0.1 so The Saaty matrix is sufficiently consistent.

For each criterion, the geometric mean of the numbers is calculated according to the equation (12).

$$b_i = \sqrt[n]{\prod_{j-1}^{n} s_{ij}}.$$

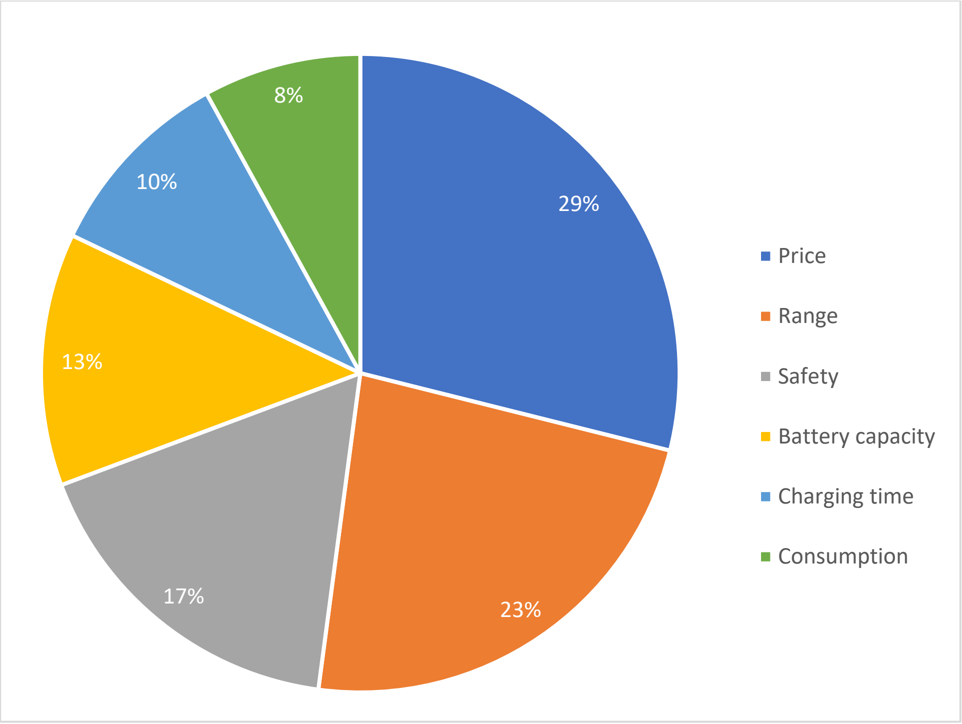
Then the weights are calculated by dividing the values by their sum according to equation (13). the sum of the weights must be equal to 1.

Table 14: Weights of criteria

	C_1	C_2	C_3	C_4	C_5	C_6	bi	ω_j
C_1	1.00	2.00	2.00	2.00	3.00	5.00	2.014	0.289
C_2	0.50	1.00	2.00	2.00	3.00	3.00	1.617	0.232
C_3	0.50	0.50	1.00	2.00	2.00	3.00	1.199	0.172
C_4	0.50	0.50	0.50	1.00	2.00	2.00	0.892	0.128
C_5	0.33	0.33	0.50	0.50	1.00	2.00	0.690	0.099
C_6	0.20	0.33	0.33	0.50	0.50	1.00	0.558	0.08

(Source: own work)

Figure 20: Weights of the criteria



(Source: own work)

4.3.2 Pairwise comparison of alternatives based on criteria

we apply the pairwise comparison method at another level of the hierarchy between the selected variants. The tables below show Saaty's matrices of alternatives against each criterion.

