Czech University of Life Sciences Prague

Faculty of Economics and Management

Department of Systems Engineering

Bachelor Thesis

Selection of the real estate for the company using multi-criteria decision-making methods

Anastasiia Pohorila

CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Economics and Management

BACHELOR THESIS ASSIGNMENT

Anastasiia Pohorila

Economics and Management

Thesis title

Selection of the real estate for company using multi-criteria decision-making methods

---

Objectives of thesis

The main objective of the thesis is to determine an optimal choice of real estate for the company's office based on criteria provided by three different clients, using multi-criteria analysis methods.

Methodology

This work is devoted to the problem of choosing a suitable real estate for an office for three companies using the method of multi-criteria decision making.

To achieve the goal, the article sets the task of studying and comparing existing methods aimed at solving multicriteria problems, and then choosing one method based on the comparisons obtained.

In the practical part, the selected method will be applied to the multi-criteria real estate selection problem for three companies (with different weights of the selected criteria) and three solutions of the problem by the selected method will be presented.

The main results of the work are three final optimal real estate options, as well as a comparison of the results obtained in terms of the decision-making procedure.

The practical significance of the study lies in the possibility of using the developed classification of clients into the three most common groups according to the criteria weights in the analysis of real estate in order to select the most appropriate option for solving a similar multi-criteria problem.

The proposed extent of the thesis

30-40

Keywords

Multi-criteria analysis, decision-making, weighted sum approach, TOPSIS, Saaty method, real estate

Recommended information sources

ISHIZAKA, Alessio; NEMERY, Philippe. *Multi-criteria decision analysis : methods and software.* Chichester: John Wiley & Sons, 2013. ISBN 978-1-119-97407-9.

KAHRAMAN, Cengiz. *Fuzzy multi-criteria decision making : theory and applications with recent developments.* New York: Springer Science+Business Media, 2008. ISBN 978-0-387-76812-0.

KÖKSALAN, M. Murat; WALLENIUS, Jyrki.; ZIONTS, Stanley. *Multiple criteria decision making : from early history to the 21st century.* Singapore ; Hackensack, NJ: World Scientific, 2011. ISBN 9789814335584.

Expected date of thesis defence

2022/23 SS – FEM

The Bachelor Thesis Supervisor

Ing. Robert Hlavatý, Ph.D.

Supervising department

Department of Systems Engineering

Electronic approval: 16. 11. 2022

doc. Ing. Tomáš Šubrt, Ph.D.

Head of department

Electronic approval: 24. 11. 2022

doc. Ing. Tomáš Šubrt, Ph.D.

Dean

Prague on 13. 03. 2024

Declaration

I declare that I have worked on my bachelor thesis titled "Selection of the real estate for the company" by myself and I have used only the sources mentioned at the end of the thesis. As the author of the bachelor thesis, I declare that the thesis does not break the copyrights of any person.

In Prague on ___________________________

Acknowledgment

I would like to thank Ing. Robert Hlavatý, Ph.D. for his invaluable guidance, encouragement, and unwavering support throughout the research process. Special thanks go to my family and my boyfriend, for their endless patience, understanding, and encouragement during the challenging oments of thesis writing. Their support and belief in my abilities have been a constant source of inspiration. Lastly, I would like to acknowledge Czech University of Life Sciences Prague for providing the necessary resources and environment conducive to academic growth and learning.

Selection of the real estate for company using multi-criteria decision-making methods

Abstract

This bachelor's thesis deals with the selection of real estate for a company. The company currently deals with a problem of searching for a new place for an office, because the old one does not fit the current requirements anymore.

At the beginning of the theoretical part of this thesis, the issue of the decision-making process will be outlined. The model of multiple criteria decision analysis (MCDA) will be described, and its elements will be specified. This section explains the method of determining the weights of the criteria and the method for selecting a suitable, efficient alternative using multiple criteria decision-making (MCDM).

The practical part of this thesis presents the decision-making problem and its specifics, as well as and selection of the best alternative from the options presented. Approach chosen to determine the optimal decision is TOPSIS, with the weights of individual criteria determined through Saaty's method. After performing all the calculations, the alternative with the greatest relative closeness value is selected as the best option and will be recommended to company.

Keywords: multi-criteria analysis, decision-making, weighted sum approach, TOPSIS, Saaty method, real estate.

Vícekriteriální rozhodování k výběru nemovitosti pro společnost

Souhrn

Tato bakalářská práce se zabývá výběrem nemovitosti pro podnik. Firma v současné době řeší problém hledání nového místa pro kancelář, protože ta stará již nevyhovuje současným požadavkům.

Na začátku teoretické části této práce bude nastíněna problematika rozhodovacího procesu. Bude popsán model vícekriteriální rozhodovací analýzy (MCDA) a specifikovány jeho prvky. V této části bude vysvětlen způsob stanovení vah kritérií a metoda výběru vhodné a efektivní alternativy pomocí vícekriteriálního rozhodování (MCDM).

V praktické části této práce je představen rozhodovací problém a jeho specifika, jakož i výběr nejlepší alternativy z předložených možností.

Pro určení optimálního rozhodnutí byl zvolen přístup TOPSIS, přičemž váhy jednotlivých kritérií byly stanoveny pomocí Saatyho metody. Po provedení všech výpočtů bude jako nejlepší varianta vybrána alternativa s největší hodnotou relativní blízkosti, tato varianta následně bude společnosti doporučena.

Klíčová slova: multikriteriální analýza, rozhodování, přístup váženého součtu, TOPSIS, Saatyho metoda, nemovitosti

Table of Contents

1. Introduction

Decision-making is an eternal problem for all mankind. From the very beginning of time, people have always faced the issue of choice, and each choice in one way or another affects the future of an individual or the whole world.

With the development of human civilization, the question of choice became more and more difficult, the greatest minds of mankind tried to find the answer to one question: "how to make the right choice?"

At present, the issue of decision-making (especially in the business sphere) is a matter that requires careful analysis and even expert advice.

