

Environmental Impacts of the Mashhad's Southern Bypass on Sustainable Development

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Abstract: Environmental management is crucial in infrastructure projects like road construction. It aims to identify how these projects impact the surrounding environment, understand the interactions between the project and its environment, and assess the effectiveness of these impacts. Effective environmental management can lead to optimal design strategies that minimize environmental harm. This study focuses on environmental management in relation to the Southern Belt project in Mashhad. It evaluates the project's environmental impact using sustainable development indicators. The evaluation employs two main approaches: exploratory methods (descriptive-survey) and hierarchical analysis (AHP). The exploratory approach involves both library and field studies to gather information for the AHP analysis. The AHP method, using expert input and questionnaires, assesses the impact of various factors on the environment around the belt. The study identifies eight main factors influencing the project: human, environmental, managerial, social, economic, and political factors. Among these, environmental factors have the most significant impact (47%), followed by political factors (19.4%), while economic factors have the least impact (2.8%). The model's validity and reliability, assessed using convergence and Cronbach's alpha approaches, show it is valid with coefficients of 0.89 and 0.748, respectively.

Keywords: Environmental management, Road construction, Exploratory approach, Hierarchical analysis, Mashhad.

I. INTRODUCTION

Sustainable development can be defined as the interaction between the environment and urban development. After the one-sided economic and social development that followed the Industrial Revolution in France, which caused significant environmental damage globally, the concept of sustainable development has gained serious attention from the international community (Parris & Kates, 2003). The goal is to prevent the implementation of uncontrolled industrial structures that lead to adverse environmental consequences (Elliott, 2012). In other

words, sustainable development encompasses actions aimed at ensuring a desirable future for human societies by improving living conditions, resource utilization, aesthetic value, and the stability of vital systems based on specific requirements (Mitlin, 1992). Emphasized since the 1990s, sustainable development focuses on the interactive relationship between humans and the environment and aims to allocate resources for future generations. The term 'sustainable development' was first used by Barbara Ward in the 1970 Cocoyoc Declaration on environment and development. This was followed by global strategies from the Club of Rome (modoze 75), the Hammer-schold Foundation, and the International Union for Conservation of Nature (IUCN-82), which sought to achieve sustainable development through the protection of essential resources. The concept gained significant attention from scholars and development thinkers (Elliott, 2012).

The term was officially defined in the 1987 Brundtland Report by the World Commission on Environment and Development (WCED), which provided a set of proposals and legal principles for achieving sustainable development in developing countries. Subsequently, the issue of sustainable development was extensively discussed at the 1992 United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro (Mitlin, 1992). This conference highlighted the importance of proper and efficient management of natural, financial, and other resources to achieve an optimal consumption pattern (Elliott, 2012). The conference results established key objectives based on sustainable development, including revitalizing economic growth, improving the quality of growth, meeting essential needs, ensuring population sustainability, protecting and enhancing natural resources, reorienting technical knowledge (including indigenous knowledge), environmental and economic decision-making, and adjusting international economic relations (Jabareen, 2008). These goals encompass social, economic, fundamental, and environmental aspects of sustainable development, which must be thoroughly addressed and examined (Parris & Kates, 2003).

Sustainable development in construction and infrastructure refers to the practice of designing, building, and managing projects in a way that meets current needs without compromising

the ability of future generations to meet their own needs. It integrates environmental stewardship, social responsibility, and economic viability to create structures and systems that have a minimal negative impact on the environment while providing long-term benefits to communities (Parris & Kates, 2003). This approach considers the entire lifecycle of a project, from planning and design to construction, operation, and eventual decommissioning or renovation. In construction, sustainable development emphasizes the use of environmentally friendly materials and practices (Elliott, 2012). This includes selecting materials that are renewable, recyclable, or have low environmental impact during their production and use. It also involves minimizing waste through efficient use of resources and incorporating recycling and reuse strategies. Building designs often incorporate energy-efficient technologies and systems, such as high-performance insulation, renewable energy sources like solar panels, and water-saving fixtures, to reduce the overall ecological footprint of the building (Jabareen, 2008).

Infrastructure projects, such as roads, bridges, and utilities, also benefit from sustainable development practices. Sustainable infrastructure aims to minimize environmental disruption and promote resilience against climate change (Elliott, 2012). This involves using sustainable materials, optimizing land use, and incorporating green infrastructure elements like permeable pavements and stormwater management systems. By considering the environmental impact of construction activities and the operational phase of infrastructure, sustainable development helps to reduce carbon emissions, manage natural resources more effectively, and protect ecosystems (Blewitt, 2012). Another key aspect of sustainable development in construction and infrastructure is social responsibility. This involves ensuring that projects contribute positively to communities by enhancing quality of life, providing equitable access to resources, and supporting local economies (Elliott, 2012). Sustainable projects are designed to be inclusive and accessible, addressing the needs of diverse populations and fostering community engagement throughout the planning and implementation phases. By prioritizing social equity, sustainable development helps to create environments that are not only functional but also supportive of community well-being (Jabareen, 2008).