Renault zoe: A_1 Škoda Enyaq: A_4 Volkswagen ID.3 : A_7

BMW i3: A_2 Hyundai KONA: A_5

KIA e-Niro: A_3 Tesla model 3: A_6

4.3.2.1 Saaty's matrix of alternatives based on the price

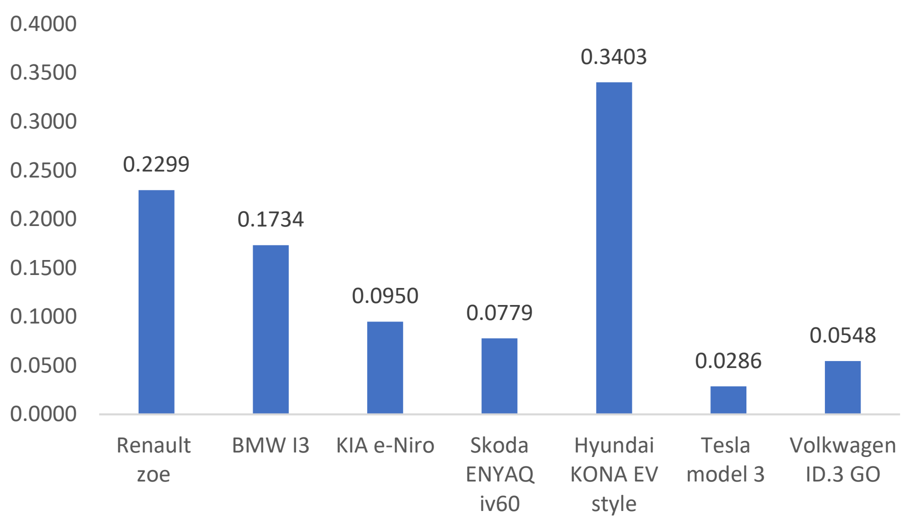
Table 15: Saaty's matrix of alternatives based on the price

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	2.00	3.00	3.00	0.50	6.00	4.00	2.155	0.2299
A_2	0.50	1.00	3.00	3.00	0.33	5.00	4.00	1.626	0.1734
A_3	0.33	0.33	1.00	2.00	0.25	4.00	2.00	0.891	0.0950
A_4	0.33	0.33	0.50	1.00	0.25	4.00	2.00	0.731	0.0779
A_5	2.00	3.00	4.00	4.00	1.00	7.00	5.00	3.190	0.3403
A_6	0.17	0.20	0.25	0.25	0.14	1.00	0.33	0.268	0.0286
A_7	0.25	0.25	0.50	0.50	0.20	3.00	1.00	0.513	0.0548

(Source: own work)

CI = 0.0511. CR= 0.0387 < 0.1

Figure 21: Comparison of alternatives based on the price



(Source: own work)

4.3.2.2 Saaty's matrix of alternatives based on the range

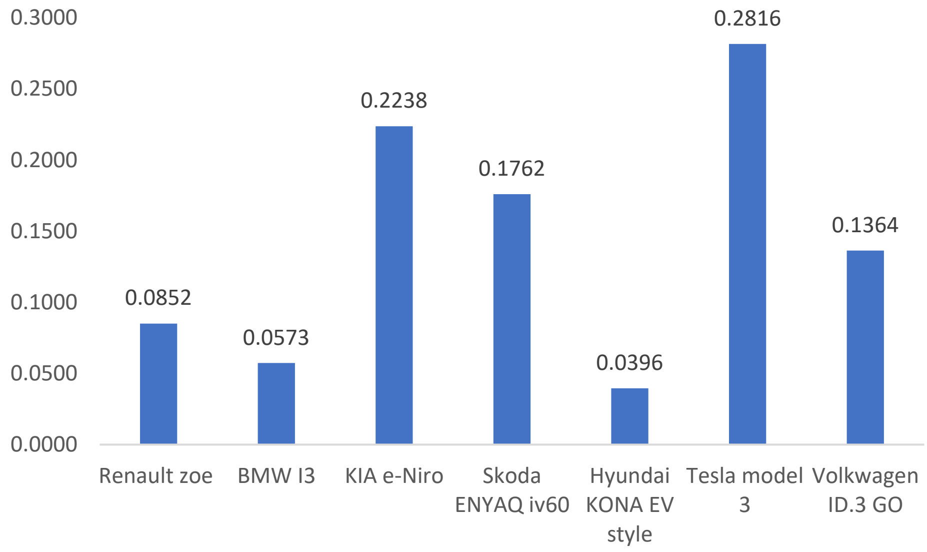
Table 16: Saaty's matrix of alternatives based on the range

