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Application of AHP in Civil Engineering- A Review

Pravin V. Desai[1] and Shreyas Pande[2]
Assistant Professor,Civil Engineering Department[1,2]
D.Y.Patil College of Engineering and Technology, Kolhapur[1]
Chhatrapati Shivaji Maharaj Institute of Technology, Panvel, Navi Mumbai[2]

Abstract*: The real world has many problems to be solved, including selection decisions, and one initial step is to identify problem characteristics and obtain their measures. This is termed as modelling process. AHP (Technique for Order Preference by Similarity to Ideal Solution) is a prominent distance-based MCDM/MADM (multi-criteria or multi-attribute decision making) technique. AHP is a useful technique to handle real world MCDM problems. It helps decision maker(s) (DMs) conduct analysis, comparisons, and rankings of available alternatives when multiple criteria are involved. This paper will review its origin followed by developments in various fields of civil engineering.*

Keywords: civil engineering.

I. INTRODUCTION

The Analytic Hierarchy Process is a powerful multi-criteria decision-making tool that allows decision-makers to structure complex problems into a hierarchical form, enabling the systematic evaluation of alternative options based on a set of criteria. This method, developed by Thomas L. Saaty in the 1970s, provides a consistent and quantifiable approach to prioritizing decisions when dealing with multiple, often conflicting, factors(Saaty, 2013).

The core of the AHP method involves three key steps: hierarchical decomposition, pairwise comparisons, and synthesis of priorities. First, the decision problem is broken down into a hierarchy, with the overall goal at the top, followed by the relevant criteria, sub-criteria, and finally, the alternative options. Next, the decision-maker conducts pairwise comparisons between the elements at each level, assigning relative importance values using a standardized scale. These pairwise comparisons are then used to calculate the priority weights for each element, allowing for the ranking of the alternative options.

The AHP method has been successfully applied to a wide range of decision-making scenarios, including forest road investment prioritization, beach object design selection, and other complex problems involving multiple, often conflicting, factors. By providing a structured and quantifiable approach to decision-making, the AHP method helps decision-makers reach more informed and well-justified conclusions, leading to better outcomes.

The Analytical Hierarchy Process has emerged as a prominent decision-making tool in the realm of multi-criteria decision-making since its introduction by Thomas L. Saaty in the 1970s (Harker, 1987). The core principle of this method lies in its ability to decompose complex problems into hierarchical structures, allowing decision-makers to prioritize and weigh various criteria to arrive at a well-informed conclusion. The fundamental approach of the Analytical Hierarchy Process involves establishing a hierarchical structure that captures the primary goal, the relevant criteria, and the potential alternatives or courses of action. This structured representation enables decision-makers to systematically assess the relative importance of each factor and its impact on the overall objective. The process of pairwise comparisons, wherein decision-makers assess the relative importance of two criteria or alternatives, forms the crux of the Analytical Hierarchy Process.

The Analytical Hierarchy Process has found applications in diverse domains, including forest road investment prioritization, campus bookstore location selection, and various other areas where multi-criteria decision-making is crucial. The versatility of the Analytical Hierarchy Process lies in its ability to handle both quantitative and qualitative data, allowing for a comprehensive evaluation of complex problems.

Researchers have also explored methods to streamline the comparison process and enhance the efficiency of the Analytical Hierarchy Process, such as utilizing the derivatives of the right Perron vector and graph-theoretic interpretations of positive reciprocal matrices.

AHP Algorithm

Steps involved in the AHP method

The Analytic Hierarchy Process is a widely recognized decision-making methodology that assists individuals, groups, and organizations in structuring complex problems, evaluating alternative solutions, and arriving at informed decisions. The key steps involved in this process are as follows:

First, the problem is modeled as a hierarchy, where the overall goal or objective is at the top, followed by the criteria and sub-criteria that influence the decision, and finally, the alternative solutions or options at the bottom. This hierarchical structure helps decision-makers better understand the relationships between the various elements of the problem.

Next, pairwise comparisons are made to determine the relative importance or preference of each element within the hierarchy. The decision-maker compares each pair of elements at the same level and assigns a numerical value to represent the strength of their preference for one element over the other. These pairwise comparisons are typically based on a 1-9 scale, where 1 indicates equal importance and 9 indicates an extreme preference for one element over the other.

