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BSc in Electrical and Computer Engineering

# DEVELOPMENT OF A PREDICTIVE DECISION SUPPORT SYSTEM FOR GROUP DECISION PROCESSES

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*À minha família e a todos os que me acompanharam  
nesta jornada.*



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## **ABSTRACT**

This thesis addresses the development of a decision support system for facilitating decision-making processes in a multi-person environment. The problem lies in the complexity of decision making when involving multiple stakeholders with diverse perspectives and priorities and the increase in the number of criteria and alternatives, demanding a considerable amount of time and effort for conducting pairwise comparisons. This challenge makes it crucial to develop a tool that can aid in evaluating and prioritizing alternatives based on criteria efficiently. The proposed approach intends to leverage the analytic hierarchy process (AHP), a well-established decision-making method, to assist users in the evaluation and prioritization of alternatives in order to reach the goal of certain challenge. Additionally, the thesis explores the integration of predictive capabilities using linear regression to enhance decision-making predictions. The significance of this work lies in providing a user-friendly web application that enables collaborative decision making, incorporating both the analytical hierarchy process method and predictive modeling. The application aids users in making informed decisions based on historical data and anticipates future decision patterns. The implications of this solution are improved decision outcomes, time savings, and the ability to anticipate future decision patterns due to decision simulations made possible by the predictive analysis of the users pairwise comparisons.

**Keywords:** Decision-Making, Analytical Hierarchy Process, Decision Support System, Web Application



## RESUMO

Esta tese aborda o desenvolvimento de um sistema de apoio à decisão para facilitar os processos de tomada de decisão num ambiente multi-pessoal. O problema reside na complexidade da tomada de decisão quando este envolve múltiplos intervenientes com perspetivas e prioridades diversas, bem como no aumento do número de critérios e alternativas, exigindo uma quantidade considerável de tempo e esforço para realizar comparações par a par. Este desafio torna crucial o desenvolvimento de uma ferramenta que possa auxiliar na avaliação e priorização de alternativas com base em critérios de forma eficiente. A abordagem proposta pretende utilizar o processo hierárquico analítico (AHP), um método de tomada de decisão bem estabelecido, para auxiliar os utilizadores na avaliação e priorização de alternativas, de modo a ser atingido o objetivo para o problema proposto. Além disso, a tese explora a integração de capacidades preditivas usando regressão linear para melhorar as previsões de tomada de decisão. A importância deste trabalho reside em fornecer uma aplicação web amigável ao utilizador que permita a tomada de decisões colaborativas, incorporando tanto o método de processo de hierarquia analítica quanto a modelagem preditiva. A aplicação auxilia os utilizadores a tomar decisões informadas com base em dados históricos e antecipa padrões futuros de decisão. As implicações desta solução incluem resultados de decisões aprimorados, poupança de tempo e a capacidade de antecipar padrões futuros de decisão devido às simulações de decisão possibilitadas pela análise preditiva das comparações par a par feitas pelos utilizadores.

**Palavras chave:** Tomada de Decisão, Processo Hierárquico Analítico, Sistema de Suporte à Decisão, Aplicação Web



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## ACRONYMS

<b>AHP</b>	Analytic Hierarchy Process 2, 3, 1 , 13, 15, 36, 55
<b>ACID</b>	Atomicity, Consistency, Isolation, Durability 33
<b>API</b>	Application Programming Interface 32, 33, 40
<b>CPO</b>	Chief Product Officer 46, 48
<b>CRUD</b>	Create, Read, Update, Delete 40
<b>DSS</b>	Decision Support System 17, 18, 19
<b>HTTP</b>	Hypertext Transfer Protocol 32, 40
<b>MADM</b>	Multi-Attribute Decision Making 12
<b>MCDM</b>	Multi-Criteria Decision Making 12
<b>MODM</b>	Multi-Objective Decision Making 12
<b>NPM</b>	Node Package Manager 33
<b>RDBMS</b>	Relational Database Management System 33, 41
<b>REST</b>	Representational State Transfer 40
<b>SQL</b>	Structured Query Language 41
<b>UI</b>	User Interface 31, 32, 33, 41
<b>UML</b>	Unified Modeling Language 29
<b>URI</b>	Uniform Resource Identifier 40
<b>URL</b>	Uniform Resource Locator 40

# INTRODUCTION

## 1.1 Context

In today's dynamic and interconnected world, decision making plays a crucial role in various domains such as business, healthcare, public policy, and many others. The context of this thesis is rooted in the recognition of the evolving landscape of decision-making. The dynamics of decision scenarios today extend far beyond simple choices; they often encompass multifaceted considerations involving multiple stakeholders, diverse criteria, multiple alternatives, and a deluge of data. These decisions often require evaluating alternatives based on numerous factors, and the outcomes can have significant consequences. Therefore, there is a need for effective decision support systems that can facilitate decision-making processes in such multi-person and multi-criteria environments.

As our world becomes increasingly interconnected, the consequences of decisions ripple far and wide, amplifying the importance of informed, data-driven, and efficient decision-making. In this context, the research seeks to address the pressing need for advanced decision support systems capable of navigating the intricacies of contemporary decision-making challenges.

## 1.2 Motivation

The motivation behind this research stems from the inherent complexities involved in decision making and the commitment to enhancing the quality and efficiency of these processes across diverse domains. Multi-person decision making introduces the challenge of reconciling different perspectives, preferences, and priorities. Traditional methods, while valuable in their own right, can be time-consuming, subjective, and susceptible to biases. In complex decision scenarios involving strategic business choices, public policy formulations, or healthcare resource allocation, the intricacies are further compounded. Individual decision makers bring their unique perspective into the process, influencing their decision-making styles and preferences. Understanding the impact of the different stakeholders' views on decision-making outcomes can provide valuable insights into how decisions are made and improve the design of decision support systems. This thesis intends to bridge the gap between traditional decision-making methods and the demands of the current data-driven and interconnected world by

developing a decision support system that not only streamlines the decision process but also promotes objectivity, transparency, and adaptability by having the capacity of being personalized and tailored to individual decision makers, leading to more effective and consistent decision making.

### 1.3 Objective

The primary objective of the developed platform is to address the shortcomings of existing decision-making tools and provide a versatile, user-friendly, and efficient platform for multi-person decision-making using the [Analytical Hierarchy Process \(AHP\)](#) method. Its unique features, such as participant behavior prediction and automated simulations, seek to enhance decision quality and streamline the decision-making process across diverse domains. The application aims to achieve the following specific goals:

- The application provides a practical and adaptable tool for implementing [AHP](#) in various decision contexts. It allows administrators to define and customize decision-making contexts by adding participants, criteria, and alternatives. This flexibility ensures that the tool can be used in various domains, including business, academia, healthcare, and more.
- The application enables users to measure alternatives in a quantifiable way, either by using a scale or a specific unit of measurement, which ensures that the decision-making process is based on objective and measurable data.
- The system employs a predictive model, to anticipate how participants would perform pairwise comparisons between alternatives based on their previous decision-making history. This prediction is based on a participant's historical data of quantifiable alternatives and their corresponding pairwise comparisons.
- The application offers a simulation feature where the administrator can run decision-making processes without active participation from all participants. Instead, the simulation utilizes the predicted values of pairwise comparisons generated from the historical data. This automation streamlines the decision-making process, especially in scenarios where participants are unavailable, or time is a critical factor.
- The application is designed with a user-friendly interface to ensure that both administrators and participants can easily navigate and interact with the platform. This includes straightforward data input and result visualization.

## **1.4 Document Structure**

### **Chapter 1: Introduction**

This chapter provides an overview of the research context, presents the motivation behind the study, outlines the research objective, and provides a high-level overview of the document structure, guiding the reader through the subsequent chapters.

### **Chapter 2: Literature Review**

The literature review explores the existing research and theories related to decision making and the decision-making process, focusing on group decision making and multi-criteria decision-making environments. Furthermore, the [AHP](#) method is presented in a detailed way and finally the last section of this chapter focuses on the decision support systems. This chapter establishes the theoretical foundation, highlights the gaps in the current knowledge, and sets the stage for the proposed research.

### **Chapter 3: System Development**

This chapter describes the research methodology employed in this study. It discusses the design and development process of the application, outlining the key features and functionalities. Additionally, this chapter presents the implementation details of the web application, including the integration of the AHP methodology and the predictive analysis.

### **Chapter 4: Case Study**

In this chapter, one example of a case study is presented. The goal of this case study is to explain in a more tangible and practical way how the developed application is an asset in an institutional decision-making environment. The focus is on three different scenarios in which the application support is fundamental.

### **Chapter 5: System Validating & Testing**

The System Validating & Testing chapter is where there is presented the tests that were conducted in order to verify and demonstrate that the application meets the requirements defined in the beginning of the work.

### **Chapter 6: Conclusion**

The concluding chapter summarizes the research findings, reiterates the contributions made by this work, and discusses the practical implications of the developed platform. Finally, some improvements to the developed application are proposed, concluding the thesis.





## LITERATURE REVIEW

This chapter provides a comprehensive review of the literature on decision-making processes, with a particular focus on the Analytical Hierarchy Process methodology. Additionally, it examines the evolution of decision support systems and their role in facilitating complex decision-making scenarios. The synthesis of these topics is fundamental for understanding the context of the research presented in thesis.

### 2.1 Decision Making

Decision making is a fundamental cognitive process that individuals and organizations engage in daily. Decision-making is the process of evaluating and selecting one course of action from among various alternatives that are offered [1][10]. "Choosing one alternative from among several options" is how decision-making is defined [11]. Decision making occurs across various domains, including business, healthcare, public policy, and personal life.

The Decision maker employs a strategy to get results in a predetermined circumstance in order to accomplish specific goals. There are six main factors that should be considered while making a decision [12]. Those are the following.

1. The goals: The decision-maker's intended outcomes from their course of action.
2. The decision-maker: The individual or entity responsible for making choices or determinations among a range of alternatives.
3. Preferences: The criteria by which a decision is made.
4. The strategy: The systematic plan or approach that the decision makers develop and puts into practice to make decisions effectively and achieve specific goals considering the available resources.
5. The situation: The specific circumstances and conditions that surround a decision-making environment. It includes everything from the setting in which a decision is made to the various internal and external influences that can affect the decision-making process.

6. The result: It represents what has been achieved as a direct or indirect outcome of the choices made during the decision-making process.

Knowing how decisions are made can be beneficial to understand how people behave, how organizations function, and how to ease decision-making in the real world. In order to establish a shared understanding in this context to gain a deeper insight into decision-making practices, it is crucial to understand how decision-makers think and act.

Since decision-making is an integral part of our daily lives, larger decisions, especially those related to finances, health, and life choices, hold the potential for significant consequences, and making the wrong choice can be devastating for individuals. Moreover, decision-making is not confined to personal spheres. It is equally crucial in the business world. The implications of poor decision-making can have far-reaching effects on businesses, leading to detrimental outcomes. Research even suggests that up to half of the decisions made within organizations result in unfavorable consequences [2].

It has been demonstrated that individuals struggle to fully grasp the necessary information for making rational decisions in intricate situations, even when they have access to all pertinent data [7]. Consequently, there is a requirement for a method to assist in the decision-making process [3][4].

### 2.1.1 Decision-Making Process

While a considerable portion of each person's everyday decisions is based on instinct and past encounters, relying solely on intuition falls short when it comes to more complex and pivotal decisions. If all decisions were guided solely by intuition, it would imply that every piece of information is equally vital and beneficial, suggesting that more information is always better. However, this perspective is incorrect. Often, an overload of information leads to unnecessary data, causing disruptions in the decision-making process.

The decision-making process typically involves several stages, including problem identification, information gathering, alternative generation, evaluation, and selection. Decision makers assess available options, consider relevant criteria, and weigh trade-offs before arriving at a final decision. This process can be complex, particularly in multi-person and multi-criteria environments where different perspectives and preferences need to be considered.

Herbert Simon, a prominent figure in decision-making and cognitive psychology, introduced a model of decision-making that views it as an information processing activity aimed at achieving desired outcomes. Simon's decision-making model contains four stages [7]. These stages are the following.

- **Intelligence:** In this first stage, the decision makers gather information and data related to the decision they need to make. This step involves identifying the problem or opportunity that requires a decision and collecting relevant facts, figures, and insights. The goal is to obtain a broad understanding of the situation and the available options. Simon emphasized the importance of information gathering in making rational decisions.

- **Design:** Once decision makers have gathered sufficient information, they move on to the design stage. Here, they generate potential courses of action based on the data they have collected. This stage is characterized by creative thinking and problem-solving. Decision makers may develop multiple alternatives, assess their feasibility, and consider the potential outcomes of each option. The aim is to create a set of well-thought and efficient alternatives.
- **Selection:** In the selection stage, decision makers evaluate the generated alternatives and choose the one that appears to be the most suitable based on both the goals and the criteria. This process consists of evaluating the advantages and disadvantages of each alternative, taking into consideration the potential benefits and risks, and applying decision criteria that are aligned with the objectives of the decision maker. The outcome of this stage is the selection of the preferred alternative.
- **Implementation and Review:** After making the decision, the chosen alternative is put into action in the implementation stage. This step involves executing the plan, allocating resources, and carrying out the chosen course of action. It's important to monitor the implementation process and assess whether it is proceeding as expected. The review component of this stage involves evaluating the outcomes of the decision to determine whether the desired goals and objectives have been achieved. If necessary, adjustments can be made based on the feedback and results.