There is no decision that can be addressed without referring to the decision-making process. Decision-making, as a mental complex process, is a problem-solving program that aims to determine a desirable result considering different aspects. Nowadays, complex decision-making problems can be solved by utilizing mathematical equations, manifold statistics, mathematics, economic theories, and computer devices that help to calculate and estimate the solutions to decision-making problems automatically. Multi-Criteria Decision Making (MCDM) or Multi-Criteria Decision Analysis (MCDA), is one of the most accurate methods of decision-making.

It finds applications in business and finance for investment decisions and risk management, in engineering for design optimization and project selection, in urban planning for infrastructure development, in healthcare for treatment selection and resource allocation, in environmental management for sustainability initiatives, in supply chain for logistics optimization, in government for policy-making, in education for curriculum design, in marketing for market segmentation, and in manufacturing for operations management. MCDM enables decision-makers to navigate complex scenarios and make well-informed decisions based on multiple criteria and objectives.

This bachelor thesis is devoted to the problem of choosing a suitable real estate for an office for company using the method of multi-criteria decision-making.

To achieve the goal, the article sets the task of studying and comparing existing methods aimed at solving multicriteria problems and then choosing one method based on the comparisons obtained.

In the practical part, the selected method will be applied to the multi-criteria real estate selection problem for company and solution to the problem by the selected method will be presented.

The main result of the work is a final optimal real estate option, as well as a discussion of the applicability of the decision-making procedure to real estate market.

The practical significance of this thesis lies in its exploration and application of selected methods within the real estate market context. By evaluating the results and discussing the practical implications of employing multi-criteria analysis methods in the real estate industry, this research contributes to a deeper understanding of its utility and effectiveness in real-world scenarios.

.

2. Objectives and Methodology

2.1 Objectives

The main objective of the thesis is to determine an optimal choice of real estate for the company's office based on criteria provided by decision-maker of the company, using multi-criteria analysis methods.

2.2 Methodology

This work is devoted to the problem of choosing a suitable real estate for an office a company using the method of multi-criteria decision-making.

To achieve the goal, the article sets the task of studying and comparing existing methods aimed at solving multicriteria problems and then choosing one method based on the comparison obtained. Selected methods will be described in details for easy implementation in practical part of the work.

In the practical part, the selected methods (Saaty's methos and TOPSIS method) will be applied to the multi-criteria real estate selection problem for company and solution to the problem by the selected method will be presented.

The main result of the work is a final optimal real estate option, as well as a discussion of the applicability of the decision-making procedure to real estate market.

The practical significance of this thesis lies in its exploration and application of selected methods within the real estate market context. By evaluating the results and discussing the practical implications of employing multi-criteria analysis methods in the real estate industry, this research contributes to a deeper understanding of its utility and effectiveness in real-world scenarios.

3. Literature review

3.1 Decision-making process

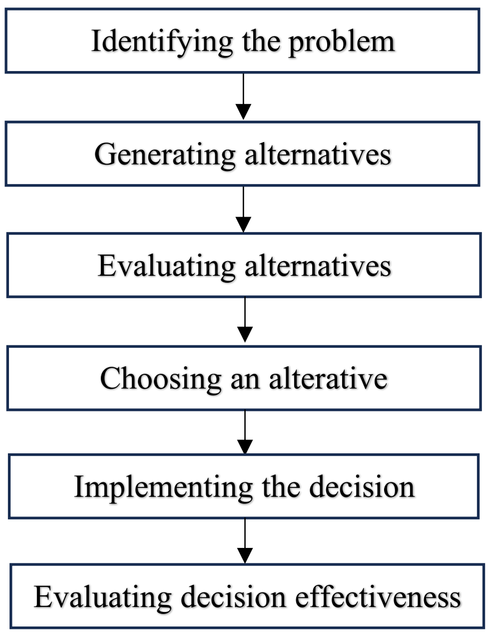
Haynes and Massie define decision-making: “Decision-Making is a process of selection from a set of alternative courses of action which is thought to fulfill the objective of the decision problem more satisfactorily than others.” (Haynes, 1990)

Simply saying, decision-making is the process of selecting one alternative from a range of possibilities in order to attain a desired result.

3.2 Steps of decision-making process

According to the rational model, the decision-making process can be broken down into six steps (Schoenfeld, 2011). (See Figure 1.)

Figure 1: six steps of decision-making process



The logical, open-minded approach to making decisions involves the following process:

1. **Identifying the problem**

Understanding the problem or strategic issues that call for decision-making must be identified and defined as the first and most crucial step in the decision-making process.

The problem must be clarified and defined in precise terms before moving on to the next step in the decision-making process.

2. **Generating alternatives**

Making decisions involves deciding between alternatives. Obtaining alternatives that might work is an important step in the decision-making process. At this stage it's better to generate as many alternatives, as possible, to make the decision-making process more effective.

3. **Evaluating alternatives**

At this stage is important to identify and analyze the advantages and disadvantages (known as qualitative factors) of each feasible alternative.

4. **Choosing an alternative**

After evaluating all alternatives decision-maker should choose the one alternative that solves the problem better than another presented alternative.

5. **Implementing the decision**

Now, when all alternatives are weighed and have chosen the best course of action, it's time to implement the decision.

6. **Evaluating decision effectiveness**

The final step is to structure in-progress reviews and a final evaluation in order to estimate progress and evaluate final results.

3.3 Multiple Criteria Decision Making (MCDM) or Multi-Criteria Decision Analysis (MCDA)

“Multi-criteria decision-making (MCDM) or Multi-Criteria Decision Analysis (MCDA) methods are mathematical models that help to take decisions in scenarios where the possible alternatives are evaluated over multiple conflicting criteria” (Ceballos, 2016)

These methods have a wide range of applications. Examples include supplier selection, technical evaluation of tenderers, service quality evaluation, and renewable energy.