Once the pairwise comparisons are complete, the next step is to calculate the priority or weight of each element within the hierarchy. This is done by normalizing the pairwise comparison matrices, which involves dividing each element by the sum of its column.

The final step in the AHP process is to synthesize the results and arrive at a decision. The priority weights of the alternatives are calculated by multiplying the alternative priority weights with the priority weights of the criteria, and then summing the results.

The Analytical Hierarchy Process in Civil Engineering: Advantages and Limitations

The Analytical Hierarchy Process has been a valuable tool in the field of civil engineering, offering a structured approach to decision-making and problem-solving. This paper aims to explore the advantages and limitations of AHP in the civil engineering domain, drawing insights from existing research.

One of the key advantages of AHP is its ability to effectively handle both quantitative and qualitative factors in the decision-making process (Alqahtani & Rajkhan, 2020). This is particularly relevant in civil engineering, where projects often involve a complex interplay of technical, economic, and environmental considerations. By breaking down a problem into a hierarchical structure of goals, objectives, and sub-objectives, AHP allows decision-makers to systematically evaluate and prioritize these diverse criteria, leading to more informed and well-rounded decisions(Partovi et al., 1990).

Moreover, AHP has been successfully applied in various civil engineering contexts, such as facility location selection, maintenance frequency optimization, and the evaluation of wind turbine performance(Huang et al., 2018). The method's ability to provide a consistent and quantifiable approach to multi-criteria analysis has made it a valuable tool for civil engineers facing complex trade-offs and decisions.

However, the use of AHP in civil engineering is not without its limitations. While the method provides a structured framework, the reliability of the results is heavily dependent on the quality of the input data and the subjective judgments of the decision-makers. Specifically, the traditional AHP approach has been criticized for its reliance on intuitive judgments, which may lack extensive investigation and statistical analysis to support the quantitative composition of the analysis process.

To address this limitation, researchers have proposed various modifications and enhancements to the AHP method in the context of civil engineering. For example, integrating AHP with other techniques, such as fuzzy logic or statistical analysis, can help improve the robustness and objectivity of the decision-making process.

Overall, the Analytical Hierarchy Process has demonstrated its potential as a valuable decision-making tool in civil engineering. While it offers several advantages, such as the ability to handle multiple criteria and provide a structured approach, the method's effectiveness is contingent on the quality of the input data and the subjective judgments of the decision-makers. To fully harness the benefits of AHP in civil engineering, on-going efforts to refine and enhance the method, as well as to integrate it with other techniques, will be crucial.

Applications of AHP in civil engineering

Applications in Structural engineering

One of the key applications of AHP in structural engineering is the selection of the optimal cool storage type for air-conditioning systems. The improved AHP method has been shown to be an effective quantitative approach for making such decisions, offering a universal applicability across a range of applications, from simple personal decisions to complex capital-intensive ones(Zheng & Jing, 2008).

In addition to these applications, AHP has been employed in other areas of operations management within the field of structural engineering. It has been used in forecasting, supplier selection, facility location, and the choice of technology, among other applications. The versatility of AHP allows it to be applied to a wide range of decision-making problems in structural engineering, from the selection of materials and components to the optimization of construction processes.

Applications in Geotechnical engineering

Geotechnical engineering, a critical field within the broader domain of civil engineering, deals with the design, construction, and analysis of structures that interact with the earth's surface and subsurface. Analytical Hierarchy Process, a multi-criteria decision-making tool, has found increasing application in various aspects of geotechnical engineering.

In the realm of geotechnical engineering, AHP has demonstrated its potential in various applications. One such application is in the prioritization of forest road investments, where AHP can be used to rank different road construction and maintenance alternatives based on multiple criteria, including environmental impact, cost, and accessibility(Coulter et al., 2006). Additionally, AHP can be employed in the selection of suitable geotechnical materials, the evaluation of slope stability, and the optimization of foundation design.

Overall, the application of AHP in geotechnical engineering has proven to be a valuable tool in addressing complex decision-making challenges, where multiple, often conflicting, factors must be considered.

Applications in transportation engineering

The Analytic Hierarchy Process is a powerful multi-criteria decision-making tool that has found numerous applications in various fields, including transportation engineering. In the context of transportation, AHP has been utilized to address a wide range of challenges, from infrastructure planning to logistics optimization(Susano et al., 2019).