Economic viability is also crucial in sustainable development. Sustainable projects are designed to be cost-effective over their entire lifecycle. This includes considering not only initial construction costs but also long-term operational and maintenance expenses (Carley & Christie, 2017). By focusing on efficiency and durability, sustainable development aims to deliver value for money and reduce the total cost of ownership. This approach encourages investments in technologies and practices that may have higher upfront costs but result in significant savings and benefits over time (Blewitt, 2012). Ultimately, sustainable development in construction and infrastructure represents a holistic approach to building and managing projects that balance environmental, social, and economic considerations. It requires collaboration among architects, engineers, planners, and other stakeholders to create solutions that are innovative, resilient, and adaptable to future challenges (Londoño-Pineda et al., 2021). By integrating these principles into every stage of a project, sustainable development

ensures that construction and infrastructure contribute positively to a sustainable future (Carley & Christie, 2017).

The current study evaluates the technological and environmental sustainability of the Southern Belt project in Mashhad, located in Khorasan Razavi Province. This evaluation considers various influential factors related to sustainable development, such as economic and social conditions, with a focus on the project's environmental impact. The study aims to develop a targeted approach based on sustainable development indicators to assess the importance and sensitivity of each parameter. The study employs the Analytic Hierarchy Process (AHP), a popular multi-criteria decision-making method, to prioritize and evaluate the impact of factors on the project's environmental goals. AHP helps in determining the priority and influence of criteria, whether independent or dependent, by defining and assessing them through a hierarchical structure. This method uses pairwise comparisons and matrix analysis to ensure that decisions are made with high accuracy and consistency. Overall, the AHP approach is effective in ranking and assessing the importance of various factors in multi-criteria decision-making, providing a quantitative model that covers a wide range of indicators. This allows for continuous assessment and prioritization of parameters, offering a comprehensive evaluation of their impact on the project's environmental objectives.

II. ENVIRONMENTAL PERFORMANCE INDEX

Due to the growing importance of environmental concerns and the alarming levels of environmental degradation and pollution on Earth, researchers worldwide have dedicated significant efforts over the years to developing suitable environmental indicators (Elliott, 2012). These indicators are designed to monitor and assess global environmental processes, providing benchmarks for comparative studies between countries (Azizpour et al., 2020). Despite criticisms regarding the nature of these indicators and the accuracy of the data used, there are relatively effective metrics for evaluating environmental performance across nations. Among these, the Environmental Performance Index (EPI) is considered one of the most comprehensive environmental indicators due to its broad approach (Elliott, 2012).

The EPI was developed because traditional metrics like eco-policies lacked the necessary scientific precision and numerical accuracy. While the seventh Millennium Development Goal (MDG), which focuses on ensuring environmental sustainability, initially highlighted the concept of sustainable development in global policy frameworks, it lacked specific metrics. To address this gap, Yale University's Center for Environmental Law and Policy (YCELP) and Columbia University's Center for International Earth Science Information Network (CIESIN), in collaboration with the Economic Studies Institute, developed indicators to assess environmental performance, leading to the creation of the EPI (Blewitt, 2012).

The EPI is a comprehensive tool designed to evaluate and compare the environmental performance of countries (Szabo et al., 2021). Developed to address gaps in traditional environmental metrics, the EPI provides a standardized framework for assessing how well nations are achieving their

environmental goals (Nuong et al., 2011). It offers a detailed analysis of a country's environmental health and ecosystem vitality, helping policymakers and researchers understand and improve their environmental impact (Blewitt, 2012). The EPI employs a 'distance-to-target' methodology to gauge how close a country is to reaching its environmental objectives. This approach involves setting specific targets for various environmental indicators and measuring the distance between current performance and these targets (Carley & Christie, 2017). The closer a country is to achieving its goals, the higher its EPI score. Scores are scaled from 0 to 100, where 0 represents the furthest distance from the target and 100 represents the closest proximity. This method provides a clear and quantifiable measure of environmental performance (Szabo et al., 2021).