According to the study of Walter Habenicht, Beate Scheubrein, and Ralph Scheubrein, there is no “ideal” alternative existing in real-life problems, so the most important task in multiple criteria decision-making is to find a “good” compromise. (Habenicht, 2002)

This method considers different qualitative and quantitative criteria that need to be fixed to find the best solution. For example, cost or price and quality of the processes are among the most common criteria in many decision-making problems (Shahsavarani, 2015). In addition, in these problems, decision-makers provide different weights to the criteria that are based on the importance of each criterion in that specific case.

Multicriteria Decision Making is a more complex way of putting available options together that is made for the purpose of arriving at and implementing decisions. It is an assistant tool that can be used to confront complex decision problems. It helps to eliminate false assumptions and provides a clearer reason for why a final decision is made (Kahraman, 2015)

3.4 History of Multiple Criteria Decision-Making

Benjamin Franklin performed one of the first research studies on multi-criteria decision-making when he released his research on the moral algebra concept. Since the 1950s, several empirical and theoretical scientists have worked on MCDM methods to investigate their mathematical modeling capability in order to give a framework that may help organize decision-making problems and generate preferences from alternatives (Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, 1980)

The next step in development was the publication made by Kuhn and Tucker when they formulated optimality conditions for nonlinear programming in 1951 (they also considered problems with multiple objectives in that work) (Kuhn, 1951)

Despite the fact that the term goal programming was first used in a book published by Charnes and Cooper in 1961, Charnes, Cooper, and Ferguson published an article in 1955 that encapsulated the essence of goal programming (Charnes, 1955)

Charnes and Cooper's findings inspired several other scientists. Bruno Contini and Stan Zionts (both of whom studied with Cooper) were early contributions, developing a multiple-criteria negotiation model that was published in 1968.

In 1976, Ralph Keeney and Howard Raiffa released an important work. This book was essential for the growth of multiattribute value theory (including utility theory) as a discipline. It became a fundamental reference and text for so many generations of decision analysis and MCDM researchers (Keeney, 1976)

In the late 1960s, Bernard Roy and his colleagues in Europe created ELECTRE, a family of Multi-Criteria Decision Analysis methodologies.

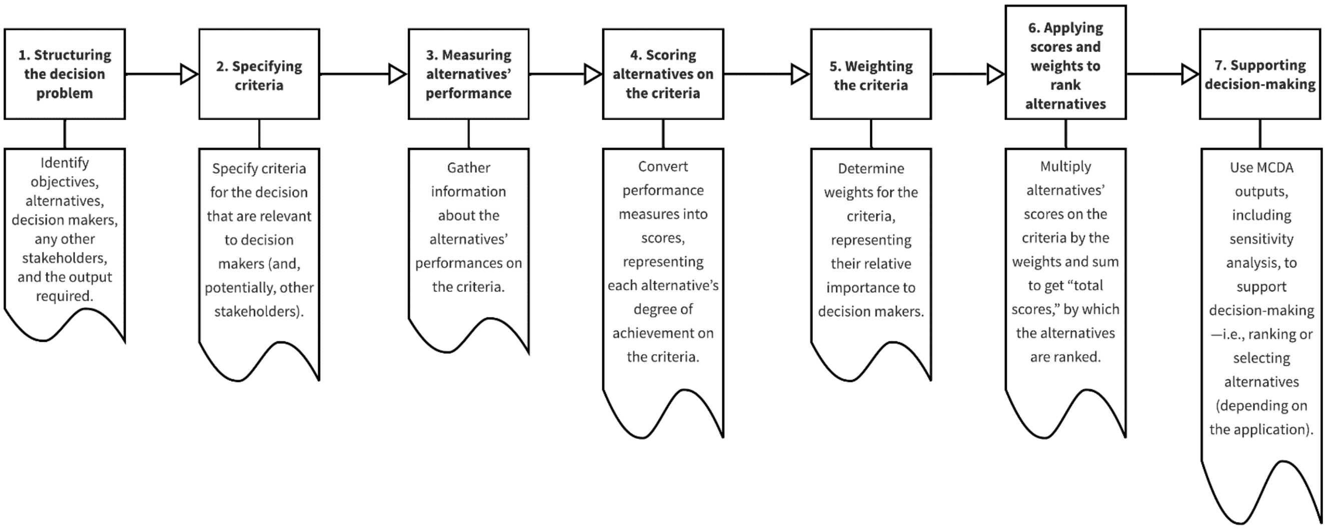
In the 1970s, Thomas Saaty pioneered the Analytic Hierarchy Process, and more recently, the Analytic Network Process. Ernest Forman and Luis Vargas are among his co-authors and collaborators. Saaty is one of MCDM's most recognized success stories, having been profiled in Fortune magazine.

3.5 Steps in the MCDA Process

The goal of the decision-maker is to be as objective as possible while making decisions using various procedures and approaches.

In order to make the MCDA process clear and understandable for the common users, Hansen and Devlin split the procedure into a detailed series of steps. (Hansen, 2019) (See Figure 2)

Figure 2: MCDA process



3.6 Comparison of existing MCDM methods

There are several methods available for solving multicriteria problems, each with its own strengths and weaknesses. The choice of method depends on the specific problem being addressed, the decision-maker's preferences and priorities, and the availability of data. (Hansen, 2019)

Some of the commonly used multicriteria decision-making methods include:

Analytic Hierarchy Process (AHP): This method involves pairwise comparisons of criteria and alternatives to determine their relative importance. AHP is useful when there are complex or interdependent criteria, and when subjective opinions are important.

Simple Additive Weighting (SAW): This method involves the addition of weighted scores for each criterion to determine the overall performance of each alternative. SAW is simple to use and is suitable for problems with a small number of criteria.

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS): This method ranks alternatives based on their similarity to the ideal solution and their distance to the negative ideal solution. TOPSIS is useful when there are multiple criteria and when the decision-maker wants to identify the best alternative based on overall performance.

ELECTRE: This method uses outranking relations to compare alternatives based on their performance on each criterion. ELECTRE is useful when there are multiple criteria and when there are conflicting preferences or trade-offs.

PROMETHEE: This method uses preference functions to compare alternatives based on their performance on each criterion. PROMETHEE is useful when there are multiple criteria and when there are complex or nonlinear relationships between criteria.