One application of AHP in transportation engineering is the prioritization of forest road investments to minimize environmental impacts and maximize economic benefits. The hierarchical structure of AHP allows for the consideration of multiple criteria, such as ecological, social, and economic factors, in the decision-making process. Similarly, AHP has been used in the design of beach objects in Bali, where the method aids in the prioritization of tourist attraction destinations based on community preferences.Beyond infrastructure planning, AHP has also found applications in operations management within the transportation industry. The method has been employed in supplier selection, facility location, and the choice of transportation technology, enabling decision-makers to navigate complex trade-offs and arrive at informed decisions.

Applications in construction management

The construction industry is a complex and dynamic field that often requires decision-making processes involving multiple criteria and stakeholders. The Analytic Hierarchy Process has emerged as a valuable tool for addressing these challenges in construction management (Danesh et al., 2015).

One key application of AHP in construction management is in the area of supplier selection. Construction projects often involve procuring materials, equipment, and services from multiple suppliers and the AHP can be used to evaluate and select the most appropriate suppliers based on criteria such as cost, quality, delivery time, and past performance. Another application of AHP in construction management is in facility location decisions. When planning new construction projects, the AHP can be used to evaluate and select the optimal site for a facility based on factors such as accessibility, infrastructure, environmental impact, and proximity to key stakeholders.

The AHP has also been used in construction management for project selection and prioritization. By breaking down the decision-making process into a hierarchy of criteria, decision-makers can more effectively evaluate and prioritize different construction projects based on their potential benefits, costs, and risks.

Applications in Environmental Engineering

The Analytic Hierarchy Process is a versatile decision-making tool that has found numerous applications across various domains, including operations management and environmental engineering. In the context of environmental engineering, AHP has demonstrated its utility in addressing complex challenges involving multiple criteria, both quantitative and qualitative in nature.

One area where AHP has been particularly effective is in prioritizing forest road investments to minimize environmental impact. Traditionally, forest road management decisions have relied on expert judgment, which can be subjective and inconsistent. AHP provides a environmental approach to systematically evaluate alternatives based on a hierarchical decomposition of the problem, pairwise comparisons, and the scaling of attribute values. Furthermore, the use of AHP has been explored in the selection of optimal cool storage types for air-conditioning systems, a critical consideration in environmental engineering. The improved AHP method has been shown to offer an effective quantitative approach to making such complex decisions, with universal applicability across various fields.

Comparison of Analytic Hierarchy Process with Other Multi-Criteria Decision-Making Methods

The Analytic Hierarchy Process has been a widely used multi-criteria decision-making method since its development by Thomas L. Saaty in the 1970s. However, it faces certain limitations, particularly when dealing with a large number of alternatives. One key issue is the large number of pairwise comparisons required, which can become prohibitive as the number of alternatives increases.

To address this limitation, researchers have proposed various extensions and modifications to the original AHP method. One approach is to utilize a method with clusters and pivots, which can help reduce the number of required judgments while also addressing other AHP limitations such as the choice of priorities derivation method and the ability to handle incomparable alternatives. Another proposed solution is to use a generalized formula to generate valid approaches that follow prescribed rules for criteria comparison, which can provide a more unified approach to AHP(Schoner et al., 1993).

While AHP has been successfully applied in many domains, including forest road investment prioritization, its reliance on expert judgment and pairwise comparisons can be challenging, especially for complex problems with a large number of criteria and alternatives. Researchers have therefore explored ways to streamline the AHP process, such as using the derivatives of the right Perron vector and a graph-theoretic interpretation of the positive reciprocal matrix to shorten the comparison process. Ultimately, the selection of an appropriate multi-criteria decision-making method will depend on the specific problem at hand, the number of alternatives and criteria, the availability of data, and the decision-maker's preferences.

Integration of AHP with Other Techniques

The Analytic Hierarchy Process is a widely-used multi-criteria decision-making technique that has been extensively studied and applied in various domains, including business, engineering, and social sciences. While AHP is a powerful tool for prioritizing and evaluating alternatives, it is often advantageous to integrate AHP with other techniques to enhance its capabilities and address specific challenges.