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	2.00	0.33	0.33	3.00	0.33	0.50	0.731	0.0852
A_2	0.50	1.00	0.25	0.33	2.00	0.25	0.33	0.492	0.0573
A_3	3.00	4.00	1.00	2.00	4.00	0.50	2.00	1.919	0.2238
A_4	3.00	3.00	0.50	1.00	4.00	0.50	2.00	1.511	0.1762
A_5	0.33	0.50	0.25	0.25	1.00	0.20	0.25	0.340	0.0396
A_6	3.00	4.00	2.00	2.00	5.00	1.00	2.00	2.416	0.2816
A_7	2.00	3.00	0.50	0.50	4.00	0.50	1.00	1.170	0.1364

(Source: own work)

CI = 0.0488. CR= 0.0370 < 0.1

Figure 22: Comparison of alternatives based on the range



(Source: own work)

4.3.2.1 Saaty's matrix of alternatives based on the safety

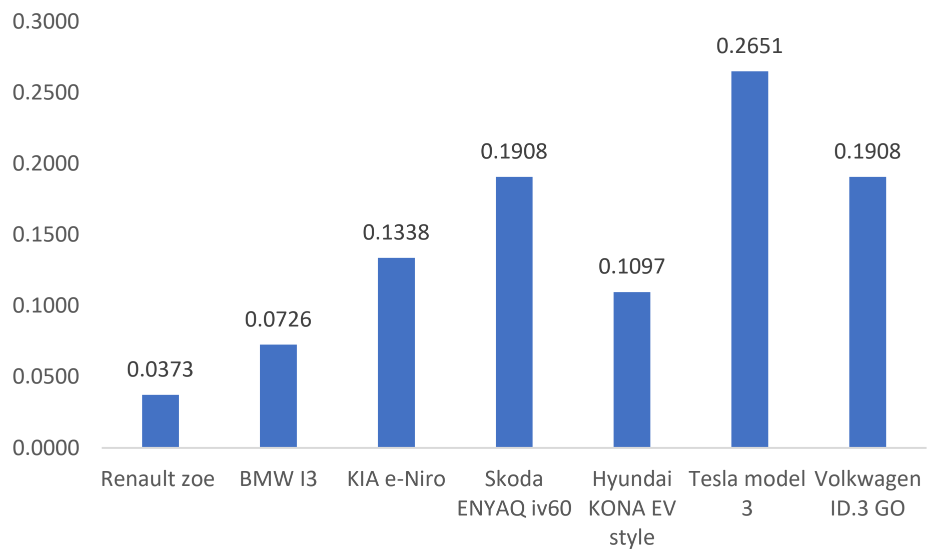
Table 17: Saaty's matrix of alternatives based on the safety

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	0.33	0.25	0.25	0.25	0.20	0.25	0.308	0.0373
A_2	3.00	1.00	0.50	0.33	0.50	0.33	0.33	0.599	0.0726
A_3	4.00	2.00	1.00	0.50	2.00	0.50	0.50	1.104	0.1338
A_4	4.00	3.00	2.00	1.00	2.00	0.50	1.00	1.575	0.1908
A_5	4.00	2.00	0.50	0.50	1.00	0.50	0.50	0.906	0.1097
A_6	5.00	3.00	2.00	2.00	2.00	1.00	2.00	2.188	0.2651
A_7	4.00	3.00	2.00	1.00	2.00	0.50	1.00	1.575	0.1908

(Source: own work)

CI = 0.0601. CR= 0.0455 < 0.1

Figure 23: Comparison of alternatives based on the safety



(Source: own work)