When choosing a method for real estate selection, it is important to consider the specific requirements of the problem and the decision-maker's preferences. TOPSIS is a commonly used method for real estate selection because it allows for the evaluation of multiple criteria and the identification of the best alternative based on overall performance. However, AHP and ELECTRE are also useful methods when there are complex or interdependent criteria, or when there are conflicting preferences or trade-offs. Ultimately, the choice of method depends on the specific requirements of the problem and the decision-maker's preferences.

3.7 Saaty Pairwise Comparison Method in Multicriteria Decision Making

In Multicriteria Analysis (MCA), decision-making often involves evaluating alternatives based on multiple criteria. Saaty's method, also known as the Analytic Hierarchy Process (AHP), is a widely recognized and applied technique for determining the weights of criteria in MCA. Developed by Thomas L. Saaty, AHP provides a structured framework for decision-makers to systematically assess the relative importance of criteria and prioritize alternatives based on these criteria. (Saaty, Decision Making with the Analytic Hierarchy Process., 2008)

In the Saaty method, decision-makers assign numerical values to represent their preferences in pairwise comparisons. These values are typically selected from a predefined scale, such as Saaty's scale, which ranges from 1 to 9. The assigned values reflect the relative importance or preference of one criterion or alternative over another.

Table 1: Scales for expressing preferences in the Saaty method

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

Decision-makers systematically compare each pair of criteria and alternatives based on their relative importance using a scale of preference. The results are captured in a pairwise comparison matrix (PCM), denoted as C, where C_{ij} represents the relative preference of criterion i over criterion j. (Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, 1980)

$$C = \begin{bmatrix} 1 & c_{12} & c_{13} & \cdots & c_{1n} \\ \frac{1}{c_{12}} & 1 & c_{23} & \cdots & c_{2n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \frac{1}{c_{1n}} & \frac{1}{c_{2n}} & \frac{1}{c_{3n}} & \cdots & 1 \end{bmatrix} \tag{1}$$

To ensure the reliability of pairwise comparisons, Saaty introduced the concept of consistency. The Consistency Index (CI) and Consistency Ratio (CR) are calculated to evaluate the degree of consistency in judgments. If CR exceeds a threshold (usually 0.1), adjustments are required to enhance consistency.

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

$$CR = \frac{CI}{RI} \tag{2}$$

Where *RI* is a random index value for different number of criteria developed by Saaty, these are represented in the below tables:

Table 2: The random index value RI (part 1)

n	1	2	3	4	5	6	7	8
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40

Table 3: The random index value RI (part 3)

n	9	10	11	12	13	14	15
RI	1,45	1,49	1,52	1,54	1,56	1,58	1,59

Achieving a fully consistent matrix where the Consistency Index (CI) equals 0 is extremely challenging in real-world scenarios. It's widely recognized that the CI consistency index is always non-negative, and lower CI values indicate greater consistency in comparisons, making them more credible.

Once it's determined that the matrix C is sufficiently consistent for further calculations, the next step is determining the weights of individual criteria. Various methods exist for this purpose, and one commonly used approach is the standardized geometric mean, as described by Ishizaka and Lusti. (Ishizaka, 2006)

$$b_i = \sqrt[n]{\prod_{j=1}^{n} C_{ij}} \qquad (3)$$

$$w_i = \frac{b_i}{\sum_{i=1}^{n} b_i}$$

3.8 Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and its application in real estate selection

The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision-making method that is often used in real estate selection. It is a simple and effective method that ranks alternatives based on their similarity to the ideal solution and their distance to the negative ideal solution.

The TOPSIS method is useful in real estate selection because it takes into account multiple criteria and allows for the identification of the best alternative based on overall performance. By using this method, companies can make more informed and objective decisions when selecting real estate options. (Hwang, 1981)

3.9 TOPSIS procedure

According to Šubrt: (Šubrt, 2010)

1. **Construct the Decision Matrix:**
   - Create a decision matrix X where X_{ij} represents the performance score of alternative i on criterion j.
2. **Normalize the Decision Matrix:**
   - For each criterion j, calculate the normalized score r_{ij} for alternative i using the formula:

$$r_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{m} X_{ij}^2}} \tag{4}$$

3. **Determine the Weighted Normalized Decision Matrix:**
   - Assign weights w_j to each criterion based on their relative importance.
   - Multiply each normalized score r_{ij} by the corresponding weight w_j to create a weighted normalized decision matrix:

$$V_{ij} = w_j r_{ij} \tag{5}$$

4. **Determine the Ideal and Anti-Ideal Solutions:**
   - Identify the ideal solution (positive ideal) and anti-ideal solution (negative ideal) for each criterion:
   - For maximization criteria, h_j=max(V_{ij}) and d_j=min(V_{ij}) for all i.

- For minimization criteria, h_j=min(V_{ij}) and d_j=max(V_{ij}) for all i.

5. **Calculate the Distance to the Ideal and Anti-Ideal Solutions:**

   - Calculate the Euclidean distance d_i^+ from each alternative i to the ideal solution h_j using the formula:

$$d_i^+ = \sqrt{\sum_{j=1}^{k}(v_{ij} - h_j)^2} \quad (6)$$

   - Calculate the Euclidean distance d_i^- from each alternative i to the anti-ideal solution d_j using the formula:

$$d_i^- = \sqrt{\sum_{j=1}^{k}(v_{ij} - d_j)^2} \quad (7)$$

6. **Calculate the Relative Closeness to the Ideal Solution:**

   - Calculate the relative closeness c_i of each alternative i to the ideal solution using the formula:

$$c_i = \frac{d_i^-}{d_i^+ + d_i^-} \quad (8)$$

7. **Rank the Alternatives:**

   - Rank the alternatives based on their relative closeness values c_i. The alternative with the highest c_i value is considered the most preferred.

4. Practical Part

In this practical part of the thesis, we will apply the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method to select the best real estate option for a company. We will use multi-criteria decision-making to evaluate the alternatives based on several criteria. The goal is to determine the alternative that best meets the company's needs and preferences while considering the limitations and trade-offs between the criteria.