This model highlights the iterative nature of decision-making, as decision makers may need to revisit earlier stages if added information becomes available or if the chosen course of action is not yielding the desired results. It also emphasizes the importance of rationality and systematic thinking throughout the whole process. The primary aim lays on arriving at an altogether structured problem. This means that all conceivable alternative decisions are explored and evaluated before making a choice. Until this point, the problem is considered either semi-structured or unstructured [9].

## 2.1.2 Rational Decision-Making Process

Rational decision-making consists of an approach that emphasizes the importance of the procedure for making a choice rather than the alternative chosen. Rationality can be defined as the harmony of choice and value [13]. Considering this, the rational model is appropriate to be applicable in high-level decisions with a more significant nature. Quoting Emma Jeanes in [16], rational decision-making is "The process for making logical, well-reasoned decisions. It is an ordered decision-making process that requires the detailed definition of a problem, the generation and evaluation of all alternatives, the selection of an alternative based on objective assessment criteria, solution implementation, and the monitoring and evaluation of results". Before making a choice, a decision maker often follows a set of analytical procedures to consider pertinent facts, observations, and potential outcomes.

Rational choice is the framework for a well-understood and well-modeled social and economic system [14]. The fundamental concept of rational choice is that cumulative social behavior is the result

from the individual choices made by everyone involved in the decision [14][15]. Thus, rational choice theory concentrates on the individual factors that influence individual choices. Rational agents must consider available information, the likelihood of events and the possible costs and benefits in order to determine their preferences and to act in a rational manner by selecting the most appropriate self-selected course of action.

According to rational choice theory, a rational agent has preferences among the available alternatives and can indicate which option he prefers. These preferences should also be complete, which means that the individual can always state which of the two alternatives they prefer or that neither of them is preferable, and also transitive, so if option 1 is favored over option 2, and option 2 is favored over option 3, then option 1 is automatically favored over option 3 [14].

The rational decision-making model is a systematic approach involving multiple steps to select the best alternative that aligns with the preferences of an individual or a group, in case of a collective decision. The model serves as a guide for individuals and organizations to make informed and sound decisions by following a logical and methodical process aimed at arriving at the most suitable choice. Figure 1 shows the model, which is a logical sequence of activities.



Figure 1. Rational Decision-Making Model

Before alternatives are generated, the problem must be identified, and so on. This process is based on specific assumptions and characteristics, being one, the fact that the decision makers have a clear and unambiguous comprehension of the nature of the problem and their goals concerning the initial challenge. Another assumption is that the decision maker has the cognitive ability to locate and collect relevant information and facts that contribute to the final decision-making process. These facts and information are based on criteria that are relevant to the decision maker or the situation. The

individual has the capacity to generate the time and resources necessary for rational decision-making to reach a successful and practical solution [17]. According to the rational model, the decision-making process can be broken down into seven steps:

- **Identifying the Problem:** This initial step involves recognizing and clearly defining the problem or decision that requires attention. It is crucial to have a comprehensive understanding of the situation, its context, and the underlying factors contributing to the problem. Effective problem identification sets the foundation for the entire decision-making process, ensuring that the right issues are addressed.
- **Setting Objectives:** Once the problem is identified, the decision-maker establishes specific and measurable objectives to guide the decision-making process. These objectives serve as the criteria against which potential alternatives will be evaluated. Well-defined objectives help keep the decision-making process focused and aligned with the desired outcomes.
- **Generating Alternatives:** In this phase, decision-makers brainstorm and create a wide range of alternatives or potential solutions to the problem. Encouraging creativity and openness to different ideas is essential at this stage to explore diverse options. The more alternatives generated, the higher the likelihood of identifying innovative and effective solutions.
- **Evaluating Alternatives:** After generating a list of alternatives, the decision-maker evaluates each one against the established objectives and criteria. This step involves a thorough analysis of the pros and cons of each alternative, considering potential risks and benefits. Decision-makers may use various tools, such as cost-benefit analysis, risk assessment, and scenario planning, to support during the evaluation process.
- **Making the Decision:** In this crucial step, the decision-maker or the group selects the most suitable alternative considering the conducted evaluation in the last step. The final decision is chosen considering the alignment with objectives, the feasibility of implementation, and the potential consequences. It is important to follow the defined constraints while making the decision and to be confident in its potential to achieve the desired outcomes.
- **Implementing the Decision:** Once the decision is made, the focus shifts to implementing the chosen alternative. This phase requires careful planning, resource allocation, and coordination to execute the decision effectively. Clear communication and delegation of responsibilities are essential to ensure a smooth implementation process.
- **Monitoring and Evaluating:** After the decision is implemented, the decision-maker continuously monitors the outcomes and evaluates the effectiveness of the chosen alternative. This step involves gathering relevant data and feedback to determine whether the decision has produced the desired results. If the outcomes are not as expected, the decision-maker may need to reevaluate the chosen alternative or consider adjustments to improve future decision-making.

### 2.1.3 Group Decision Making

By now, a substantial body of literature has emerged that illustrates the concept known as the "Wisdom of Crowds," [18]. This theory highlights the notable advantage that groups generally possess over individuals [19][20]. In many domains of tasks, the level of performance of a randomly chosen person establishes a lower boundary compared to the performance of a group. In most of these domains, groups consistently surpass this threshold [21][22]. Groups, in contrast to individuals working independently, exhibit an enhanced ability to arrive at accurate solutions to problems [23]. They also excel in making more precise hiring decisions and achieve better negotiation outcomes [24][25]. Additionally, groups are more adept at producing accurate forecasts [28] and generating innovative ideas [29]. Moreover, they tend to score higher on academic tests [26] and recall information more reliably [27]. Consequently, decisions made by groups often yield superior outcomes across various criteria.

Several scholars have claimed that the roots of collective decision-making can be traced back to the evolutionary adaptations inherent in human societies [30]. Some ancestral communities, apart from their protective function against external threats, also demonstrated an aptitude for enhancing the availability of resources due to the collaborative efforts and refining decision-making. Simulations were conducted in order to delve into the decision-making mechanisms employed by hunter-gatherer tribes when it came to selecting the appropriate locations for hunting [31]. The findings underscore the remarkable effectiveness of a simple majority, where the location with the most substantial support among tribal hunters was the chosen path. This approach consistently outperformed the best-member rules, illustrating that group decisions often outshine those of even the most accurate tribal member.

Nevertheless, it is important to note that the supremacy of groups is not an absolute rule [33] [34]. In numerous instances, decisions made by groups have led to catastrophic decisions with dire effects, such as the Space Shuttle Challenger explosion or the Bay of Pigs invasion [32].

Until recently, the theories explaining the efficacy of group decisions differed from those explaining their shortcomings. Yet, recent efforts aimed at uncovering the fundamental concepts of group decision-making processes reveal that both successful and unsuccessful group decisions may originate from the same underlying processes [19][35]. In essence, the basic processes that govern group decision-making often yield favorable outcomes. However, within specific decision environments, these processes may amplify possible existing personal biases, resulting in decisions that tend to be more inaccurate compared to those of randomly chosen individuals.

The execution of group decisions can take diverse forms, primarily characterized by two pivotal dimensions which are the extent of interaction between the group, and the implemented method to reach the final goal. For instance, in certain situations, a company's CEO may solicit individual input from a select group of workers to inform decision-making. In such scenarios, the collective members may remain oblivious to one another's contributions, and the ultimate decision may not necessarily reflect their shared preferences. Conversely, in governmental elections, citizens cast their votes for their preferred candidate, often with limited information shared between election voters, yet the final outcome is derived from the collective pick from each of these voters. On the opposite side of the spectrum, executive

boards might engage in extensive discussions and information exchange to establish a choice where the consensus is reached.

Research examining group decision-making serves a dual purpose: it provides both guidance on how groups should proceed in a decision-making process, and insight into how these decision processes are actually done by the group. These two research strands enhance the understanding of group decision processes and their overall effectiveness. Conventional ideas about group decision-making often involve individuals engaging in discussions to get to a consensus. However, many real-world group decisions do not follow this pattern. Instead, they frequently involve consolidating members' preferences through a single member or an external entity, which then becomes the group's stance. In larger organizations where it can be impractical or infeasible to get all members together in the same room, decisions are often made through methods like elections or surveys. These systems are typically justified on the grounds of fairness as well as equal representation and existing research suggests that such systems can yield accurate judgements [36]. This phenomenon aligns with the concept of Surowiecki's "wisdom of crowds" and is still consistently validated across various problem domains [36].

Larrick and Soll [20] provided further insight into the superiority of simple averages over individual judgments, employing a concept called "bracketing." By considering that the judgments made by group members are independent, these individuals produce different estimates, which include a certain degree of overestimating and underestimating the "true score". As a result, these estimates effectively "bracket" the true score. Mathematically, it has been consistently demonstrated that the average of these estimates is more accurate than relying on any single individual judgment. This holds true even when the true score is situated closer to one end of the distribution, although the margin of improvement may be reduced in such cases. Moreover, it was found that even when the true score does not fall within the bracket of the estimates, the group average still performs at least as well as the typical individual judgment [20].

While the common practice involves using the simple average as the primary method for aggregating data in group decision-making, there are alternative approaches that have gained attention. Some scholars propose the use of medians as a practical, if not preferable, substitute for means [38]. In many situations, means and medians closely resemble each other, particularly when dealing with large groups. However, in cases involving smaller groups, medians demonstrate an advantage by being less influenced by extreme estimates from individual members, thereby providing a best representation of the group's main tendency. Additionally, when decision scenarios involve discrete alternatives, aggregation systems frequently resort to the mode, such as employing majority or plurality rules, to determine the group's collective response. Substantial evidence suggests that majority/plurality rules perform admirably across various decision contexts, often surpassing the performance of random individual judgments as a baseline [39].

#### **2.1.4 Multi-Criteria Decision Making**

Solving complex decision-making challenges involves employing mathematical equations and computational tools to automatically calculate and estimate solutions for such problems.

**Multi-Criteria Decision Making (MCDM)** represents a groundbreaking approach in the realm of decision-making [40] [41]. The inception of multi-criteria decision-making dates back to Benjamin Franklin's pioneering work on the concept of moral algebra. Since the 1950s, both empirical and theoretical scientists have dedicated their efforts to exploring the mathematical modeling capabilities of **MCDM** methods. Their aim has been to create a framework that structures problems and derives choices from the available alternatives.

**MCDM** encompasses diverse methodologies, each distinguished by various aspects, which will be delved into in subsequent sections [42]. This methodology takes into account various qualitative and quantitative criteria essential for identifying the optimal solution. For instance, cost or pricing and process quality frequently constitute pivotal factors in numerous decision-making scenarios [43]. In these instances, expert panels assign varying weights to criteria based on their significance within the specific context.

Over the past few decades, several authors have introduced or enhanced various **MCDM** methods. These methods differ in terms of algorithm complexity, criteria weighting techniques, preferences evaluation, criteria representation, the handling of uncertain data, and data aggregation methods [44].

**MCDM** plays a role in assisting decision-making rather than making the actual decisions. In simpler terms, **MCDM** does not dictate how decisions must be made, instead, it guides us in establishing logical and rational rankings for decisions [45]. **MCDM** methods can be categorized into two primary groups due to variations in the problem contexts [46].

The first category is the **Multi-Attribute Decision Making (MADM)**, which is employed when dealing with challenges that inherently possess a defined goal and a distinct decision space, characterized by a quantifiable number of alternatives and attributes [42]. On the other hand, the second category is the **Multi-Objective Decision making (MODM)**, which is applied in scenarios where decision problems have explicitly defined objectives and an unbounded decision space, featuring an infinite array of alternatives and attributes. It's worth noting that not all multi-objective problems come with clearly defined alternatives, thus necessitating the use of different methodologies contingent on the inherent nature of the decision challenges.

Most decision problems in the realm of **MCDM** fall into the **MADM** category and among the methods used to tackle this kind of decision problems, the **Analytical Hierarchy Process (AHP)** stands out as a widely adopted approach in practical scenarios, primarily because of its inherent simplicity and user-friendliness.

## 2.2 Analytic Hierarchy Process

The **AHP** [58], developed by Thomas Saaty, is a multi-criteria decision-making methodology that provides a structured framework for evaluating alternatives based on multiple criteria. **AHP** has gained significant attention and popularity due to its ability to address complex decision problems and incorporate subjective judgments regarding qualitative or quantitative aspects of a decision in a systematic manner [59].

The method offers a valuable capability to transform subjective probabilities from a state of uncertainty into a structured framework based on measurable criteria and ratio measures. This process ultimately leads to a unified measure, facilitating the incorporation of quantitative data, personal experience, intuition, and insights. This versatility makes the [AHP](#) approach accessible and user-friendly, not only for decision-makers but also for individuals who may not possess expert-level knowledge, enabling their active participation in the decision-making process. Consequently, the [AHP](#) method has gained popularity as a preferred framework for Multi-Criteria Decision Making among many practitioners [60] [61].

In contrast, some other models for group decision-making exhibit inconsistencies, often violating the fundamental reciprocal property [62]. However, when the [AHP](#) method is employed correctly by the decision-maker, it offers distinct advantages as a framework for group decision-making [63]. Since its introduction, the [AHP](#) has proven to be an asset in multiple applications such as in politics, material handling, conflict resolution, medicine, marketing, and technology [64][65].

In order to use the method correctly, several steps must be followed [68]. These steps will be assessed in the following sections.