One such integration is the combination of AHP with fuzzy logic, which allows for the handling of uncertainty and imprecision in decision-making. Fuzzy AHP has been used in areas such as supplier selection, facility location, and product design, where qualitative and subjective factors play a crucial role. The integration of fuzzy theory helps to overcome the limitations of AHP, such as its susceptibility to extreme values and the subjectivity in the establishment of the hierarchical relationships.

Another area of integration is the use of AHP in conjunction with other multi-criteria decision-making methods, such as TOPSIS, VIKOR, and ELECTRE. These techniques can be used to rank and select alternatives based on their performance across multiple criteria, with AHP providing the weights for the criteria. For example, a study on the selection of a manual workshop layout used AHP to determine the weights of the criteria and then applied TOPSIS to rank the potential configurations(Besbes et al., 2017).

Current Limitations of AHP in Civil Engineering Applications

The Analytic Hierarchy Process has been widely used in civil engineering applications to aid decision-making, but it is not without its limitations. One of the primary drawbacks of AHP is the increasing complexity and number of pairwise comparisons required as the number of alternatives grows. This can become prohibitively time-consuming, especially in scenarios with a large number of potential options.

Additionally, even when the number of alternatives is manageable, the reliance on expert judgment to inform the pairwise comparisons can introduce subjectivity and bias into the decision-making process. Another limitation of AHP in civil engineering is its inability to effectively handle incomparable alternatives, which can often arise in complex infrastructure projects. Furthermore, the hierarchical structure of AHP may not always accurately reflect the interdependencies and relationships between different criteria and sub-criteria, leading to potential oversimplification of the decision problem.

Expanding the Horizons of Analytic Hierarchy Process: Potential Areas for Improvement and Growth

The Analytic Hierarchy Process has been a widely adopted decision-making tool in various fields, including operations management, strategic planning, and resource allocation. However, as the complexity of decision-making scenarios increases, the method faces several limitations that warrant further exploration and enhancement.

One significant area for improvement is the reduction of the number of pairwise comparisons required in the AHP. As the number of alternatives grows, the number of comparisons required increases exponentially, which can become prohibitively time-consuming and burdensome for decision-makers. To address this challenge, researchers have proposed methods such as the use of clusters and pivots, which can help to streamline the comparison process and reduce the overall effort required. Another potential area for expansion is the application of AHP in more diverse operational contexts. While the method has been successfully applied in areas like forecasting, supplier selection, and facility location, there are numerous other areas within operations management where AHP can be leveraged, such as product design, plant layout, maintenance frequency selection, and the choice of logistics carriers.

The improved AHP method, with its ability to handle qualitative decision areas, offers a promising path forward for enhancing the effectiveness and versatility of the technique. By exploring these potential areas for improvement and expansion, researchers and practitioners can unlock new opportunities for the Analytic Hierarchy Process to contribute to more sophisticated and informed decision-making across a wide range of applications.

The Role of Analytic Hierarchy Process in Civil Engineering Decision-Making

The Analytic Hierarchy Process is a versatile decision-making tool that has found widespread application in civil engineering(Saaty, 2013). This structured approach allows practitioners to consider both quantitative and qualitative factors, making it well-suited for the complex, multi-criteria decisions that are common in the field.

The AHP process begins by decomposing a problem into a hierarchical structure, with the overall goal at the top, followed by objectives and sub-objectives. This allows decision-makers to thoroughly examine the various aspects of the problem. Next, pairwise comparisons are used to determine the relative importance of each element, capturing the subjective judgments of experts. The results are then synthesized to rank the available alternatives and identify the optimal solution.

The utility of the AHP in civil engineering has been demonstrated across a variety of applications. One study examined the use of AHP for prioritizing forest road investments, where the method was found to provide a consistent and quantifiable approach to evaluating multiple criteria. Similarly, researchers in Saudi Arabia used AHP to identify the critical success factors for e-learning during the COVID-19 pandemic, highlighting the method's versatility beyond traditional civil engineering domains. Other potential applications of AHP in operations management include forecasting, supplier selection, facility location, and the choice of technology. Overall, the Analytic Hierarchy Process has proven to be an effective tool for supporting decision-making in civil engineering. Its ability to integrate quantitative and qualitative factors, as well as its structured and transparent approach, make it a valuable asset for practitioners faced with complex, multi-criteria problems(Siregar & Widodo, 2022).

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