The practical part of the thesis will consist of several steps, including the identification of criteria and alternatives, the collection and normalization of data, the determination of weights for each criterion, the calculation of the ideal and negative-ideal solutions, the determination of the relative closeness of each alternative to the ideal solution, and finally, the ranking of alternatives based on their relative closeness values.

The TOPSIS method is a widely used approach for multi-criteria decision-making and has been successfully applied to various fields, including real estate selection. By using this method, we can provide a structured and objective way of evaluating the alternatives, which can help decision-makers to make an informed choice based on their preferences and criteria.

The results of the practical part of the thesis will provide insights into the real estate options and their performance based on the selected criteria. This can help the company to make a well-informed decision about the most suitable real estate option for their needs and preferences.

Overall, the practical part of the thesis will provide a hands-on experience in applying the TOPSIS method for real estate selection and will demonstrate the usefulness and practicality of multi-criteria decision-making in the real world.

4.1 Company overview

According to company's website, the company’s specializes in the implementation of authentic team-building programs for companies throughout the Czech Republic and abroad. The company was founded in 2018 and during this time has already organized more than 300 successful events. At the moment, the company operates in two areas: online and offline team building.

4.2 Company problem

Due to the significant increase in sales volumes, the expansion of the staff, and the emergence of new programs, the company met the need for a new office. Due to the relatively high number of offers and requirements for the offered deals the company made a decision to rely on a mathematical model for selecting the optimal solution. The individual criteria of the model were determined and evaluated by the owner of the company who is competent to solve this decision-making problem.

4.3 Alternatives

After making all criteria clear, the decision maker made a list of alternatives:

4.3.1 (A_1)

Office on Jaromírova, Praha 2 – Nusle.

Price – 15000,- CZK

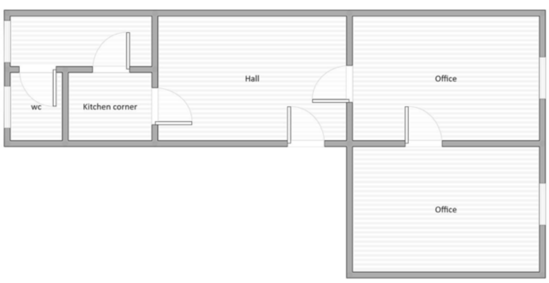
Office area – 59 square meters.

En. Label – G.

Floor – 1st floor.

Parking – 1 parking place.

Figure 3: alternative 1, office on Jaromírova



4.3.2 (A_2)

Office on Vinohradská, Praha 3 - Vinohrady

Price – 35000,- CZK

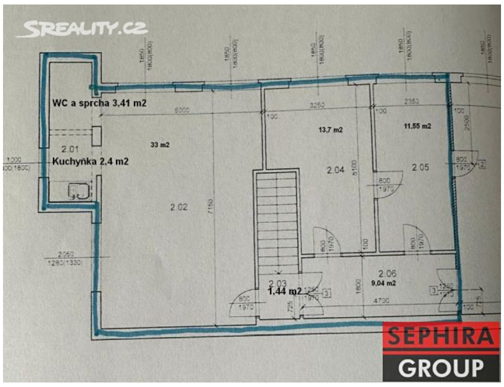
Office area – 75 square meters.

En. Label – F.

Floor – 2nd floor.

Parking – no parking place.

Figure 4: alternative 2, office on Vinohradská



4.3.3 (A_3)

Office on Břehová, Praha - Praha 1

Price – 27500,- CZK

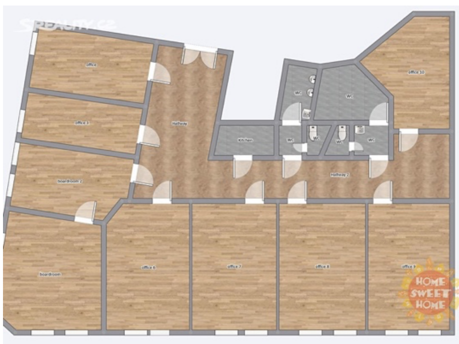
Office area – 45 square meters.

En. Label – G.

Floor – 5th floor.

Parking – no parking place.

Figure 5: alternative 3, office on Břehova



4.3.4 (A_4)

Office on Lucemburská, Praha 3 – Vinohrady

Price – 25000,- CZK

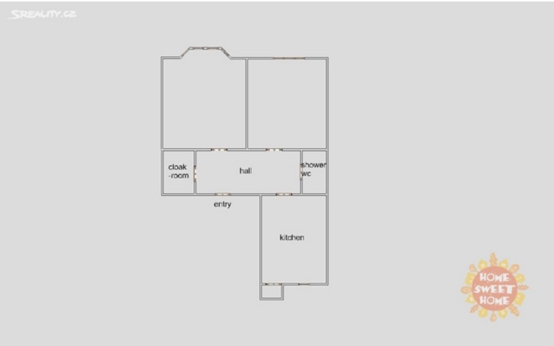
Office area – 90 square meters.

En. Label – G.

Floor – 2nd floor.

Parking – no parking place.

Figure 6: alternative 4, office on Lucemburská



4.3.5 (A_5)

Office on Křemencova, Praha 1 - Nové Město

Price – 21000,- CZK

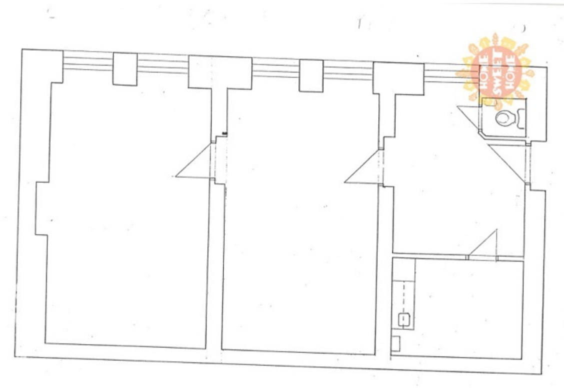
Office area – 80 square meters.