### 2.2.1 Hierarchical Structuring

A key feature of [AHP](#) is its hierarchical representation of decision problems [66]. The decision hierarchy breaks down a complex decision into a series of interconnected levels. At the top level, the decision hierarchy includes the overall goal or objective. The next level consists of the criteria or factors that contribute to achieving the goal, and further levels may include sub-criteria or sub-factors. Finally, the lowest level comprises the alternatives or options being evaluated. Figure 2 illustrates the general structure of the [AHP](#) hierarchy.

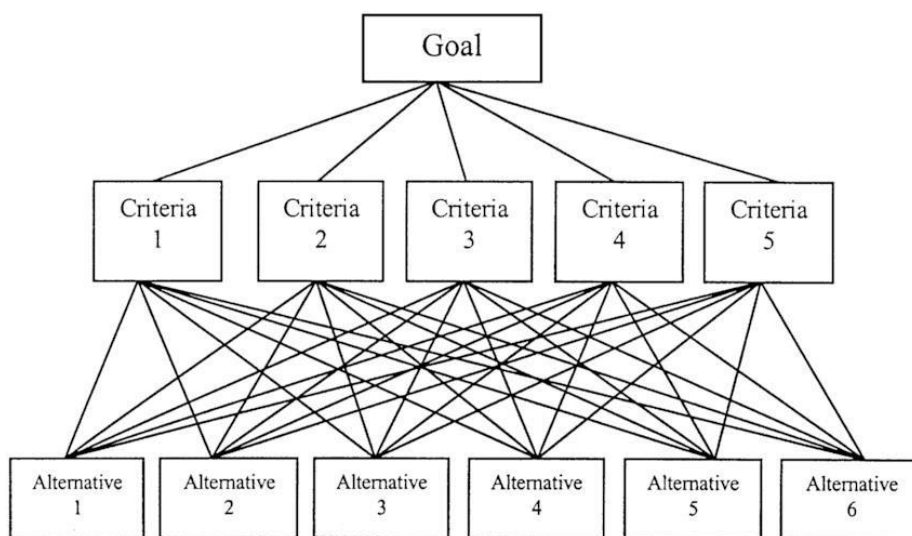


Figure 2. AHP Model Structure

The hierarchical structure allows decision makers to break down the initial problem into manageable components, providing a clear understanding of the decision's structure and interdependencies [67]. By organizing the decision into a hierarchy, decision makers can systematically analyze and compare the elements at each level [66].

**2.2.2 Pairwise Comparisons**

After having the decision well defined, with its different components aligned, the decision makers will compare elements within the same level of the hierarchy in pairs. What this means is that the pairwise comparisons involve evaluating two elements from the same level of the hierarchy side by side to discern the extent of their comparative significance. This involves making judgments that assign a numerical value to reflect the strength of one element's influence over the other. The scale for these judgments was defined by Saaty [58] and it ranges from 1 to 9, with each value representing a specific degree of preference or importance. A value of 1 implies that the two elements are equally important, while higher values signify increasing degrees of importance or preference. The scale of values for comparing the factors, Saaty's fundamental scale [71], as shown in Table 1.

Table 1. Saaty's Fundamental Scale

<b>Intensity of importance</b>	<b>Definition</b>
1	Equal importance
3	Weak importance of one over another
5	Strong importance
7	Very strong importance
9	Absolute importance
2,4,6,8	Intermediate values between two adjacent judgments

Ideally the odd-numbered evaluations in the table should be used to ensure a more consistent evaluation and a clear distinction between the values assigned to each criterion or alternative, leaving the even numbers to be intermediate values in order to reach a consensus.

Priority is defined as a score that ranks the importance of a particular alternative or criterion in the decision. There are two types of priority that can be computed, the criteria priorities, which results on the pairwise comparison between two criteria, means the importance that each criterion has in relation to the objective, and the alternative priorities, which results from the pairwise comparison between two alternatives regarding one criterion, means the importance of an alternative in relation to a specific criterion.

First, the relative importance of each criterion is defined through the pairwise comparisons between each other. Considering the number of available criteria, the necessary amount of pairwise comparisons is given by the following equation [70].

$$\text{Criteria comparison number} = \frac{n^2 - n}{2}, \text{ being } n \text{ the number of criteria}$$

Then, the same thing is done but for the alternatives, so each alternative is compared pairwise, considering a specific criterion. In this case, the number of pairwise comparisons is given by the following equation.

$$\text{Alternatives comparison number} = \frac{n(m^2 - m)}{2},$$

being  $n$  the number of criteria and  $m$  the number of alternatives

### 2.2.3 Deriving Priority Weights

After the priorities are established based on the fundamental scale, they are mirrored in a criteria or alternatives comparison matrix. All comparisons must be positive and the main diagonal values are always 1 because obviously the element is compared to himself. The matrix is reciprocal since the upper triangle is the inverse of the lower triangle of the matrix [70], as shown:

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{21}} & 1 & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \frac{1}{a_{n1}} & \frac{1}{a_{n2}} & \dots & 1 \end{bmatrix}, \text{ where } \begin{cases} a_{ij} > 0 \rightarrow \text{positive} \\ a_{ij} = 1 \therefore a_{ji} = 1 \\ a_{ij} = \frac{1}{a_{ji}} \rightarrow \text{reciprocal} \\ a_{ik} = a_{ij} \cdot a_{jk} \rightarrow \text{consistency} \end{cases}$$

As soon as the comparison matrix is carried out for all existing criteria and alternatives, comparing them with each other in relation to a criterion, in order to compute the weights of each criterion and alternative, the priority vectors have to be calculated.

AHP follows the synthetization procedure, which consists of three steps [58]:

1. Sum of each column's values of the pairwise comparison matrix (C1, C2, C3, C4).

Table 2. Addition of the Columns and Rows Elements

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Total Rows
Criterion 1	1	1/A	1/B	1/C	R1
Criterion 2	A	1	1/D	1/E	R2
Criterion 3	B	D	1	1/F	R3
Criterion 4	C	E	F	1	R4
Total Columns	<b>C1</b>	<b>C2</b>	<b>C3</b>	<b>C4</b>	<b>CR</b>

2. Division of each element from the pairwise comparison matrix by the respective column total value, defining this way the normalized comparison matrix.

Table 3. Priority Vector Calculation

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Priority Vector
Criterion 1	$\frac{1}{C1}$	$\frac{1/A}{C2}$	$\frac{1/B}{C3}$	$\frac{1/C}{C4}$	$\frac{R1}{CR}$
Criterion 2	$\frac{A}{C1}$	$\frac{1}{C2}$	$\frac{1/D}{C3}$	$\frac{1/E}{C4}$	$\frac{R2}{CR}$
Criterion 3	$\frac{B}{C1}$	$\frac{D}{C2}$	$\frac{1}{C3}$	$\frac{1/F}{C4}$	$\frac{R3}{CR}$
Criterion 4	$\frac{C}{C1}$	$\frac{E}{C2}$	$\frac{1/F}{C3}$	$\frac{1}{C4}$	$\frac{R4}{CR}$

3. It is necessary to calculate the average of each row of the normalized comparison matrix to calculate the relative weights of each element of the matrix. This average is computed by dividing the sum of the values in each row by the number of elements in the row, as seen in the last column of Table 3.

After these three steps, the priority vector is computed. This vector shows the relative weights among the elements that are being compared.

To compute the consistency of the decision, the Principal Eigen value  $\lambda_{max}$  must be calculated, which is obtained from the sum of products between each element of the priority vector and the sum of columns of the reciprocal comparison matrix. The following equation shows how  $\lambda_{max}$  is computed.

$$\lambda_{max} = (C1 \times \frac{R1}{CR}) + (C2 \times \frac{R2}{CR}) + (C3 \times \frac{R3}{CR}) + (C4 \times \frac{R4}{CR})$$

## 2.2.4 Consistency Checking

This step involves calculating the consistency of the values entered the methodology. The consistency test is a particularly useful tool in the phase immediately prior to decision-making, as it evaluates the entire process and concludes whether it has been carried out well, and whether the values entered in the comparison table are consistent with each other. In this way, decision-making on the problem in question will be based on a well-supported and coherent methodology and the conclusion can be considered reliable [67].

A comparison matrix A is said to be consistent if  $a_{ij} \cdot a_{jk} = a_{ik}$  for all  $i, j$  and  $k$ . However, the consistency should not be forced. As an example,  $B > A$  has value  $2 > 1$  and  $A > C$  has value  $6 > 1$ , there

should be no insist that  $B > C$  must have the value of  $16 > 1$ . Since it is being delt with human judgement, this would be too much consistency which is undesirable. For the purpose of consistency, the ranking can and should exhibit transitivity, yet it's important to note that the judgment values are not obliged to strictly follow the multiplication formula  $a_{ij} \cdot a_{jk} = a_{ik}$ .

The original comparison matrix is only considered consistent if  $\lambda_{max} = n$ , where  $n$  is the number of criteria evaluated, but what always occurs due to small inconsistencies is  $\lambda_{max} \geq n$ .

The consistency index is the deviation of consistency and is computed by the following formula.

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

The consistency index is subsequently evaluated by comparing it to the estimated CI using the same index  $n$ , which is obtained from a randomly generated square matrix, known as the Random Consistency Index (RI). The values of the random consistency Index for matrices which order is between 1 and 10 are shown in Table 4.

Table 4. Random Consistency Index Table

$n$	1	2	3	4	5	6	7	8	9	10
<b>RI</b>	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

The consistency ratio (CR) can then finally be computed using the following equation.

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

In order for a decision to be considered consistent, the CR must be inferior to 0.10 [66].

## 2.3 Decision Support Systems

Research consistently shows that humans often struggle to make optimal decisions, being especially noticeable when substantial amounts of unprocessed data are involved [57]. This led to studies being conducted to understand the core concepts behind systems that aim to improve the decision-making process [47]. These systems form a specialized class of information systems specifically designed to actively aid decision-making and are collectively called **Decision Support Systems (DSS)** [48].

**DSS** have become an integral part of our modern world, finding applications in various fields such as business operations, military strategy, healthcare management, finance, and traffic control. Although the term "decision support system" covers a wide range of system types, **DSS** are meticulously designed to empower users in their decision-making efforts by processing data and providing valuable

suggestions and predictions [52]. The growing popularity of **DSS** has to do with their essential role in transforming raw data into actionable insights for decision-makers, turning this system into a trusted ally, fundamentally enhancing the overall efficacy of the decision-making journey. [47][51].

During the late 90s, the development of **DSS** witnessed a remarkable surge, establishing itself as a paramount field of inquiry within the expansive landscape of information systems. In the more recent years, the surge in data availability and escalating complexity of problems has precipitated a shift away from traditional decision support systems toward more specialized solutions [54]. Nevertheless, the **DSS** panorama encompasses a diverse array of systems, each with its different attributes [47]. Some prevalent characteristics of a decision support system are data abundance, data aggregation, interactive flexibility, statistical and visual components, sophisticated data analysis and versatility in approach.

The classification of the **DSS** lacks a universally accepted standard due to the diverse roles these systems can fulfill alongside their primary function. In the taxonomy devised by Holsapple and Whinston, several types of **DSS** emerged. Firstly, the text oriented systems focus on tracking information stored in textual format, enriching the decision-making process with valuable textual data. Database-oriented systems, on the other hand, revolves around extensive databases, providing robust storage and accessibility for copious data. The spreadsheet oriented systems are an especially useful visual aid in cases where there is a demand for some kind of data representation or graphical modeling. Solver-oriented systems employs specialized modules and algorithms to bolster the decision-making process, catering to concrete needs regarding problem-solving. Rule-oriented systems suggests courses of action based on available information, reflecting a step toward artificial intelligence in some research [55] The fusion of two or more of these classifications results in the compound oriented **DSS** [50]. This type is considered to be the most prevalent and faithful of a genuine **DSS** [48][55].

Despite the absence of a universal classification, these systems can be broadly grouped based on their purpose and design approach into three categories. Firstly, there is the passive **DSS**, which serves as straightforward tools for assisting decision-making by presenting information. Nevertheless, they do not create alternatives or resolutions. These systems display information through relational databases and models, leaving the decision-maker accountable for deciphering the data.

In contrast, active **DSS** actively assist the decision-maker and excel in dynamic environments where quick decision-making is essential, such as operating rooms where medical teams must respond swiftly to changing conditions. They find applications in various organizations, including in hospitals, air traffic control and the military. Lastly, cooperative **DSS** represent highly interactive tools that not only generate options and solutions but also process data and suggest the decision-maker with a way forward. This iterative process allows for fine-tuning and validation until the desired outcome is achieved.

At the core of any **DSS** lies the Database Management System which consists of a database for relevant data to the specific problem domain that the system is designed to address. This database contains essential information for guiding the decision-making process, which can be extracted from diverse data sources. The Model-Base Management System, also known as the model, is responsible for handle and transforming the data extracted from these different sources, into actionable information tailored to

facilitate the whole decision-making process. Within each **DSS**, various models come into play. The user interface makes the bridge between the decision-maker and the inner workings of the **DSS**. It empowers the decision-maker to interact with the system, enabling inquiries and requests for information. In response, the system provides results in various formats, including numerical data and various graphical representations. Essentially, the user interface functions as a discerning filter, separating the complexities of mathematical models and extensive datasets from the user's perspective. Given that the intended user may lack intimate knowledge of the system's inner workings, this interface plays a pivotal role in presenting relevant information while filtering out the excess information.