4.3.2.1 Saaty's matrix of alternatives based on the battery capacity

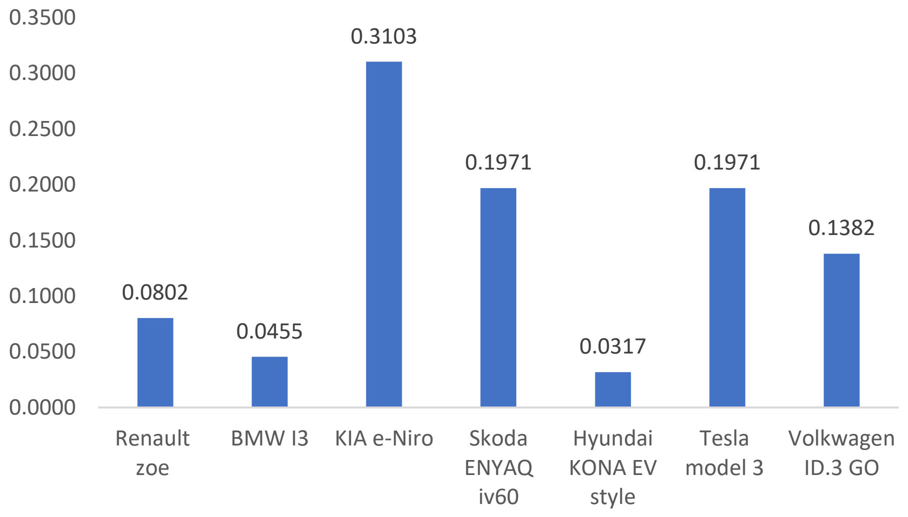
Table 18: Saaty's matrix of alternatives based on the battery capacity

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	3.00	0.25	0.33	4.00	0.33	0.33	0.731	0.0802
A_2	0.33	1.00	0.20	0.25	2.00	0.25	0.25	0.414	0.0455
A_3	4.00	5.00	1.00	2.00	6.00	2.00	3.00	2.826	0.3103
A_4	3.00	4.00	0.50	1.00	5.00	1.00	2.00	1.795	0.1971
A_5	0.25	0.50	0.17	0.20	1.00	0.20	0.20	0.289	0.0317
A_6	3.00	4.00	0.50	1.00	5.00	1.00	2.00	1.795	0.1971
A_7	3.00	4.00	0.33	0.50	5.00	0.50	1.00	1.258	0.1382

(Source: own work)

CI = 0.0473. CR= 0.0358< 0.1

Figure 24: Comparison of alternatives based on the battery capacity



(Source: own work)

4.3.2.2 Saaty's matrix of alternatives based on the charging time

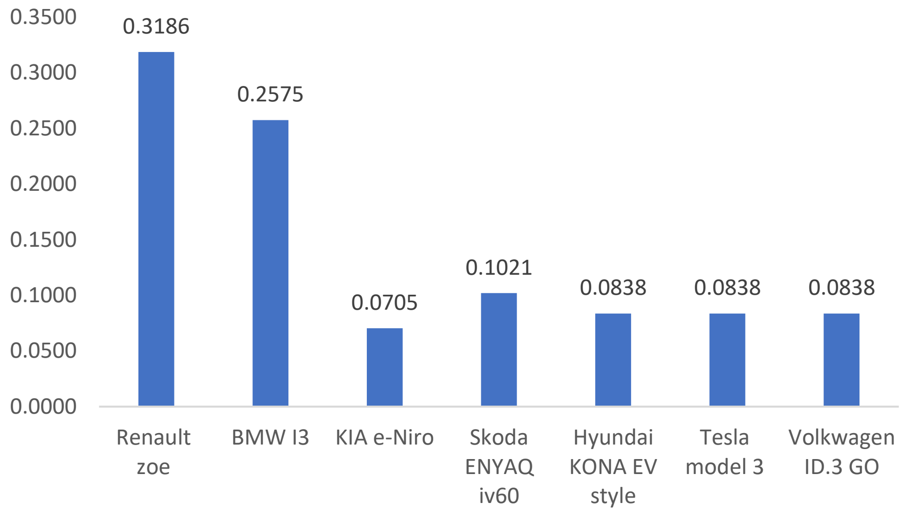
Table 19: Saaty's matrix of alternatives based on the charging time