En. Label – G.

Floor – 1st floor.

Parking – no parking place.

Figure 7: alternative 5, office on Křemencova



4.3.6 (A_6)

Office on Vršovická, Praha 10 - Vršovice

Price – 26000,- CZK

Office area – 79 square meters.

En. Label – F.

Floor – 2nd floor.

Parking – 1 parking place.

Figure 8: alternative 6, office on Vršovická

4.3.7 (A_7)

Office on Ondříčkova, Praha 3 - Žižkov

Price – 50000,- CZK

Office area – 53 square meters.

En. Label – G.

Floor – 1st floor.

Parking – no parking place.

Figure 9: alternative 7, office on Ondříčkova

4.4 Criteria

Based on requirements provided by a company, decision-maker made the criteria list which will be used in the decision-making process related to selecting a real estate for future office. All criteria will be marked as (C1-C7) and wear these marks in the following tables.

4.4.1 Price (C1)

The principle of this decision-making process is to minimize the cost. The price will be presented in Czech crowns (CZK). This is a minimization criterion.

4.4.2 Square meters (C2)

Refers to the total usable floor area. Maximization criterion.

4.4.3 Floor (C3)

High floor for an office provides better views, increased natural light, and reduced noise, fostering a more productive and comfortable work environment. Also, higher floors often offer enhanced privacy, security, and prestige, making them an attractive choice for businesses seeking an optimal workspace. This is a maximization criterion.

4.4.4 2-roomed office space (C4)

The ideal office for this company consists of two rooms. One will be used for current office work, the second will be turned into a studio for online events. This is a maximization criterion.

4.4.5 Energy label (C5)

In Czech Republic we have 7 energy label, which represent energy efficiency of the property.

A - Extremely economical

B - Very economical

C - Economical

D - Less economical

E - Inefficient

F - Very wasteful

G - Extremely wasteful

This is maximization criterion.

4.4.6 Public transport (C6)

Availability of public transport within walking distance is very important when choosing an office. Since not all employees and potential customers drive a car, it should be convenient for all of them to get to the company office. This is maximization criterion.

4.4.7 Parking place in price (C7)

Having a private parking space for an office is crucial as it ensures convenience and accessibility for employees and clients. It eliminates the hassle of searching for parking, saves time, and provides a sense of security for vehicles. Moreover, it reflects professionalism and can be a deciding factor for potential clients or employees considering the office location. This will be maximization criterion.

4.5 Determining weights

Determining the weights of criteria using the Saaty method involves a systematic approach to pairwise comparisons. Named after its creator, Thomas Saaty, this method assigns numerical values to compare the relative importance of criteria against each other. Decision-makers evaluate each criterion against all others, indicating their preference through a scale of values. These comparisons are then synthesized into a comparison matrix, which undergoes further analysis to derive the priority weights for each criterion. The Saaty method is valuable in decision-making processes, particularly in situations where multiple criteria must be considered, allowing decision-makers to objectively quantify the importance of each criterion in relation to others. (Saaty, The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation, 1980)

4.6 Criteria matrix

The alternatives and their values are shown in the table below:

Table 4: criteria matrix

	Price	m2	Floor	Rooms	Energy Label	Public transport	Parking space
a1	15000	59	1	3	G	YES	1
a2	35000	75	2	3	F	YES	0
a3	27500	45	5	1	G	YES	0
a4	25000	90	2	2	G	YES	0
a5	21000	80	1	2	G	YES	0
a6	26000	79	2	3	F	YES	1
a7	50000	53	1	3	G	NO	0

To further carry out pairwise comparison and use the TOPSIS method for calculation, it is necessary to convert the qualitative assessment to quantitative values.

The letter-decribed criteria c5 will be transformed af follows: G=1 and F=10.

The word-described criteria c6 will be transformed into binary form: yes – 10, no – 1.

Table 5: criteria matrix (quantitative form)

	Price	m2	Floor	Rooms	Energy Label	Public transport	Parking space
a1	15000	59	1	3	1	10	10
a2	35000	75	2	3	10	10	1
a3	27500	45	5	1	1	10	1
a4	25000	90	2	2	1	10	1
a5	21000	80	1	2	1	10	1
a6	26000	79	2	3	10	10	10
a7	50000	53	1	3	1	1	1

4.7 Criteria weights (Saaty’s method)

Weights for the criteria were determined using Saaty's method, which derives it as a normalized geometric mean, as detailed in the theoretical section of the work. Company decision maker conducted pairwise comparisons of individual criteria by comparing them against each other and assigning numerical values ranging from 1 to 9 to the preferred criterion and the inverse values to the less preferred criterion. The results of this pairwise comparison are documented in the table below:

Table 6: Saaty's matrix (pairwise comparison)

Cij	c1	c2	c3	c4	c5	c6	c7
c1	1,00	3,00	9,00	3,00	3,00	5,00	5,00
c2	0,33	1,00	7,00	0,33	3,00	5,00	5,00
c3	0,11	0,14	1,00	0,11	0,20	0,20	0,20
c4	0,33	3,00	9,00	1,00	3,00	3,00	3,00
c5	0,33	0,33	5,00	0,33	1,00	0,33	0,33
c6	0,20	0,20	5,00	0,33	3,00	1,00	1,00
c7	0,20	0,20	5,00	0,33	3,00	1,00	1,00

Explained earlier in the theoretical part consistency ratio has resulted 0,09 which complies with the requirement $CR<0.1$, meaning that the Saaty's matrix is sufficiently consistent.