The ultimate component in a **DSS** is the decision maker. Without a user interaction, the system remains inactive, as its essence revolves around facilitating decision-making through user engagement. Figure 3 shows an illustrative representation of the theoretical framework that underpins a decision support system. It's important to note that various sources may present distinct portrayals of this framework [56]. The decision support system is designed to receive information from diverse origins, and its subsequent processing is tailored to suit the specific characteristics of the data in question. While the precise configuration of a decision support system's structure may undergo variations contingent on its designated use, it is noteworthy that the core elements remain consistent across all system incarnations.

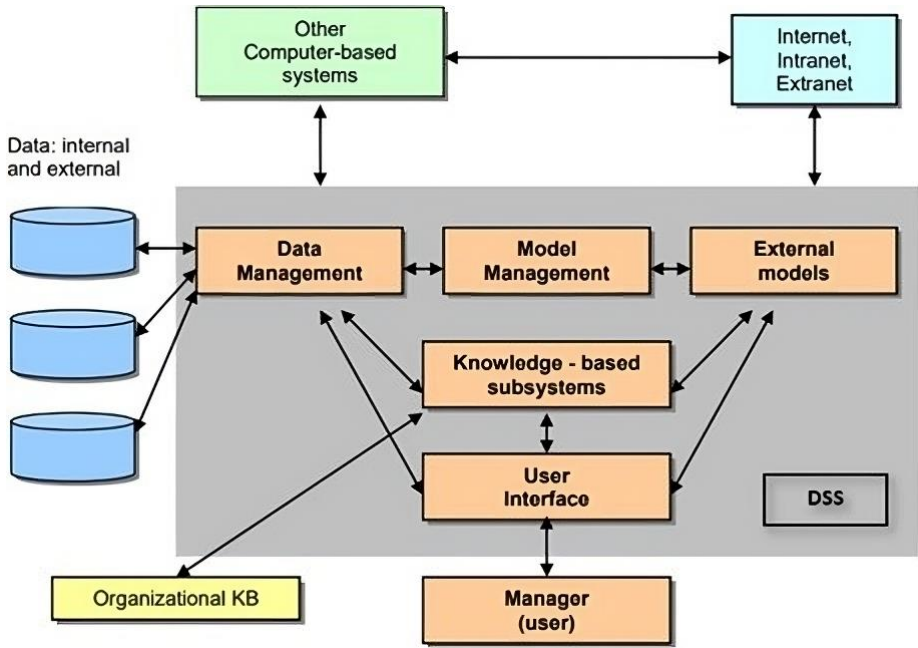


Figure 3. DSS Architecture



## SYSTEM DEVELOPMENT

Throughout this chapter, the architecture developed will be presented, contextualizing each of its elements with the theoretical concepts already presented. Initially, the functional and non-functional requirements of the architecture will be numbered. Following that, the use cases will be presented, both from the administrator and the participant perspectives. The system architecture and the used programming stack are then described in detail. Moreover, the platform functionalities are shown, followed by the implementation of the API and the database in the application.

### 3.1 Context Identification

The purpose of the developed solution is to introduce a web-based application that facilitates multi-person decision-making in a structured, efficient, and transparent manner. This solution targets scenarios where a group of participants collaboratively engages in decision-making processes, each contributing their unique insights, preferences, and expertise.

By implementing a user-friendly web interface, the solution aims to provide decision-makers with a reliable and adaptable platform to create and customize decisions and to enable collaborative decision-making across a spectrum of domains. It empowers administrators to formulate well-informed decisions and leverages the collective intelligence of participants to drive more accurate and insightful outcomes. Furthermore, the incorporation of quantifiable alternatives sets the stage for predictive analyses that could enrich decision support even further.

### 3.2 System requirements

Serving as the crucial link between envisioning and bringing to life, the definition of system requirements plays a significant role in the evolution of every technological solution. This phase precisely sculpts the shape of the web application. System requirements serve as the guiding compass, steering the development process toward the creation of an application that meets the diverse needs of users, aligning with industry standards.

### 3.2.1 Functional requirements

Functional requirements serve as the foundational bedrock upon which the application's operational capabilities are constructed. They wield the authority to prescribe the core functionalities that define the scope of potential actions for both administrators and participants. The expanse of these requirements is both extensive and intricate, encompassing an array of essential facets within the application's framework. This comprehensive canvas includes critical aspects such as the establishment and management of entities, user engagement, data aggregation, intricate calculations, and the orchestration of user administration activities. The list of the functional requirements is presented in Table 5.

Table 5. System Functional Requirements

<b>ID</b>	<b>Functional Requirements</b>
1.	Registration for administrator creation
2.	Authentication for participants added in the system
3.	Addition of participants
4.	Addition of decision category
5.	Addition of category and corresponding criteria
6.	Processing and displaying of participants data
7.	Processing and displaying of decisions data
8.	Processing and displaying of decision category and respective criteria data
9.	Processing and displaying of specific decision information data
10.	Creation of a decision
11.	Creation of a simulation
12.	Processing of the participant decision making data
14.	Displaying of previously made decisions
15.	Processing and displaying of prediction of the participant pairwise comparisons
16.	Modeling and management of participant data
17.	Modeling and management of decision data

### 3.2.2 Non-Functional requirements

Non-functional requirements, also referred to as quality attributes, are essential aspects of a software system that go beyond its functional capabilities. While functional requirements outline what the system should do, non-functional requirements define how well the system should perform those functions. These requirements encompass a wide range of characteristics that contribute to the overall effectiveness, reliability, usability, and performance of the software. The most relevant non-functional requirements are shown in Table 6.

Table 6. System Non-Functional Requirements

<b>ID</b>	<b>Non-Functional Requirements</b>
1.	All the data in every page should be updated in no more than 2 seconds
2.	The charts displaying the weights values of the alternatives or categories throughout the decision-making process of the participants should reload in less than 1 second every time that the participant makes a change in the pair wise comparison
3.	Only the Administrator can manage the decision data and create decisions or simulations
4.	Only the participants can participate in the decisions
5.	The participant only has access to its previous decisions details
6.	The application's user interface must be user friendly, being easy and intuitive to be used

### 3.2.3 Use Cases

Use cases represent specific interactions or functionalities of a system from the perspective of an external actor, typically a user or another system. Each use case describes a distinct goal or task that the system can perform. Use cases serve as a foundation for system design and development and help clarifying how users interact with the software and what functionalities are essential to meet their needs. In the next section, the use cases that apply for the administrator and the use cases that apply for the participants will be separated for a matter of better understanding of the different goals for both actors.

#### 3.2.3.1 Administrator Use Cases

##### Registration

The login use case has the purpose of explaining how the admin creates the credentials to initiate the use of the application. As soon as the server validates the credentials introduced by the admin, it is possible to start using the platform. The use case flow is presented in Table 7.

Table 7. Registration Use Case

<b>Use Case ID:</b>	1.0
<b>Use Case Title:</b>	Registration
<b>Primary Actor:</b>	Administrator
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Administrator enters the registration/login page</li> <li>2. System displays the registration/login form</li> <li>3. Administrator fills out the form with the necessary data</li> </ol>

	4. Administrator submits the form
	5. The system validates the administrator registration
<b>Alternative Flow(s):</b>	5.a System alerts that the registration was not successful

### Add Participant

Add the participant use case demonstrates how the admin adds new participants to the system environment so that they can eventually take part in the decision-making process of any given decision. The system will notify the participant via email its addition providing a random password unknown to the admin. The use case flow is presented in Table 8.

Table 8. Add Participant Use Case

<b>Use Case ID:</b>	2.0
<b>Use Case Title:</b>	Add participant
<b>Primary Actor:</b>	Administrator
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Admin enters management page</li> <li>2. System displays management details</li> <li>3. Admin selects participants management</li> <li>4. System displays the participants previously added by the admin</li> <li>5. Admin selects the participant addition form</li> <li>6. System displays a participant form</li> <li>7. Admin fills out the form with all the relevant information</li> <li>8. System validates the participant details</li> <li>9. System creates random password for the new participant login</li> <li>10. System sends email to the participant with login details</li> </ol>
<b>Alternative Flow(s):</b>	8a. System alerts that the form is incomplete

## Manage Decision Categories and Criteria

The manage decision categories and criteria use case serves the purpose of demonstrating how the admin adds new decision categories to the system environment. With the addition of a category also comes the association of existing criteria to this new category or the creation of new criteria that are related to this category. The use case flow is presented in Table 9.

Table 9. Manage Decision Categories and Criteria Use Case

<b>Use Case ID:</b>	3.0
<b>Use Case Title:</b>	Manage decision categories and criteria
<b>Primary Actor:</b>	Administrator
<b>Main Success Flow:</b>	<ol style="list-style-type: none"><li>1. Admin enters management page</li><li>2. System displays management details</li><li>3. Admin selects category management</li><li>4. System displays the decision categories previously added by the admin</li><li>5. Admin creates new category associating previously created criteria and/or creating new criteria specifically for the new decision category</li><li>6. System validates the category details</li></ol>

## Create a Decision

The create a decision use case is essential to show how the admin creates a decision. The admin has the function of creating all the details of the decision including the final goal, the category and its criteria, the participants, and the alternatives of the decision. Then the selected participants proceed to do their individual decision-making process. The use case flow is presented in Table 10.

Table 10. Create a Decision Use Case

<b>Use Case ID:</b>	4.0
<b>Use Case Title:</b>	Create a decision
<b>Primary Actor:</b>	Administrator
<b>Main Success Flow:</b>	<ol style="list-style-type: none"><li>1. Admin enters the home page</li><li>2. System displays the home page</li><li>3. Admin selects start new decision</li><li>4. System displays the decision details page</li><li>5. Admin fills out information for the simulation of the decision</li></ol>

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	6. Admin submits the decision details
	7. System validates the simulation details
	8. The selected participants will have in their home page the decision to be part of

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<b>Alternative Flow(s):</b>	7.a System alerts that the decision details submission was not successful
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### Create a Simulation

The create a simulation use case is used to understand how the admin creates a decision simulation. This means that no participant action will be needed. The simulation will occur with predictions of each participant's previous decisions. new decision categories to the system environment. The use case flow is presented in Table 11.

Table 11. Create a Simulation Use Case

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<b>Use Case ID:</b>	5.0
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<b>Use Case Title:</b>	Create a simulation
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<b>Primary Actor:</b>	Administrator
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<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Admin enters the home page</li> <li>2. System displays the home page</li> <li>3. Admin selects start new simulation</li> <li>4. System displays the simulation details page</li> <li>5. Admin fills out information for the simulation of the decision</li> <li>6. Admin submits the simulation details</li> <li>7. System validates the simulation details</li> <li>8. System presents the results of the simulation</li> </ol>
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<b>Alternative Flow(s):</b>	7.a System alerts that the simulation details submission was not successful
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### View All Decisions and Simulations

The view all decisions and simulations use case is needed to understand how the admin visualizes the past decisions and simulations. The use case flow is presented in Table 12.

Table 12. View All Decisions and Simulations Use Case

<b>Use Case ID:</b>	6.0
<b>Use Case Title:</b>	View all decisions and simulations
<b>Primary Actor:</b>	Administrator
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Admin enters the home page</li> <li>2. System displays the home page listing all the previous decisions and simulations</li> <li>3. Admin selects the decision or simulation that wants to check</li> <li>4. System displays the corresponding simulation or decision details</li> </ol>

### 3.2.3.2 Participant Use Cases

#### Login

The login use case demonstrates how the participant has access to the application. This is only possible if the admin ads him to the system. As soon as that is done, the participant will receive an email with the details to enter the system. The participant only needs to introduce this data into the login form, and he then will have access to the platform. The use case flow is presented in Table 13.

Table 13. Login Use Case

<b>Use Case ID:</b>	7.0
<b>Use Case Title:</b>	Login
<b>Primary Actor:</b>	Participant
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Participant enters the registration/login page</li> <li>2. System displays the registration/login form</li> <li>3. Participant fills out the login form with the necessary data that was provided by email from the admin</li> <li>4. Participant submits the form</li> <li>5. The system validates the administrator registration</li> </ol>
<b>Alternative Flow(s):</b>	5.a System alerts that the login was not successful

#### View All Decisions

The view all decisions use case has the purpose of showing how the participant visualizes the details of the past decisions in which he was part of. The use case flow is presented in Table 14.

Table 14. View All Decisions Use Case

<b>Use Case ID:</b>	8.0
<b>Use Case Title:</b>	View all decisions
<b>Primary Actor:</b>	Participant
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Participant enters the home page</li> <li>2. System displays the home page</li> <li>3. Participant selects the decision that he wants to view</li> <li>4. System displays the corresponding decision details</li> </ol>

### Participate in a Decision

The participate in a decision use case is helpful to understand how the participant is part of a decision-making process attributed to him by the administrator. The participant will be presented with a form with the pairwise comparisons between criteria and alternatives to be made for the decision to be made by him. The use case flow is presented in Table 15.

Table 15. Participate in a Decision Use Case

<b>Use Case ID:</b>	9.0
<b>Use Case Title:</b>	Participate in a decision
<b>Primary Actor:</b>	Participant
<b>Main Success Flow:</b>	<ol style="list-style-type: none"> <li>1. Participant enters the home page</li> <li>2. System displays the home page</li> <li>3. Participant selects an incomplete decision to participate in</li> <li>4. System displays the corresponding decision details</li> <li>5. Participant does the decision-making process, filling out the pairwise comparisons of the decision</li> <li>6. Participant submits the decision data</li> <li>7. System validates the decision data</li> </ol>
<b>Alternative Flow(s):</b>	7.a System alerts that the decision data submission was not successful

### **3.2.3.3 Use case diagram**

A use case diagram is a visual representation in [UML \(Unified Modeling Language\)](#) that illustrates the several ways in which users or actors, in this case the administrator and the participants, interact with a system or software application. It shows the different use cases, along with the actors or entities that initiate those actions. Use case diagrams are commonly used in software development and systems engineering to help define, visualize, and understand the system requirements and the interactions between users and the system. Considering the functional requirements defined and the use cases, both from the Administrator and the participants, the platform's use case diagram is seen in [Figure 4](#).