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	1.00	5.00	3.00	4.00	4.00	4.00	2.667	0.3186
A_2	1.00	1.00	4.00	2.00	3.00	3.00	3.00	2.155	0.2575
A_3	0.20	0.25	1.00	0.50	1.00	1.00	1.00	0.590	0.0705
A_4	0.33	0.50	2.00	1.00	1.00	1.00	1.00	0.855	0.1021
A_5	0.25	0.33	1.00	1.00	1.00	1.00	1.00	0.701	0.0838
A_6	0.25	0.33	1.00	1.00	1.00	1.00	1.00	0.701	0.0838
A_7	0.25	0.33	1.00	1.00	1.00	1.00	1.00	0.701	0.0838

(Source: own work)

CI = 0.0105. CR= 0.0080 < 0.1

Figure 25: Comparison of alternatives based on the charging time



(Source: own work)

4.3.2.3 Saaty's matrix of alternatives based on the consumption

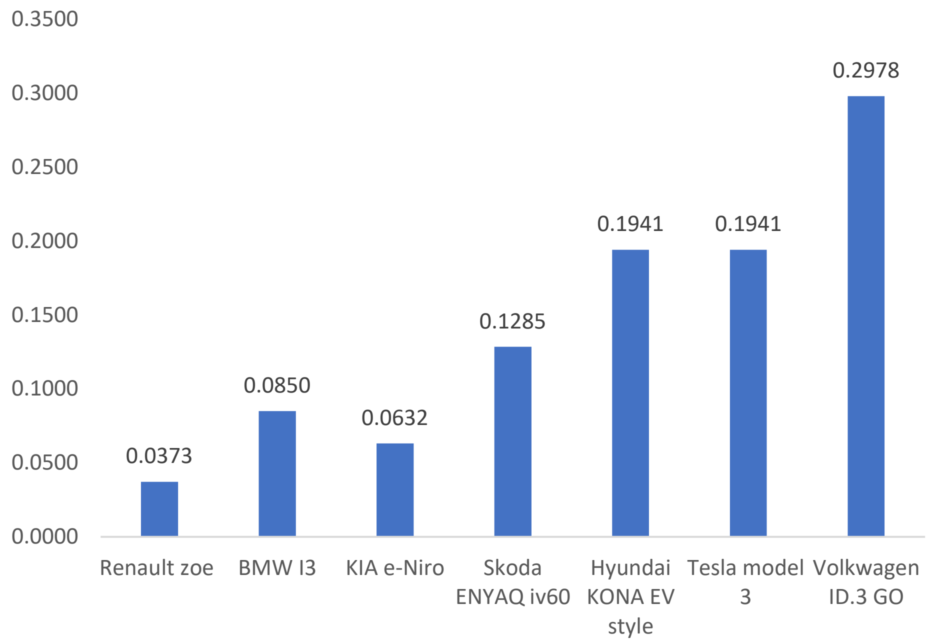
Table 20: Saaty's matrix of alternatives based on the consumption

	A_1	A_2	A_3	A_4	A_5	A_6	A_7	bi	W_{ij}
A_1	1.00	0.33	0.33	0.25	0.25	0.25	0.20	0.320	0.0373
A_2	3.00	1.00	2.00	0.50	0.33	0.33	0.33	0.731	0.0850
A_3	3.00	0.50	1.00	0.33	0.33	0.33	0.25	0.543	0.0632
A_4	4.00	2.00	3.00	1.00	0.50	0.50	0.33	1.104	0.1285
A_5	4.00	3.00	3.00	2.00	1.00	1.00	0.50	1.669	0.1941
A_6	4.00	3.00	3.00	2.00	1.00	1.00	0.50	1.669	0.1941
A_7	5.00	3.00	4.00	3.00	2.00	2.00	1.00	2.560	0.2978

(Source: own work)

CI = 0.0501. CR= 0.0379 < 0.1

Figure 26: Comparison of alternatives based on the consumption



(Source: own work)

4.3.3 Selection of the compromise alternative

The last step of the AHP method is to select the compromise alternative, we have the weights of criteria and all matrices of alternatives. Now we calculate the total utility X of each alternative A.