In the next step of the Saaty's method we will calculate geometric means (b_i) of the rows. Then these values will be used to deremine criteria weights (w_i) that will be used further in TOPSIS calculation. The weights are shown in the following table:

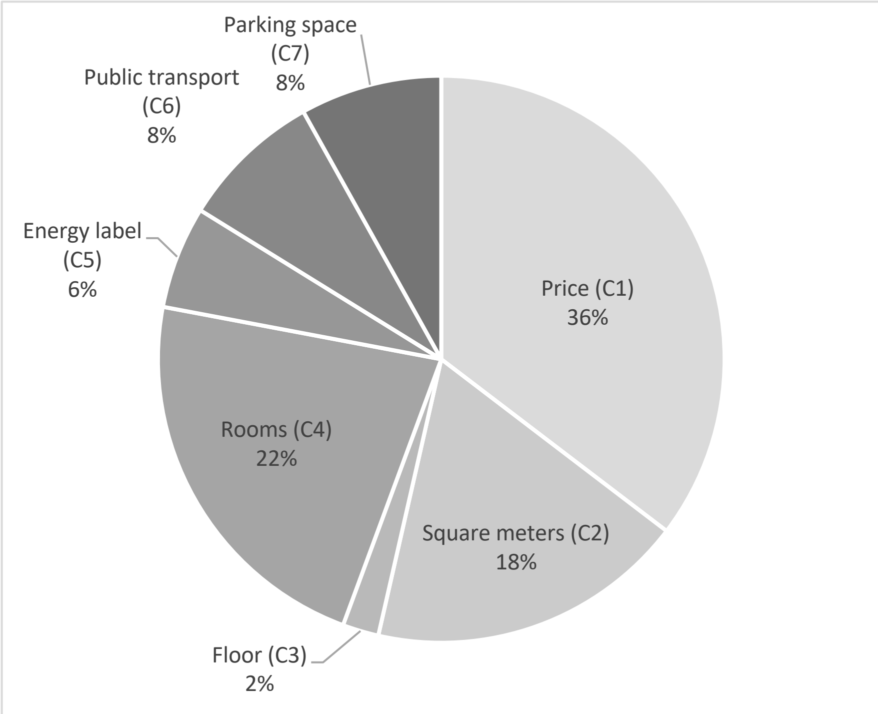
Table 7: criteria weights

	bi	wi
c1	3,471416	0,353612
c2	1,787614	0,182094
c3	0,202802	0,020658
c4	2,1918	0,223265
c5	0,574185	0,058489
c6	0,794597	0,080941
c7	0,794597	0,080941

As can be seen from the final table, criteria C_1 (Price) has obtained the highest weight (0,353612), which is followed by criteria C_4 (Rooms) with weight 0,223265 and third-top criteria C_2 (Square meters) with weight 0,182094. The lowest weight has resulted in the criterion C_3 (Floor).

The visual interpretation demonstrated below:

Figure 10: pie chart of criteria weights



4.8 TOPSIS

With the weights determined in the previous paragraph, we will perform a calculation using the TOPSIS method whose general procedure was given in the theoretical part. For this reason, the above-mentioned general formulas will not be repeated in the practical part. The solution will indicate the optimal result of the decision-making process - the best office option to choose.

Decision matrix was already presented in previous part. See Table 4.

Next step of TOPSIS procedure is to form a normalized criterial matrix $R = (r_{ij})$

Table 8: normalized criterial matrix

	Price	m2	Floor	Rooms	Energy Label	Public transport	Parking space
a1	0,186797	0,316815	0,158114	0,447214	0,069843	0,407909	0,698430
a2	0,435860	0,402731	0,316228	0,447214	0,698430	0,407909	0,069843
a3	0,342462	0,241639	0,790569	0,149071	0,069843	0,407909	0,069843
a4	0,311329	0,483278	0,316228	0,298142	0,069843	0,407909	0,069843
a5	0,261516	0,429580	0,158114	0,298142	0,069843	0,407909	0,069843
a6	0,323782	0,424210	0,316228	0,447214	0,698430	0,407909	0,698430
a7	0,622657	0,284597	0,158114	0,447214	0,069843	0,040791	0,069843

In the next step we are going to multiply all the values by the relevant criterion weights, obtained by Saaty's method. Results in the below table represent normalized weighted matrix.

Table 9: normalized weighted matrix

	Price	m2	Floor	Rooms	Energy Label	Public transport	Parking space
a1	0,066054	0,057690	0,003266	0,099847	0,004085	0,033016	0,056532
a2	0,154125	0,073335	0,006533	0,099847	0,040850	0,033016	0,005653
a3	0,121099	0,044001	0,016332	0,033282	0,004085	0,033016	0,005653
a4	0,110090	0,088002	0,006533	0,066565	0,004085	0,033016	0,005653
a5	0,092475	0,078224	0,003266	0,066565	0,004085	0,033016	0,005653
a6	0,114493	0,077246	0,006533	0,099847	0,040850	0,033016	0,056532
a7	0,220179	0,051823	0,003266	0,099847	0,004085	0,003302	0,005653

Next step of TOPSIS procedure is to determine the ideal (h_j) and anti-ideal (d_j) solutions.

Table 10: ideal and anti-ideal solutions

	c1	c2	c3	c4	c5	c6	c7
h (ideal)	0,066054	0,088002	0,016332	0,099847	0,04085	0,033016	0,056532
d (anti-ideal)	0,220179	0,044001	0,003266	0,033282	0,004085	0,003302	0,005653

Fifth step consists of calculating the distance of alternatives to the ideal and anti-ideal solutions. Result of the aplying needed formulas you can see in the table below:

Table 11: distance of alternatives to the ideal and anti-ideal solutions

	d+	d-
a1	0,04940843	0,17845
a2	0,10322972	0,109086
a3	0,11548677	0,104262
a4	0,08416174	0,126717
a5	0,07753986	0,139536
a6	0,05057753	0,146764
a7	0,17337104	0,067023

Then we need to calculate indicator C_i - the relative closeness of each alternative to the ideal solution.

Table 12: indicator Ci for all alternatives

	Ci
a1	0,78316205
a2	0,51379183
a3	0,47446101
a4	0,60089957
a5	0,64279775
a6	0,74370527
a7	0,27880461

In final step we need to arrenge all alternatives in descending order according to the c_i indicator to get an optimal solution of the problem.