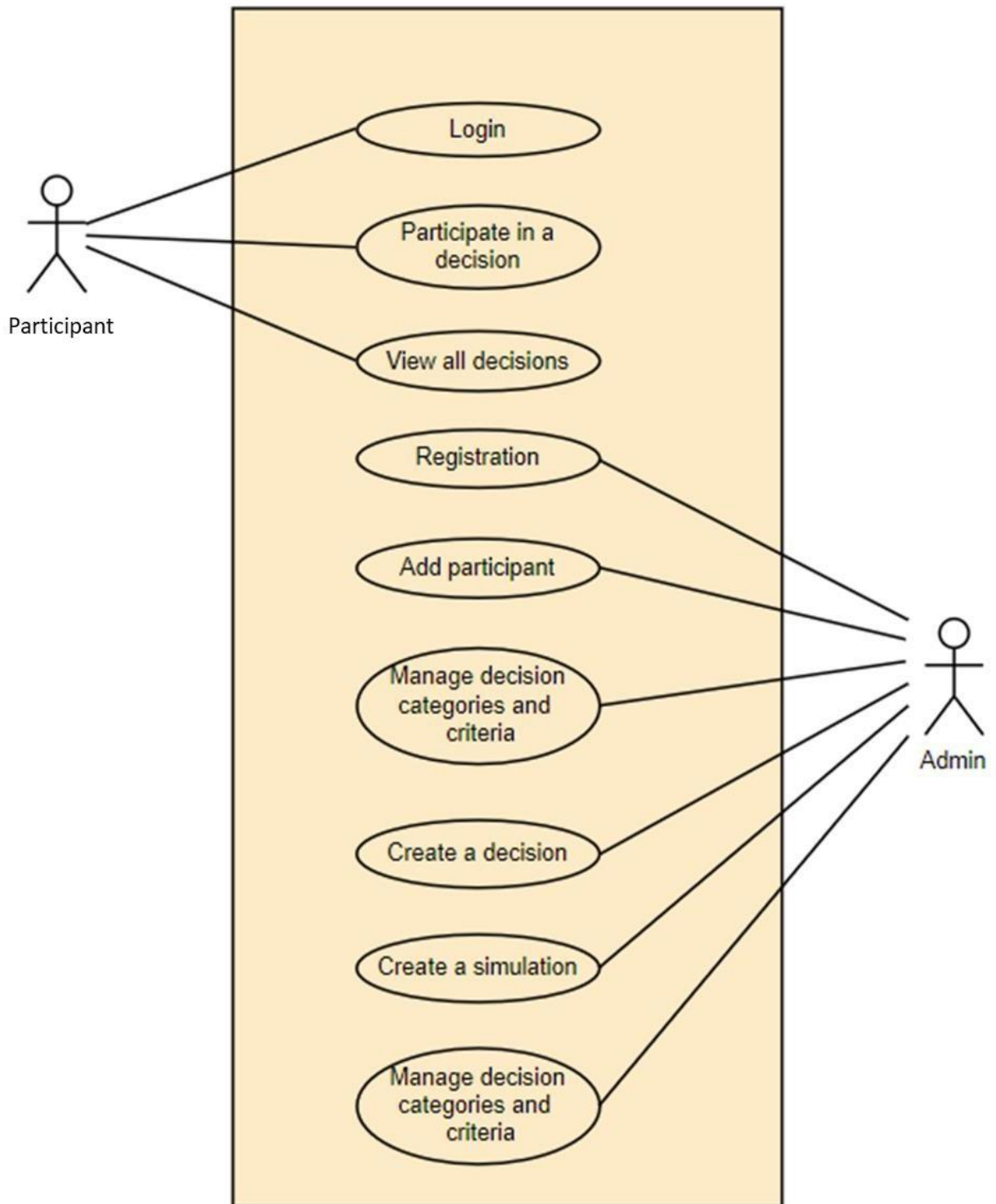


Figure 4. System Use Case Diagram

### 3.3 System Architecture

Web applications are composed of various tiers that are assigned specific roles. The configuration of these tiers determines whether an application follows a 2-tier, 3-tier, or multi-tier architecture.

After having the requirements and the targets for the system well defined, the system architecture can be chosen in a way that tackles them the best way possible. The developed platform follows the three-tier architecture, composed of three primary layers: Presentation, Application, and Data. This architecture is shown in Figure 5.

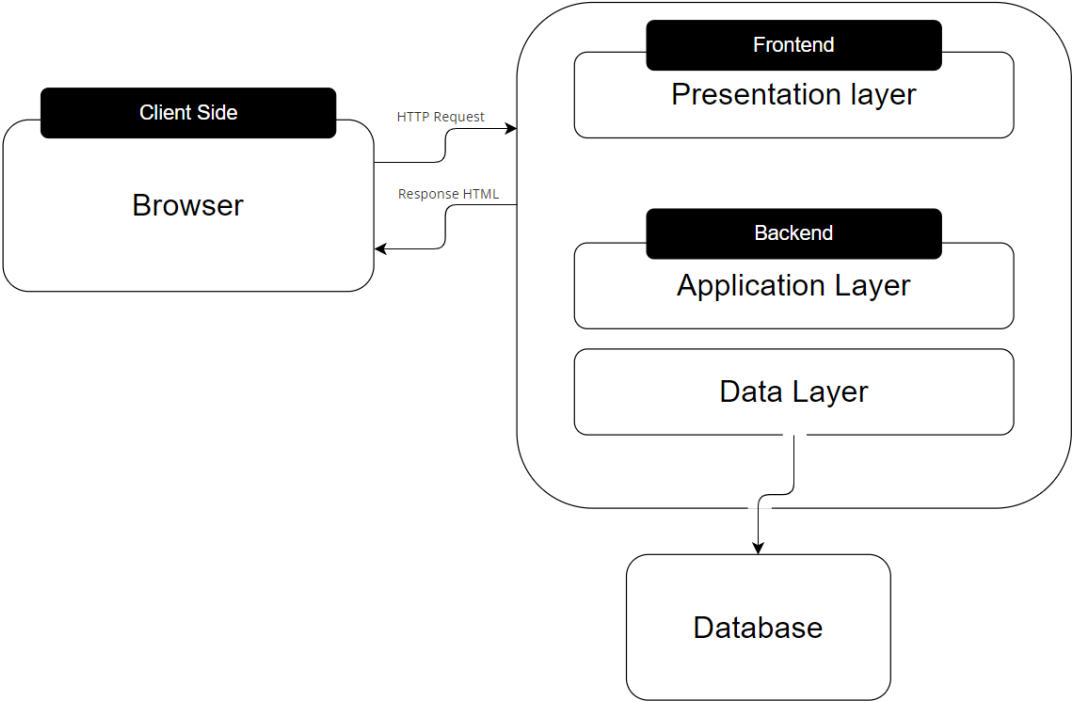


Figure 5. System Architecture

The Presentation layer oversees user interactions within the client application. The Application layer handles the core business logic and coordinates various workflows. Meanwhile, the Data layer is responsible for the storage and administration of data. These layers in a web application's architecture are interconnected to facilitate smooth and uninterrupted functionality.

The presentation layer is responsible for rendering the [user interface \(UI\)](#) elements that users interact with. It translates data into visually comprehensible forms, incorporating images, text, and interactive components like buttons and forms. Beyond just appearance, this layer handles user input, interpreting clicks, keystrokes, and gestures, and converts them into meaningful actions within the application. Additionally, the presentation layer may implement client-side scripting to facilitate real-time updates, input validation, and dynamic behavior, further enhancing the user experience. This layer serves as the direct point of interaction between users and the web application. It is the first aspect of

the users' experience, influencing their initial impression and overall satisfaction. A well-designed presentation layer enhances usability, engagement, and user adoption.

The application layer houses the business logic that drives the application's behavior. It orchestrates processes, implements rules, and manages workflows that represent the essence of the application's purpose. Additionally, this layer handles incoming [API](#) requests, which are the enablers for the presentation layer to access the stored resources through [HTTP](#) requests, processes them, and delivers appropriate responses. Furthermore, authorization and authentication mechanisms are often implemented here, safeguarding sensitive data and resources. Error handling is also a crucial function, ensuring that errors are caught and reported, preventing them from disrupting the user experience. The application layer serves as the backbone of the web application's functionality, maintaining the business logic that governs how the application responds to different scenarios, offering consistency and reliability to users.

The data layer manages the storage and retrieval of data. It facilitates the interaction between the application and the database. This layer handles various functions, including storing new data entries, updating existing ones, retrieving specific data sets, and removing data when no longer needed. Data modeling takes place here, defining how data is structured and related, ensuring consistency across the application. Data validation rules are enforced to ensure that only accurate and valid information enters the system. This layer ensures that the user-generated information, application state, and other essential data are reliably stored and retrieved as needed, maintaining the credibility and functionality of the whole application.

## 3.4 Programming Stack

The front-end development of the platform leverages the Angular framework, enriched by the capabilities of Angular Material, a [UI](#) component library designed explicitly for Angular applications. This combination ensures a robust and aesthetically pleasing user interface that aligns seamlessly with modern design principles and user experience standards.

Angular's role in the technology stack extends beyond its structural and architectural advantages, as it provides a comprehensive framework for building dynamic web applications. Its component-based architecture encourages code modularity and reusability, while TypeScript, a statically typed superset of JavaScript, enhances code quality and development productivity. Angular Material's integration within Angular enhances the user interface with a suite of pre-designed, responsive, and accessible [UI](#) components. Angular promotes a structured and organized codebase through its component-based architecture. Developers create encapsulated [UI](#) components which can be reused seamlessly throughout the application. This modularity streamlines development, encourages code maintainability, and simplifies collaboration among team members.

TypeScript brings the benefits of static typing to the front end, reducing the likelihood of runtime errors and improving code quality. This not only enhances developer productivity but also ensures a more reliable user experience.

Furthermore, Angular Material was also used as a [UI](#) component library from Angular. Angular Material augments Angular by providing a cohesive set of [UI](#) components, such as buttons, dialogs, tables, and navigation menus. These components are designed to adhere to Material Design principles, offering a consistent and visually appealing user interface. Moreover, Angular Material's accessibility features ensure that the application is inclusive and usable by individuals with diverse needs.

Regarding the backend development of the platform, it relies on Node.js and the Express framework for building a robust and scalable [API](#). Node.js, known for its event-driven architecture, is a natural fit for real-time applications. It excels in handling concurrent connections, which is essential for ensuring the responsiveness and performance of the platform. Express complements Node.js by simplifying the development of RESTful [APIs](#), offering a rich set of tools and middleware for request processing. The integration of [Node Package Manager \(NPM\)](#) into the backend development workflow further enhances productivity. NPM provides access to a vast repository of open-source libraries and packages, accelerating the development process and enabling the seamless integration of third-party solutions.

Finally, the choice for database management was MySQL, a reliable and widely used [relational database management system \(RDBMS\)](#). The relational data model aligns perfectly with the need of managing structured data, including decision criteria, alternatives, participant information, and historical decision records. This structured approach ensures data integrity and consistency. MySQL's adherence to the [ACID \(Atomicity, Consistency, Isolation, Durability\)](#) properties provide assurance that data transactions are reliable, and that decision-related data remains accurate.

### 3.5 Platform Functionalities

In this section, it will be presented the diverse and most relevant functionalities of the platform. These functionalities have the purpose of tackling the application requirements described on the previous sections. Table 16 presents these functionalities, which are presented throughout the following sections.

Table 16. Platform Functionalities

Section	Platform Functionalities
3.5.1	System Management
3.5.2	Decision creation
3.5.3	Decision Process Participation - Scenario 1
3.5.4	Pairwise Comparisons Predictive Analysis
3.5.5	Decision Process Participation - Scenario 1
3.5.6	Simulation Creation

### **3.5.1 System Management**

The system management is the responsibility of the administrator. It gives the possibility of adding participants to the system. The participants added to the system will then be available to be part of any decision that the administrator creates. Furthermore, when the system has sufficient data from the participant's previous decisions, his pairwise comparison values can be taken into account in the eventual simulations that the administrator creates.

In addition, the system management provides the administrator capabilities of creating decision categories and its corresponding criteria. The decision categories group related decision processes and are critical to be defined because they play a big part in the predictive analysis aspect of the platform. A person has a completely different way of making decisions, depending on the type and characteristics of the decision. So, it would not make sense to treat every decision as the same for the predictive analysis since the response values from the pairwise comparisons could vary tremendously depending on the type of decision and criteria that is at stake. The categories are a way of encapsulating similar decisions containing applicable and purposeful criteria for those decisions.

It is worth mentioning that distinct categories may use a certain number of identical criteria as would be expected. Even though the decisions may have diverse types, there are some criteria that are transversal to a broad range of categories.

### **3.5.2 Decision creation**

The creation of a new decision is done by the system administrator. The action is straightforward. Firstly, the goal of the decision is stated, then the category of the decision is defined. For the different existing categories, the criteria are also obviously different so that they conform to the corresponding category. The administrator then chooses the relevant criteria, available for the chosen category. The alternatives to solve the problem should also be defined and there should always exist two or more alternatives for the decision. Finally, the administrator chooses the participants that will take part in the decision process.