The utility of each alternative is based on the values of weights of each criterion multiple by the preference value of each alternative when we compared based on this criterion.

The total utility then is according to the equation (35):

$$u(X_i) = max \sum_{i=1}^{m} \omega_j . w_{ij}$$

Table 21: Utility values

	ω_1	ω_2	ω_3	ω_4	ω_5	ω_6	X
	0.289	0.232	0.172	0.128	0.099	0.08	
A_1	0.2299	0.0852	0.3186	0.0373	0.0802	0.0373	**0.1374**
A_2	0.1734	0.0573	0.2575	0.0850	0.0455	0.0726	**0.1140**
A_3	0.0950	0.2238	0.0705	0.0632	0.3103	0.1338	**0.1541**
A_4	0.0779	0.1762	0.1021	0.1285	0.1971	0.1908	**0.1418**
A_5	0.3403	0.0396	0.0838	0.1941	0.0317	0.1097	**0.1543**
A_6	0.0286	0.2816	0.0838	0.1941	0.1971	0.2651	**0.1682**
A_7	0.0548	0.1364	0.0838	0.2978	0.1382	0.1908	**0.1301**

(Source: own work)

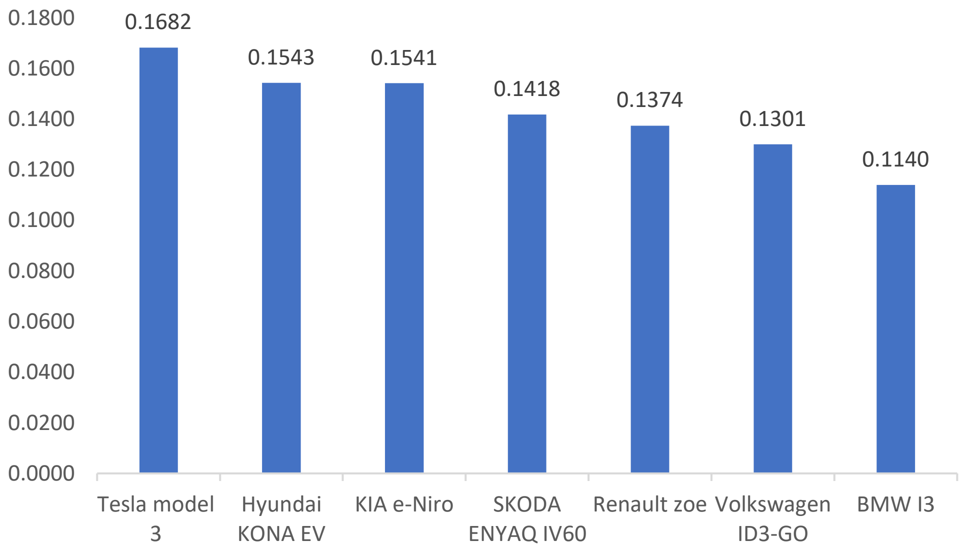
The individual alternatives are ordered in descending order according to the calculated values of the total utilities. The compromise variant is the variant with the highest total utility value. The resulting order of alternatives according to the utilities is shown:

Table 22: Order of alternatives according to total utilities

Order	Alternative	Total utilities
1	Tesla model 3 long	0.1682
2	Hyundai KONA EV	0.1543
3	KIA e-Niro	0.1541
4	ŠKODA ENYAQ iv60	0.1418
5	Renault zoe	0.1374
6	Volkswagen ID3-GO	0.1301
7	BMW I3	0.1140

(Source: own work)

Figure 27: Order of alternatives



(Source: own work)