Table 13: indicator Ci for all alternatives in descending order

	Ci
a1	0,78316205
a6	0,74370527
a5	0,64279775
a4	0,60089957
a2	0,51379183
a3	0,47446101
a7	0,27880461

5. Results and discussion

Based on the arrangement of alternatives provided above (see Table 13), the TOPSIS method resulted that office on Jaromírova, Praha 2 – Nusle (A1) is the most efficient alternative, with a value of 0.78, which indicates that A1 exhibits the biggest distance from the negative-ideal alternative. This can also be explained by the fact that this particular alternative maximally fulfills all the company's wishes for its future office: low rental cost, even more than 2 rooms, availability of public transport and parking. Meanwhile, office on Vršovická, Praha 10 – Vršovice (A6) can be also considered as second-best option, because of value resulted 0,74, which is close enough to the first alternative. Nevertheless, the alternative A1 will be recommended to the company as a solution, since it has almost the best parameters among the other proposed options.

On my opinion, using of Saaty's Analytic Hierarchy Process (AHP) and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method in the sphere of real estate selection presents a robust framework for decision-making, offering distinct advantages and considerations.

The Saaty method has truly been a revelation for me, as it provides a structured approach to evaluating critical decision criteria. Through this method, I have gained a deeper understanding of the significance of each criterion and learned to make decisions based on a balanced assessment of facts rather than solely relying on emotions. This systematic approach has empowered me to make well-informed decisions, ensuring that considerations are thoroughly evaluated and weighed before reaching a conclusion.

In the context of real estate selection, Saaty's method enables decision-makers to prioritize criteria such as location, price, size, etc, reflecting the diverse considerations related to property investment of any kind. By assigning numerical weights to each criterion based on their perceived importance, Saaty's method assists decision-makers in reaching informed and transparent decisions.

Continuing calculations, TOPSIS method provides a quantitative approach of ranking alternatives based on their proximity to an ideal solution. In real estate selection, TOPSIS gives decision-makers the possibility to objectively view the performance of various alternatives against predetermined criteria, considering factors such as location, price, etc. By calculating the distance of each alternative from the ideal solution and the negative-ideal solution, TOPSIS offers a comprehensive assessment of all best qualities of each property, facilitating the identification of the most desirable option.

However, it is essential to acknowledge certain limitations associated with the application of Saaty's method and TOPSIS in real estate selection. These methods mostly rely on the accuracy of input data and the subjective judgments of decision-makers, which may bring biases and uncertainties into the decision-making process. Additionally, the complexity of real estate markets and the dynamic nature of property values may create issues for the accurate modelling of criteria and alternatives. As such, decision-makers must exercise caution and critical judgment when applying AHP and TOPSIS in real estate decision-making, supplementing quantitative analysis with qualitative insights and market expertise.

6. Conclusion

In accordance with the tasks set, this study explores a multi-criteria analysis of alternatives, detailing the Saaty's and TOPSIS methods step by step. The practical part focuses on a specific example, considering insights from the theoretical part.

The thesis aims to identify the optimal office to rent for the company. To achieve this, the decision maker established 7 criteria, and 7 alternatives were filtered accordingly. Criteria weights were determined using the Saaty method, followed by the application of the TOPSIS procedure to calculate the best alternative.

After calculations explained in theoretical ad practical parts of the thesis, the office on Jaromírova, Praha 2 – Nusle (A1) emerged as the recommended choice, based on its highest indicator value representing its distance from the negative-ideal alternative.

As a conclusion, we can agree, that integration of Saaty's and TOPSIS methods in the real estate selection process offers a systematic and structured approach to decision-making, enabling decision-makers to prioritize criteria, evaluate alternatives, and reach informed choices. While these methods provide valuable tools for rational decision-making, their successful application requires careful consideration of input data, critical judgment, and market expertise. By using the strengths of the presented methods, decision-makers can navigate the complexities of real estate investment and optimize outcomes in an increasingly competitive market environment.

7. References

Saaty, T. L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation.* New York: McGraw-Hill.

Saaty, T. L. (2008). *Decision Making with the Analytic Hierarchy Process.* International Journal of Services Sciences, 1(1), 83-98.

Saaty, T. L. (1996). *Decision Making with Dependence and Feedback: The Analytic Network Process.* Pittsburgh: RWS Publications.

Schoenfeld, A. H. (2011). *Decision Making: A Theory of Goal-Oriented Decision Making and Its Educational Applications. .*

Ceballos, B. L. (2016). *A comparative analysis of multi-criteria decision-making methods.*

Habenicht, W. S. (2002). *Multiple-criteria Decision Making. Optimization and Operations Research. .*

Shahsavarani, A. M. (2015). *The Bases, Principles, and Methods of Decision-Making: A Review of Literature. .* International Journal of Management Research.

Kahraman, C. O. (2015). *Fuzzy Multicriteria Decision-Making: A Literature Review.* International Journal of Computational Intelligence Systems.

Kuhn, H. W. (1951). *Nonlinear programming. In J. Neyman (Ed.), Proceedings of the Second Berkeley Symposium on Mathematical Statistics and Probability* . University of California Press.

Charnes, A. C. (1955). *Optimal estimation of executive compensation by linear programming. Management Science. .*

Keeney, R. L. (1976). *Decisions with multiple objectives: Preferences and value tradeoffs.* New York: Wiley.

Hansen, P. (2019). *Multi-Criteria Decision Analysis (MCDA) in Healthcare Decision-Making. Health Economics.*

Tzeng, G. H. (2011). *Multiple attribute decision making: methods and applications. .* CRC Press.

Lamata, M. T. (2002). *A method for improving the consistency of judgments.*

Ishizaka, A. (2006). *How to derive priorities in AHP: A comparative study.* Central European Journal of Operations Research.

Hwang, C. L. (1981). *Multiple Attribute Decision Making Methods and Applications: A State of the Art Survey.* New York: Springer.

Šubrt, T. (2010). *Ekonomicko-matematické metody.* .

Haynes, S. N. (1990). *Decision making: A psychological perspective.* New York.

8. Table of figures and tables