As soon as everything previously mentioned is entered into the decision creation form, it can be submitted, leading to the last step before the decision process is created and sent to the participants. This last step is crucial for the goal of this tool. It is quantification of the alternatives considering each criterion. What this means is that for every chosen criterion of the decision, there should be defined a number to quantify the alternative in relation to the criterion and to the other alternatives. This can be made either with a unit, if the criterion is measurable numerically, for example cost, time, or power, or by a scale defined by the team, for the criteria that cannot be measurable numerically in such an obvious way. Both the unit and the scale should be well defined according to the decision goal. These quantifiable values will be crucial for the predictive analysis of the tool.

Having everything completed, the decision form is ready to be created. The system will automatically create a decision form on the chosen participants home page, so that it is completed by them.

### **3.5.3 Decision Process Participation - Scenario 1**

As it was mentioned in the previous section, when the administrator creates a decision, the corresponding participants will have it on their home page and have to complete it.

Now, there can be two scenarios. The first one is that the participant has not yet taken part in a lot of decision processes and so, there is still not enough data available for computing and generating a prediction of his pairwise comparisons. The second scenario is when the participant took part in a reasonable number of decisions, which means that there is already enough data available for this prediction to happen. Let us focus on the first scenario, the second scenario will be approached afterwards since it is important to understand the pairwise comparisons predictive analysis described on the next section.

Considering the scenario where the participant has been part of less than three decisions of the same category, when the participant clicks on one decision process to complete, the system will redirect him to a page with the pairwise comparisons of the chosen criteria.

For every criterion there must be a comparison to every criterion. The way to compare the criteria is simple. There is a list with the comparisons to be done, in the middle of each pairwise comparison there is a slider which the participant can move and choose the correct value to compare the two criteria. This values, as discussed previously, go from 1 to 9 to both ways, being 1 the value given to two criteria with the same importance, and 9 the value given to one criterion which is considered to be much more relevant to the decision, in comparison to the other. The participant must keep in mind that these pairwise comparisons should be consistent, so that the results make sense.

After every pairwise comparison between the criteria is made, the participant can advance to the next phase of the decision, which will involve the alternatives. This step of the decision is similar to the previous one. Now the goal is to make pairwise comparisons of the alternatives accordingly to each criterion. What this means in practice is that for each selected criterion to be part of the decision, every alternative will be compared to each other considering the criterion at stake. The way to make the comparison is the same as for the criteria, changing the slider value from 1 to 9 to both ways corresponding to the preference of the alternatives. Again, the consistency of the comparison values must be considered.

When all the comparisons are done by the participant, the decision form can be submitted, and the decision process is finished. All the comparison values provided by the participant to the decision will be stored in the corresponding tables in the database so that it can be used and processed in the future for the predictive analysis. In the end, when all the participants have completed making their decision, the results are aggregated, resulting in the final result of the group decision.

### **3.5.4 Pairwise Comparisons Predictive Analysis**

Predictive analysis is a fundamental part of the work done. It has two main goals in the platform. The first one is to provide the participants with a reference value for the pairwise comparisons between the criteria or alternatives. The second goal is to provide the administrator with the possibility of doing a simulation of a decision. What this means in practice is that, having enough data from previous decisions

from each participant, the administrator could have the opportunity to create a simulation with the predicted pairwise comparisons values generated by the system for each participant.

The choice of implementing linear regression for predicting pairwise comparisons in the application is motivated by several key factors. Firstly, linear regression is favored for its simplicity and ease of interpretation. In the context of decision-making, where transparency and user trust are vital, linear regression provides a straightforward understanding of how input features (such as quantifiable values of alternatives) relate to the predicted pairwise comparisons. This transparency is crucial for both administrators and participants to comprehend the decision-making process. Furthermore, linear regression is well-aligned with the principles of the [AHP](#). The [AHP](#) typically assumes that pairwise comparisons can be expressed as linear combinations of alternative attributes or values. This compatibility makes linear regression a natural fit for approximating the underlying decision-making mechanisms within [AHP](#). In addition to its suitability, linear regression is advantageous due to its limited complexity. Many real-world decision-making scenarios involve uncomplicated relationships between alternatives and criteria. In such cases, linear regression can effectively capture these relationships without introducing unnecessary intricacies into the application. This choice ensures that the model remains efficient while avoiding the risk of over-engineering. Lastly, linear regression is straightforward to implement and maintain, requiring fewer hyperparameters to fine-tune compared to more complex machine learning models. This saves both development time and ensures the long-term sustainability of the application.

As seen in previous sections, for a prediction to be made, there must be relevant available data. The decision categories have a fundamental role regarding the predictive analysis because, when a decision is created, a category needs to be selected. Every category already includes all the relevant criteria for evaluating the decision, which means that the criteria for decisions of the same category are always more or less the same, varying from the list of available criteria for the chosen decision category. The category is relevant because it sets boundaries for the predictive analysis, meaning that, it would not make sense to make predictions of pairwise comparison values, even if regarding the same criteria, if the decisions had completely diverse types and goals.

So, taking this into consideration, for the prediction of the pairwise comparison between two alternatives, the relevant data that needs to exist are previous pairwise comparison values for the same criterion related to the same decision category.

Table 17 illustrates the quantifiable values of the alternatives according to a specific criterion in column 1 and 2 and the pairwise comparison value given by the participant in column 3. Note that the first column will take the value of the smallest alternative quantifiable value and the second the largest alternative quantifiable value. According to this, the pairwise comparison value needs to be inverted depending on if the values are already in the correct order or not. This is done to ensure that the following values are computed the correct way.

Table 17. Quantifiable Values of The Alternatives

First alternative quantifiable value	Second alternative quantifiable value	Pairwise comparison value
Q11	Q21	P1
Q12	Q22	P2
Q13	Q23	P3
Q14	Q24	P4
Q15	Q25	P5

First, let us create a variable  $x$ , which will take the value of the square root of the product between both respective alternative quantifiable values. Secondly a variable  $y$  corresponds to the second alternative quantifiable value divided by the first alternative quantifiable value. Finally, a variable  $z$  will take the value from the pairwise comparison.

These values  $x$ ,  $y$  and  $z$  will form a matrix  $M$ .

$$M = \begin{bmatrix} x1 & y1 & z1 \\ x2 & y2 & z2 \\ x3 & y3 & z3 \\ x4 & y4 & z4 \\ x5 & y5 & z5 \end{bmatrix}$$

After having the matrix defined, the next step is the polynomial fitting. Choosing the appropriate order for a polynomial regression model is an essential step in building a good predictive model. This selection must take into consideration a balance between underfitting which means choosing a too low degree, leading to a simple model that does not capture the data's complexity, and overfitting which on the other hand is the choice of a too high degree, causing the model to fit noise in the data and not generalize well to new data.

After some experiences with different degrees, a second-degree polynomial regression or a quadratic polynomial was chosen to fit the data. This quadratic polynomial has the form represented by the following equation.

$$z = a0 \cdot x^2 + a1 \cdot x + a2 \cdot y^2 + a3 \cdot y + a4,$$

Where,  $a0$ ,  $a1$ ,  $a2$ ,  $a3$  and  $a4$ , are the coefficients to be determined.

The next step is constructing the Design Matrix  $DM$ , consisting of rows for each data point  $x$ ,  $y$  and  $z$ , and columns for each term in the quadratic polynomial equation. The columns should include  $x^2$ ,  $x$ ,  $y^2$ ,  $y$ , and a constant term of ones.

After having the  $DM$ , the next step is to set up and solve the linear system of equations using the  $DM$  and the observed  $z$  values. The system takes the form shown by the following equation.

$$DM \cdot [a_0; a_1; a_2; a_3; a_4] = z,$$

Where,  $[a_0; a_1; a_2; a_3; a_4; a_5]$  represents a column vector of the coefficients to be estimated.

The least squares solution will provide the estimated coefficients that minimize the sum of squared differences between the observed  $z$  values and the values predicted by the quadratic polynomial equation. Once the coefficients are obtained, those can now be used to generate predicted  $z$  values for any combination of  $x$  and  $y$  by simply plugging the values into the quadratic polynomial equation to calculate  $z$ . To illustrate this, a Matlab script was created with random values so that it is easier to visualize the final goal. The plotted grid of points is illustrated in Figure 6 and corresponds to the values to the values of the fitted quadratic polynomial surface, based on the estimated coefficients.

Even though the model takes a low degree for the polynomial equation, it is possible to see by inspecting Figure 6, that for regions where the density of points is high, the model fits well to the data values. On the contrary, where there are no values, the model does not behave in the best way possible and overfits. In order to tackle this challenge, the decided approach was to only be possible to predict the pairwise comparison values when its corresponding matrix  $M$  data point relative to  $x$  and  $y$  is inside a triangle of other already existing data points. The method used is based on the concept of barycentric coordinates. This approach will ensure that the prediction is done correctly according to the model.

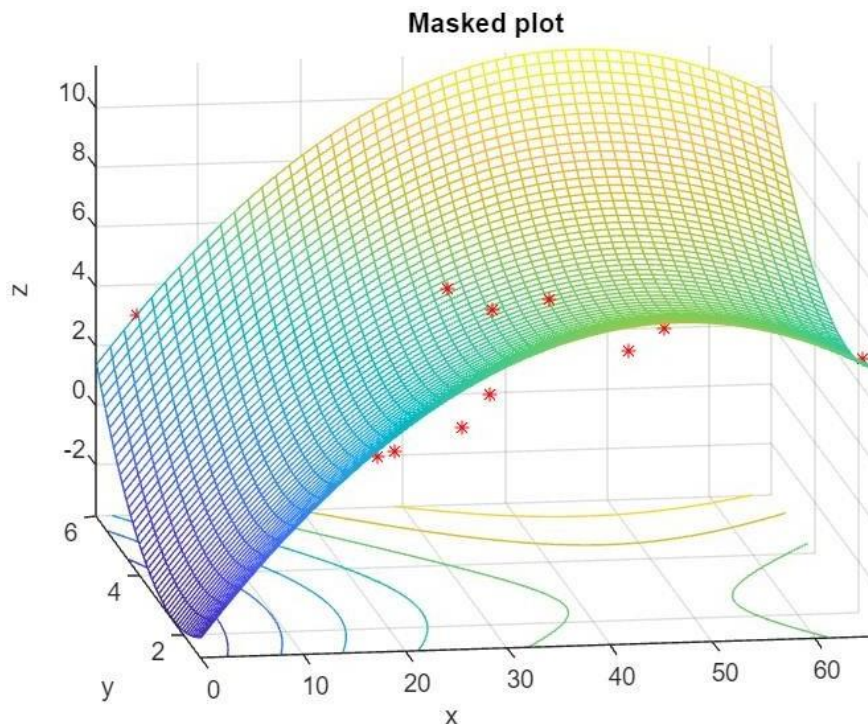


Figure 6. Fitted Polynomial Surface Plot in Matlab

### **3.5.5 Decision Process Participation - Scenario 2**

After understanding how the predictive analysis in the platform works it is easier to understand the second scenario on how the participant makes the decision. This scenario occurs when the participant has been part of many decision processes.

Being this the panorama, the system already has enough data for how the specific participant does the pairwise comparisons and what is normally more valued by him.

Now, when the participant wants to complete a decision process that was assigned to him, the pairwise comparison predicted values will be present along the decision process.

The interface provides the option for the participant to apply all the predicted values to the corresponding pairwise comparisons automatically, still giving the possibility for changing the value of each of them, with the slider.

It is purposeful to refer that these predicted values serve as a reference for each pairwise comparison, based on past similar decisions, so they can and should be considered for the pairwise comparisons but are not in any way a mandatory value for the current decision or comparison. It is always beneficial that the participant gives a logical and thought through value, even if it does not correspond to the predicted value. This way, the system will continuously adapt and improve.

Apart from the described changes made possible by the predicted values, the rest of the decision-making process is like scenario 1.

### **3.5.6 Simulation Creation**

The creation of a simulation of a decision is an innovative feature that the platform provides to the administrator. This feature offers numerous advantages for decision-makers in various domains. It enables predictive decision-making based on historical data, saving time, and reducing the need for active participant involvement. It ensures consistency and fairness by eliminating biases, while the generated data provides valuable insights for ongoing improvement.

The creation of simulation follows the same steps as the creation of a decision process, having some particularities. The simulation, for instance, does not require the participants to act. Instead, the decision is made considering the prediction of each chosen participant's pairwise comparisons from previous decisions. What this means in practice is that, for the simulation of a decision-making process created by the administrator, the participants do not directly take part as they would do in the decision processes, also created by the administrator. Their contribution to the simulation is rather indirect, via the pairwise comparisons from previous decisions.

The fact that the simulation of a decision depends necessarily on the predictive analysis of a participants previous decision-making process, means that it may result in the number of participants available for the simulation being reduced, compared to the existing number of participants in the system.

For the simulation to be created, a form with the decision process that the administrator wants to simulate has to be filled with the necessary details, which means, the goal of the decision, its category,

the alternatives to reach the goal, the criteria to evaluate the alternatives, the weights of each criterion, and last but not least, the participants whose predicted pairwise comparisons will in the end effectively make the decision. The results are presented to the administrator after the submission of the form.

## 3.6 Rest API

The **REST (Representational State Transfer) API** is a key component of the application. It serves as the bridge between the frontend and backend, enabling communication and data exchange. In this section, the design and implementation of the **REST API** is outlined.