Using the Analytical Hierarchy Process (AHP) method, we determined the order of alternatives according to overall utility. Tesla Model 3 has the highest total utility value 0.1682, Hyundai KONA EV took second place 0.1543. The third place belongs to KIA e-Niro which has almost the same total utility as 2nd place 0.1541. The fourth place was taken by the ŠKODA ENYAQ iv60 0.1418, followed by the Renault Zoe in fifth place 0.1374. The sixth and seventh places are shared by Volkswagen ID3-GO 0.1301 with a relatively small difference in the value of the total utility from the fifth-placed and finally, BMW i3 0.1140 which took the last place.

The compromise alternative is Tesla Model 3 followed by Hyundai KONA EV, and KIA e-Niro. There is no big difference between the three alternatives so after presenting the results to the managers, it was decided to compare these three alternatives. Each one of these alternatives has cons and pros, therefore, the comparison will show more in which criterion the alternative is better than another.

Table 23: Comparison of the criteria of the first three alternatives

	Tesla Model 3	**Hyundai KONA EV**	**KIA e-Niro**
Price	1,369,990 CZK	959,990 CZK	1,169,980 CZK
Range	495 km	310 km	455 km
Safety	87.5%	73.5%	77.5%
Battery Capacity	60 kWh	40 kWh	64 kWh
Charging time	6.5 hours	6.5 hours	7 hours
Consumption	157 Wh/km	157 Wh/km	164 Wh/km

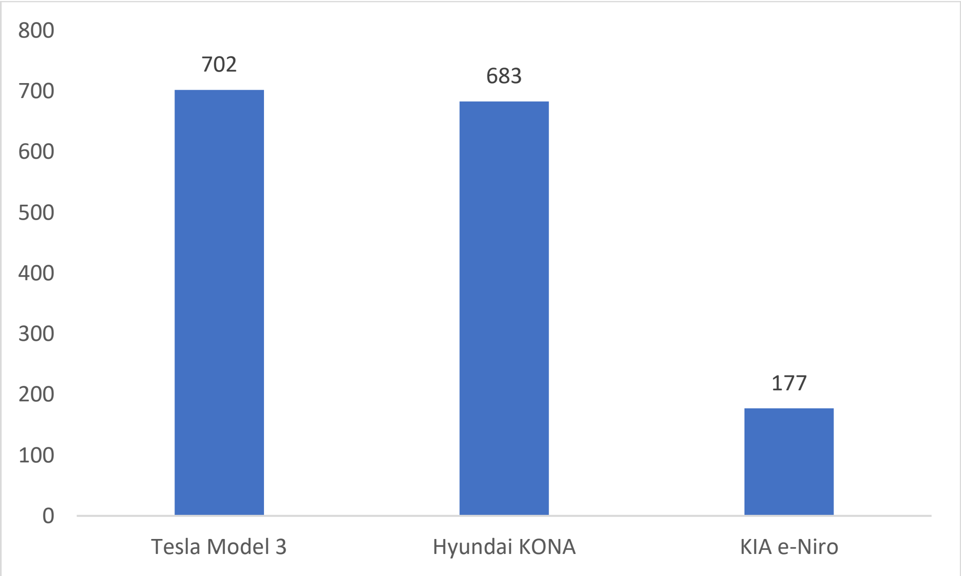
(Source: own work)

Table 24: Ranking of the first three alternatives according to the criteria

	Tesla Model 3	Hyundai KONA EV	KIA e-Niro
Price (Min)	3rd	1st	2nd
Range (Max)	1st	3rd	2nd
Safety (Max)	1st	3rd	2nd
Battery Capacity (Max)	2nd	3rd	1st
Charging time (Min)	1st	1st	3rd
Consumption (Min)	1st	1st	3rd

(Source: own work)

Figure 28: Number of new car registrations from 2005 to 2022



(Source: (doprava, 2022))

Table 22 shows that the compromise alternative Tesla Model 3 has the highest rank according to maximization criteria like range and safety and the lowest rank according to minimization criteria like charging time and consumption. Regarding the price, the Tesla Model 3 has the highest price among alternatives, it is about 200,000 CZK more than KIA e-Niro and 400,000 CZK more than Hyundai KONA EV. However, if we consider other criteria, Tesla Model 3 values can make up the difference.