### 3.6.1 Implementation

For the implementation of the **API**, two main tools were used to facilitate and streamline the process. These tools are Swagger and Postman. Swagger is an open-source framework used for designing, building, and documenting RESTful **APIs**. It simplifies the process of creating and managing **APIs** by providing a suite of tools and a standardized approach to **API** development. Postman, on the other hand, is a versatile **API** testing tool that provides a user-friendly graphical interface which allows developers to interact with **APIs** and perform a wide range of tasks related to **API** testing, simplifying the process of testing them.

The implemented **API** adheres to RESTful principles, which emphasize the use of standard **HTTP** methods, GET, POST, PUT, DELETE to perform **CRUD (Create, Read, Update, Delete)** operations on resources. Each endpoint should represent a resource, and interactions with these resources are stateless. These resources represent data entities. Each resource is associated with a **URL (Uniform Resource Locator)** endpoint. Furthermore, each resource is uniquely identified by a **URI (Uniform Resource Identifier)**, which serves as a unique address.

Some of the most fundamental routes implemented in the **REST API** are displayed in Table 18, Table 19 and Table 20.

Table 18. Users Routes

Method	URL	Route Description
GET	/users	Retrieves all the users.
GET	/users/:id	Retrieves a specific user.
POST	/users	Creates a user.

The exact same routes and methods were implemented respectively for the routes /criteria, /alternatives and /category.

Table 19. Decisions Routes

Method	URL	Route Description
GET	/decisions	Retrieves all the decisions.
GET	/decisions /:id	Retrieves a specific decision.
POST	/decisions	Creates a decision.
Put	/decisions	Changes the done status of a decision.

Table 20. Decision\_participants Routes

Method	URL	Route Description
GET	/decision_participants/participant/:id	Retrieves the decisions made by a specific participant.
GET	/decision_participants/decision/:id	Retrieves the participants of a specific decision.
POST	/decision_participants	Defines the participants of a decision.
PUT	/decision_participants	Replaces a specific decision's done status for a specific participant.

### 3.7 Database

As previously mentioned, in a three-tier architecture application, the responsibility for data management resides within the database tier.

For the purpose of the application, where the data is structured, it makes sense to use a relational database. The idea of tables, where data is arranged into rows and columns, serves as the framework for a relational database. Each column denotes a data attribute, whereas each row denotes a record. The relationships between the different tables are established using keys, more specifically, primary keys, and foreign keys. This structured approach allows for consistent data modeling and the enforcement of data integrity through well-defined schemas. Relational databases use [Structured Query Language \(SQL\)](#) for querying and manipulation.

The data management englobes a range of tasks, such as storing and retrieving data, handling updates, accommodating concurrent access by multiple middle-tier processes, ensuring data security and upholding data integrity. These functions are facilitated through a [RDBMS](#) in many web database applications, with data being stored in a relational database.

MySQL was the adopted [RDBMS](#) to oversee data management in this platform. MySQL has a well-established reputation for speed, particularly excelling in scenarios where data retrieval outweighs updates, and where straightforward, small-scale modifications are predominant, as it applies to the build system.

### 3.7.1 Database entities

An entity refers to a distinct and identifiable object, concept, or thing that is wanted to store and manage data about. Entities are the core building blocks of a database, and each table represents an entity within the database schema. Each row in the table represents a specific instance of that entity, and each column represents an attribute or property associated with the entity. The following are the relevant entities created for the database structuring:

- **Users:** It stores the information of both the participants and the administrator.
- **Category:** It stores the information about the different decision categories.
- **Criteria:** It stores the information of the different decision criteria.
- **Alternatives:** Stores the information of the different decision alternatives.
- **Category\_criteria:** It stores the information of the association between a decision category and its specific criteria.
- **Decision:** Stores the information regarding the decisions.
- **Decision\_participant:** Stores the information of the participants that are part of a specific decision-making process.
- **Decision\_criteria:** Stores the information of the criteria used for a specific decision.
- **Decision\_alternatives:** Stores the information of the alternatives specifically used for a certain decision.
- **Decision\_alternatives\_criterion\_values:** Stores the information of the quantifiable values given to an alternative regarding a specific criterion in a specific decision.
- **Criteria\_comparisons:** Stores the pairwise comparisons between criteria of a specific user in a specific decision.
- **Alternatives\_comparisons:** Stores the pairwise comparisons between alternatives considering a criterion, made by a user in a specific decision.
- **User\_final\_results:** Stores the results of a decision-making process made by a specific user.
- **Decision\_final\_results:** Stores the results of a decision, aggregating the results from the different participants in the decision-making process.

### 3.7.2 Data Diagram

As soon as all the entities are defined, related to each other and how data flows within the system, it is possible to visualize the data diagram, also known as the entity-relationship diagram. Data diagrams are essential during the database design phase as they provide a clear visual representation of the database schema, enabling the identification of potential issues or improvements. Due to the nature of the platform and the created tables, there are various and diverse relationships between the tables. To illustrate these relationships, Figure 7 shows the data diagram of the system.

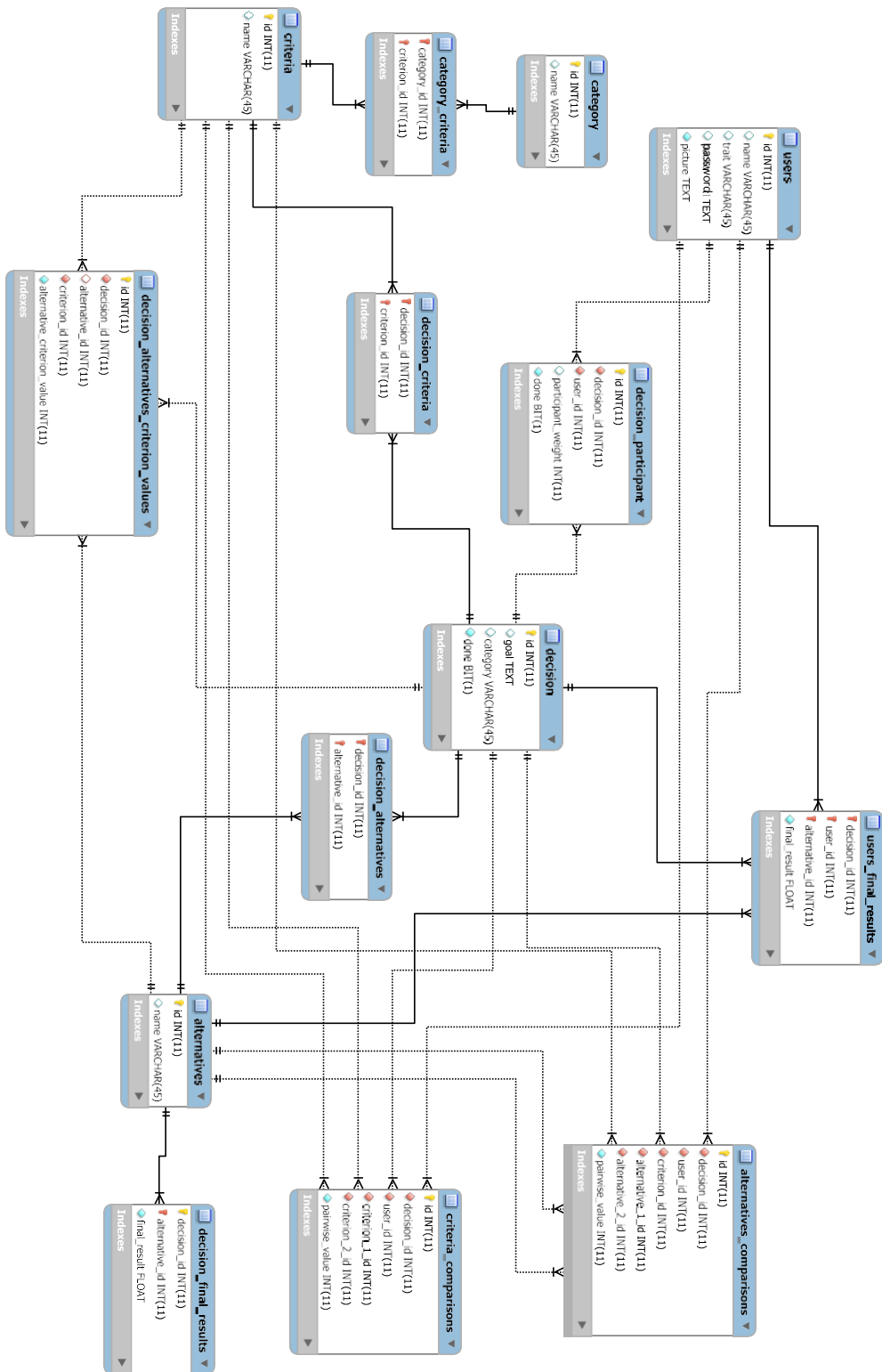


Figure 7. System Data Diagram



## CASE STUDY

In this section, an example case study is presented to understand more in concrete, the possible applications of the developed platform. Firstly, the context of the case study is explained, focusing on the organization that will carry on the decision-making process and the goal that wants to be achieved. Following that, the team that will take part in the decision process is presented and finally, the criteria and the alternatives for making the decision are defined. Having the context delineated, the platform will be used to support in three different scenarios.

### 4.1 Case Study Context

For the purpose of the case study, let us consider a company called TechSolutions. TechSolutions is a medium-sized technology company that specializes in developing innovative software and technology solutions for a small range of industries. TechSolutions is known for its commitment to excellence, technical expertise, and a culture of continuous innovation. The company has experienced steady growth and is currently exploring opportunities for expansion and diversification.

The primary goal of the decision is to strategically prioritize projects within TechSolutions. This entails identifying which projects the company should invest in, allocate resources to, and execute based on a set of predefined criteria. The overarching goal is to maximize the return on investment while considering factors such as market potential, technical feasibility, resource availability, and alignment with the company's strategic objectives.

By making informed decisions, TechSolutions aims to enhance its competitive position in the market, drive innovation and technological advancement, optimize resource allocation for project execution, ensure that the selected projects align with the company's mission and goals, and achieve long-term profitability and sustainability.

In order to bring diverse perspectives, encourage holistic thinking and ensure that the decision align with strategic goals, the decision-making group at TechSolutions for project prioritization consists of key stakeholders from various departments within the organization. This group is responsible for determining which projects should receive funding, resources, and attention based on the established criteria. The group includes:

- The **Chief Product Officer (CPO)**, who is responsible for overseeing the company's product portfolio.
- **Technical Leads**, which represent different technical teams within the company and provide technical expertise and assess the feasibility of proposed projects.
- **Project Managers**, who play a crucial role in project execution. They provide insights into resource requirements, timelines, and project management aspects.
- **Finance Department**, which evaluate the budgetary aspects of proposed projects, ensuring financial feasibility and alignment with available resources.
- **Marketing and Sales**, which have a crucial role assessing the market potential and alignment of projects with customer needs.

By using your application in this manner, TechSolutions can systematically and data-drivenly prioritize projects that align with their goals and resource availability while maximizing their return on investment.

Once the participants of the decision are defined, there is a need to define the criteria and the alternatives to access the decision.

The criteria for the described challenge are the following:

1. **Market Size:** Measure the potential market size in terms of the total addressable market in millions of dollars.
2. **Technology Readiness:** Use a scale from 1 to 20 to represent the readiness of the required technology, with 20 indicating high readiness.
3. **Technical Risks:** Use a scale from 1 to 20 to assess potential technical challenges and risks, with 20 indicating the optimal level of risk (low risk).
4. **Budget:** Measure the estimated budget required for the project in euros.
5. **Timeframe:** Use a scale from 1 to 20 to represent the expected duration of the project, with 20 indicating the optimal timeframe (lowest timeframe).
6. **Human Resources:** Specify the number of team members required for the project.

In turn, the alternatives defined are as follows:

- **Project A:** Develop a new software product for a niche market.
- **Project B:** Expand the existing product line with additional features.
- **Project C:** Invest in a research project to explore emerging technologies.
- **Project D:** Enter a strategic partnership with another technology company.
- **Project E:** Optimize internal processes and workflows.

Having defined the group, the goal of the decision, the criteria and the alternatives, the only thing missing is to attribute quantifiable values to each alternative taking into consideration each criterion. Table 21 shows these values.

Table 21. Quantifiable Values of The Case Study

<b>Project</b>	<b>Market size (Millions \$)</b>	<b>Technology readiness (1-20)</b>	<b>Technical Risks (1-20)</b>	<b>Budget (Millions \$)</b>	<b>Timeframe (Months)</b>	<b>Human resources (Nr of people)</b>
<b>Project A</b>	70	15	10	5.0	12	5
<b>Project B</b>	90	8	15	3.5	8	11
<b>Project C</b>	50	18	8	2.3	18	18
<b>Project D</b>	85	11	12	6.5	14	5
<b>Project E</b>	50	15	17	1.8	7	7

For all three scenarios, the developed platform will be used to support the decision-making method. For Both the scenario 1 and scenario 2, the initial part of the procedure to start a decision making process is the same. The administrator completes the form with all the necessary details regarding the decision. As soon as this step is done, then the chosen participants will be able to see the decision form to complete in their main page and can be part of it.

### 4.1.1 Scenario 1: Decision Making Without Predictive Analysis

For this scenario let us consider John, a relatively new addition to the project management team. While he possesses a wealth of technical knowledge and project management expertise, his tenure with the company has been relatively short. John has not had the opportunity to participate in many decisions at TechSolutions, and the few he did engage in were unrelated to the current decision at hand. The previous decisions pertained to entirely different projects and were categorized differently. This means that John lacks sufficient historical data from previous decisions for a predictive analysis of his pairwise comparisons to be conducted using the application developed for the platform. As John faces this new decision-making challenge, he is well aware of the importance of this particular choice for TechSolutions. The decision at hand involves strategically prioritizing projects within the company, taking into account criteria such as market size, technology readiness, technical risks, budget, timeframe, and human resources. Each project alternative represents a unique opportunity, and the outcome of this decision could significantly impact TechSolutions' future direction.

John proceeds to evaluate the available project alternatives (Project A, B, C, D, and E) based on his current knowledge and understanding of the decision criteria. He carefully considers each

project's potential market size, technology readiness, technical risks, budget requirements, expected timeframe, and necessary human resources. Although John lacks historical data for predictive analysis, he applies his best judgment and expertise to provide initial assessments for each criterion. These values introduced John will then be saved and as soon as he has the necessary relevant number of historical data, the system will be able to provide predictions of the pairwise comparisons on the following decision processes, making the procedure more efficient and reliable.

#### **4.1.2 Scenario 2: Participant With Predictive Analysis**

For this second scenario let us consider Lisa, a highly experienced Technical Lead at TechSolutions and has been an integral part of the company for several years. She is a seasoned professional in the world of collaborative decision-making. Over her tenure, Lisa has actively participated in numerous decisions spanning over a wide range of categories. Her substantial involvement in diverse decision-making contexts has resulted in the accumulation of a significant historical dataset within the decision-making platform. This extensive history of contributions provides her with a unique and invaluable advantage as she approaches the current decision.

Lisa's history of contributions within the platform translates into a vast repository of data at her disposal. She has consistently input her pairwise comparisons and assessments in prior decision-making processes, allowing her to access a great number of historical information. So, taking this into consideration, in Lisa's case, when she clicks on the form to make the decision created by the administrator the form displays the pairwise comparisons in a similar way to John but with a substantial difference. For each pairwise comparison, a pairwise predicted value is presented to Lisa from her previous decisions. In the interface with which Lisa interacts, she has the option to automatically press the button on the top right side of the page which says, "Autocomplete with predicted pairwise values" and every comparison will take the value from the respective predicted value.

These predicted values serve as a reference based on her previous decisions so they should be considered as correct for the current decision, since they are computed based on Lisa's decision choices for the same category of decisions. Nevertheless, Lisa should verify if all of them apply to the decision being made and change them when it makes sense to do so. This way, the system will learn from these new values and adapt for future predictive analysis.

#### **4.1.3 Scenario 3: Administrator-Driven Simulation**

Finally, for the last scenario, the creation of a simulation, let us consider Anna. Anna is the [CPO](#) of TechSolutions and was the one introducing the software to the company as an asset to improve the decision making process throughout the whole team. She is the administrator of the platform.

The context presented in 4.5.1 is similar to the context defined by Anna. However, Anna has defined more initial alternatives. Apart from the alternatives defined in the context, extra alternatives defined by Anna are the following:

- Project F: International Expansion
- Project G: Product Diversification
- Project H: Sustainability Initiatives
- Project I: Mergers and Acquisitions
- Project J: Employee Training and Development
- Project K: Customer Experience Enhancement
- Project L: Supply Chain Optimization
- Project M: New Market Research
- Project N: Intellectual Property Development
- Project O: Regulatory Compliance Enhancement

As Anna realizes that the team is in a phase with high amount of pressure due to the ongoing projects, she recognizes that it would be difficult that a significant amount of the team elements came together. Adding to this, she is aware that the number of alternatives for this decision is extremely high and such decision would be too time-consuming and overwhelming. Her goal is to streamline the decision-making process while ensuring that the chosen projects align with TechSolutions' strategic objectives. Taking this into consideration, Anna decides to leverage the capabilities of the platform to create a decision simulation. This simulation will serve as a means to tailor out the alternatives that are less popular according to the participants predicted values. Since all the team members that Anna plans to include in the decision have been part of multiple decisions, the system has sufficient data from all of them to make the predictive analysis. This way, according to the results of the simulation, she can analyze the data and from there make a choice on which alternatives have potential to be a feasible way forward and which ones should be taken out from the decision that will actually be presented to the participants.



## SYSTEM VALIDATION & TESTING

After the application is fully implemented, there is a need for verifying that the implementation was well succeeded. In this chapter there are presented the tests that were conducted to validate the platform's functionalities.

### 5.1 Testing User Registration

User registration processes are critical functionalities within the platform. The accurate operation of user registration is of great importance. During this testing phase, an examination of user registration processes takes place to guarantee the seamless functionality for administrators.

**Scenario:** An administrator initiates the user registration process by adding a new participant to the platform.

**Testing Objectives:** The primary objectives of this testing are to validate the accuracy of the user registration process and the efficacy of email notifications.

**Test Steps:**

1. **Validation of User Inputs:** Thorough testing occurs to ensure that the registration form properly validates user inputs, such as usernames, emails, and passwords.
2. **Successful Registration:** The testing process involves verifying that the registration process successfully adds the user to the system's database.
3. **Email Notification Verification:** The testing procedure confirms that an automated email notification is dispatched to the newly registered user to provide them with login credentials.
4. **Duplicate User Handling:** Error handling mechanisms are tested by attempting to register a user with a username or email that already exists in the system. The system's response is expected to display an error message.

**Test Result:** The test was conducted successfully. The administrator is able to add participants to the system in a simple way. The system verifies for duplicate entries, warning the administrator if that is the case. The participants receive an automatic email after being added to the system with the necessary information to access it.

## 5.2 Testing Decision and Simulation Creation

Decision creation stands as a pivotal administrative task within the platform. Administrators must be capable to create decisions or simulations and configure its necessary details.

**Scenario:** An administrator initiates the decision creation process by defining decision details.

**Testing Objectives:** The principal objectives of this testing are to validate that administrators can create decisions and simulations accurately.

**Test Steps:**

1. **Decision Creation:** This phase of testing encompasses the creation of a decision. Administrators fill out a form with necessary details, including decision name, participants that will take part, the decision category and respective criteria, and lastly the alternatives.
2. **Alternatives Values Configuration:** Additional testing is conducted to verify that for the chosen alternatives of the decision, it is possible to associate a quantifiable value to each of them regarding the different criteria.

**Test Result:** The test was conducted successfully. The administrator is capable of creating both a decision and a simulation with the wanted details. Once the alternatives and criteria are defined, the administrator proceeds to add the quantifiable values for the alternatives. The submission of the decision form introduces all the data in the database.

## 5.3 Testing System Configuration

System configuration constitutes a multifaceted aspect of system management. It encompasses the management of not only users in the system but also defining categories and their respective criteria.

**Scenario:** An administrator configures existing categories, criteria, and participants.

**Testing Objectives:** The principal objectives of this testing are to validate that administrators can effectively configure categories, criteria, and participant selection.

**Test Steps:**

1. **Category and Criteria Configuration:** The testing phase includes the ability to add and modify decision categories and criteria in the system.
2. **Participant Configuration:** Verification procedures are implemented to ensure that administrators can manage participants once they are in the system.

**Test Result:** The test was conducted successfully. The administrator has the capability add diverse categories to the system as well as associating new or already existing criteria to the newly created category. The system however does not allow the deleting of categories and criteria that have been already employed in any decision-making process.

## 5.4 Testing Decision Participation

Decision participation requires participants to interact with the platform, providing input and making pairwise comparisons. Ensuring the seamless and accurate execution of this process is paramount for platform success.

**Scenario:** A participant logs into the platform to participate in a decision-making process.

**Testing Objectives:** The primary goals of this testing phase are to validate the accuracy of participant interactions and the correctness of pairwise comparisons.

**Test Steps:**

1. **User Authentication Testing:** Participants must log in to the application and the validation checks ensure only authorized users access the platform.
2. **Decision Selection Testing:** Participants select a decision to participate in, and the platform must accurately present decision choices for participant selection.
3. **Pairwise Comparison Testing:** Participants perform presented pairwise comparisons for the current decision. The platform must correctly display criteria and alternatives and record participant choices.
4. **Predicted Values Display Testing:** For the participants that have sufficient historical data regarding decisions of the same category as the current one, the system provides the participant with predicted values for the pairwise comparisons.
5. **Submission and Confirmation Testing:** After completing comparisons, participants submit their choices. The system must accurately record these choices and provide confirmation to participants.

**Test Result:** The test was conducted successfully. The procedure of the participant login in the system works without any issue. In the respective home page, the participant can only take part in the decisions that were attributed to him. Moreover, the participation in a decision process runs smoothly with the system displaying all the necessary details and data to the user. As soon as the user completes the decision, the data introduced from the pairwise comparisons is stored correctly in the database.

## 5.5 Testing Decision Visualization

Effective visualization of decisions aids participants and administrators in understanding results and making informed choices. This testing phase assesses the accuracy and clarity of decision visualizations.

**Scenario:** An administrator or participant views the visualization of a completed decision.

**Testing Objectives:** The primary goals of this testing are to validate the accuracy and clarity of decision visualizations.

**Test Steps:**

1. Visual Representation Testing: The platform's representation of decision data, including criteria, alternatives, and relationships, must be examined. This includes graphical representation such as charts.
2. Data Consistency Testing: Visualized data should match the actual data entered during the decision-making process.

**Test Result:** The test was conducted successfully. The previously done decisions are available to be visualized and analyzed. The details of the decisions are presented in an organized and efficient manner in order to improve user experience. The results of the decisions are presented in bar charts that make it easy for the users to analyze.

## 5.6 Testing Predictive Analysis

The platform provides a unique feature of predicting participants' pairwise comparisons based on their historical decisions. Testing the accuracy of these predictions is crucial for enhancing decision-making efficiency.

**Scenario:** The platform predicts a participant's pairwise comparisons based on their historical decisions.

**Testing Objectives:** The primary goals of this testing are to validate the accuracy of predictive analysis and assess its impact on decision-making.

**Test Steps:**

1. Data Collection Testing: The system must collect and store sufficient historical data on participants' decisions, including pairwise comparisons and quantifiable values.
2. Prediction Accuracy Testing: The accuracy of predictive analysis is assessed by comparing its predictions with actual participant choices in new decisions.

**Test Result:** The test was conducted successfully. The system starts to evaluate if there is enough historical data from the specific participant to conduct a predictive analysis. If that is the case, the system is able to compute correctly the pairwise comparisons values.

## CONCLUSION

This chapter emphasizes the topics addressed throughout this thesis. It begins by delineating the context in which the solution was developed, examining the different applications that were adopted. Furthermore, this chapter concludes by presenting potential improvements or additions to features that could be considered for a future work.

### 6.1 Conclusion

This master's thesis project has led to the development of a web application tailored to streamline decision-making processes within multi-person settings. The primary analytical method employed was the [AHP](#), a widely recognized approach for addressing complex decision scenarios.

The application empowers administrators to create custom decision-making scenarios by specifying participants, criteria, alternatives, and other relevant parameters, ensuring it can accommodate a wide spectrum of decision scenarios. The integration of the [AHP](#) method lends structure and objectivity to the decision-making process by offering participants a systematic framework for conducting pairwise comparisons between alternatives, thereby enhancing decision quality.

Quantifiability of alternatives is a core principle in the application. The decision makers in group can assign numerical values or units to alternatives, bolstering the precision and objectivity of the decision-making process. This quantifiability of the alternatives, opens the door for the innovative aspect of the application which is the predictive analytics capability. Employing linear regression, it can forecast how participants are likely to conduct pairwise comparisons based on their past decision patterns. This predictive function empowers administrators to anticipate participant preferences, thus enhancing decision analysis.

Furthermore, the predictive analytics component underpins the simulation feature, enabling the analysis of decision scenarios without requiring active participant involvement. The system leverages predicted pairwise comparisons derived from historical data, facilitating scenario analysis and strategic planning. The work done underscores the importance of adaptability in decision support systems, ensuring they can cater to the unique requirements of diverse organizations and decision contexts. The predictive analytics component adds a data-driven dimension to decision analysis, while the simulation feature provides flexibility for scenario analysis.

## 6.2 Future work

As the master's thesis project reaches its current stage, although the work was successful, there is still room for future development and improvement of the platform. One aspect that warrants attention is the predictive modeling incorporated into the application. Currently, the model relies on linear regression to anticipate how participants conduct pairwise comparisons between alternatives. While this is a valuable feature and a light, easy and efficient solution, future work could explore more advanced machine learning techniques. Techniques such as neural networks or support vector machines can potentially enhance the accuracy and granularity of predictions. This would provide administrators with increasingly accurate insights into participant preferences, resulting in the enhancement of the decision-making process.

Regarding the platform design, given the prevalence of mobile devices, optimizing the application for mobile platforms can also be an interesting way of improving the platform since it can further enhance accessibility and user engagement on mobile platforms.

Finally, another area to explore for future development is the expansion of the application to support real-time collaborative decision-making sessions. Maintaining an effective feedback loop with participants and administrators is essential for ongoing improvement. Features such as live chat, synchronized updates, and collaborative scoring can significantly enhance the interactive decision-making experience, particularly in team-based decision scenarios. This way, the platform could be used for the discussions previously to the decision-making process itself. Regular communication and engagement can provide insights into participants' needs, pain points, feature requests, and areas for improvement. Responsiveness to participants' feedback will be instrumental in ensuring the application remains relevant and effective.

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