Tesla Model 3 the compromise alternative is a good choice to fulfill the company's requirements and demand. The car can represent the vision of the company and be used for testing the products of the company. With its high range, managers of the company will enjoy driving on a business trip without being afraid, moreover, The car has a luxury model and comes with smart software and many other accessories.

Hyundai KONA EV took the highest rank in Price and shared the place with Tesla when we look at charging time and consumption. It costs 400,00 CZK less than Tesla Model 3 which is a good saving and 200,00 CZK less than KIA e-Niro. Hyundai KONA EV with a 40 kWh battery is a good choice when the buyer doesn't look for a speed and luxury car since it is not the best choice with its basic specification. The range is 310 Km and it is the lowest value among all alternatives due to the small capacity of the battery and consumption, it has the same consumption rate as Tesla Model but with less range.

KIA e-Niro has the highest battery capacity 64 kWh, the car costs 1,169,980 CZK which is 200,000 less than Tesla Model 3. The car has 2nd rank considering the range of 455 Km which is a good range and only a few kilometers less than Tesla. This version of KIA has a luxury model and a good motor power of 150 kW. Due to the high battery capacity, the car took 3rd place in charging time with 7 hours. However, it is 30-40 minutes less than other alternatives.

Figure 28 shows the number of new vehicle registrations by brand and what cars were the preferred choice in the Czech Republic, Tesla was registered the most during this period 702 followed by Hyundai KONA 683, and then KIA e-Niro 177. The figure is an important indicator of vehicle value and reliability. More cars registered means more maintenance points and show how much car buyers trust this brand.

5 Conclusion

The aim of this thesis was to select a suitable electric car for the selected company AGEMSYS using one of the multicriteria decision-making methods. The process of selection was made according to the company's preferences and requirements.

General concepts of decision-making theory were described in the theoretical part, including the process and environment behind each decision. The part outlined some methods for determining the weights of criteria and choosing the compromise variant, some of these methods subsequently were applied in the practical part. All information in the theoretical part was obtained from professional sources that deal with the field of decision-making and multicriteria methods.

The formulation of the decision-making model was made based on the company's specific requirements and goals. One of the multicriteria cardinal methods AHP was chosen to process the model. The calculation part was started by creating a hierarchical system of problems. The alternatives level included seven electric cars that were selected from the Czech market and these alternatives had to meet the conditions specified by the company's process manager Mr. Lovecky and the financial manager Mrs. Novotná, information about each alternative was obtained from the official websites. The criteria level in the AHP structure contains six quantitative criteria with a description of their nature, whether they are maximization or minimization.

Saaty's quantitative pairwise comparison method was used for determining the weights of criteria, this method is done by one expert, and in this work, Mr. Lovecky evaluates the importance of the criteria. The criteria were ranked according to importance in order: price, range, safety, battery capacity, charging time, and consumption. After determining the weights of the criteria, pairwise comparisons of alternatives based on each criterion were made. The result of the model was shown in table 22, the compromise alternative was the Tesla Model 3 with a utility value of 0.1682 followed by the Hyundai KONA EV 0.1543 and KIA e-Niro 0.1541. The outcome of the model with all calculations was presented to the company, moreover, the compromise alternative was recommended as the most suitable car in terms of the company’s requirements and prerequisites for fulfilling their work activities.

The results were recognized by the process manager as suitable for implementation and will be discussed in the next meeting of the company's upper managers. The final result demonstrates that AHP was a proper method in this work, all calculations in the model were well done, therefore, the model can be recommended for future use. The main goals of this thesis were fulfilled.

6 References

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7 List of figures and tables

7.1 List of Figures

7.2 List of Tables