The EPI is divided into two main categories: Environmental Health and Ecosystem Vitality. Environmental health assesses aspects such as air quality, water and sanitation, and the impact of health effects from environmental factors (Elliott, 2012). Ecosystem Vitality evaluates elements like water resources, agriculture, forests, fisheries, biodiversity, and climate and energy. Each category is further broken down into specific indicators that measure various aspects of environmental performance. The combination of these indicators offers a holistic view of a country's environmental status (Boccia et al., 2013). The EPI uses data from multiple sources, including international treaties, standards set by global organizations, national statistics, and expert judgments. These data sources provide a robust foundation for evaluating a country's environmental policies and practices. The indicators are weighted based on their relevance and the quality of the data available. This weighting ensures that the most significant and accurate measures have the greatest impact on the overall EPI score. In the 2014 EPI, the Environmental health component was weighted at 40%, while ecosystem vitality was given a weight of 60%. This distribution reflects the importance of maintaining a balance between human health and ecological sustainability. It highlights the interdependence of these two aspects, emphasizing that a healthy environment is essential for the well-being of human populations. The weighting system helps to prioritize areas where improvements can have the most significant impact on overall environmental performance (das Neves Almeida & García-Sánchez, 2016). Finally, the EPI serves as a valuable tool for governments, organizations, and researchers aiming to track and enhance environmental performance. By providing a clear and quantifiable measure of progress towards environmental goals, the EPI helps to identify areas of strength and opportunities for improvement. It supports evidence-based decision-making and encourages countries to adopt more effective environmental policies and practices, ultimately contributing to global sustainability efforts (Boccia et al., 2013).

III. ENVIRONMENTAL SUSTAINABLE DEVELOPMENTS

In urban communities, sustainability indicators serve as leading measures of sustainability and reflect essential components for the long-term economic, social, and environmental health of society across generations. These indicators are distinguished from simple environmental, economic, and social metrics by their integrative nature, forward-

looking perspective, distributive qualities, and multi-organizational performance (Oțoiu & Grădinaru, 2018). Integrative indicators illustrate the connections between economic, environmental, and social dimensions, demonstrating their integrated and nature. For example, the extent of damaged land within an urban area is a type of integrative indicator that reflects how environmental degradation intersects with urban development. These indicators help in understanding how various aspects of sustainability are interconnected and impact one another (Kaymaz et al., 2022). Indicators that focus on future outcomes are particularly useful for assessing progress towards achieving generational equity. These indicators are designed to provide a vision of future conditions and can help in evaluating whether current actions are paving the way for a sustainable future. They allow for the anticipation of future scenarios based on present trends and conditions (Nuong et al., 2011).

One common method for representing these characteristics is through trend indicators. A trend indicator explains historical trends and provides indirect information about future sustainability (Elliott, 2012). By analyzing past data and trends, policymakers can gain insights into potential future outcomes and adjust their strategies accordingly. These indicators are instrumental in shaping new policies and making informed decisions. Sustainability indicators in urban settings are crucial for assessing and guiding sustainable development. They offer a comprehensive view of how different aspects of sustainability interact and impact long-term societal well-being (Nuong et al., 2011). By utilizing these indicators, cities can better plan for a balanced and resilient future, ensuring that economic, social, and environmental goals are met in harmony. So, sustainability indicators are essential tools for urban planning and policy-making. They provide valuable insights into the interplay between various dimensions of sustainability, help in forecasting future conditions, and support the development of strategies aimed at achieving long-term sustainability goals (Poveda & Lipsett, 2013).

Environmental sustainable development in construction and infrastructure is all about creating projects that meet our current needs while also ensuring that future generations can enjoy the same resources and quality of life (Blewitt, 2012). It focuses on integrating environmental care with economic and social goals, aiming to design and manage buildings and infrastructure in ways that have minimal negative effects on the environment and provide long-lasting benefits to communities (Elliott, 2012). A major aspect of sustainable development is resource efficiency. This involves using materials, energy, and water in a way that minimizes waste and reduces environmental impact. For instance, sustainable construction might involve using recycled materials, installing energy-efficient systems, and designing buildings that use natural light effectively to cut down on energy use. By being mindful of how resources are used, sustainable development helps to conserve valuable natural assets (Poveda & Lipsett, 2013).

Reducing the environmental impact of construction projects is another key goal. Sustainable development seeks to minimize pollution, cut down on waste, and protect natural ecosystems. Techniques such as green building practices, which follow standards like Leadership in Energy and Environmental Design (LEED), help achieve lower environmental impacts (Nuong et

al., 2011). This focus on minimizing harm is crucial for protecting our planet's health (Kaymaz et al., 2022).

Long-term resilience is also a critical component. Sustainable development aims to create infrastructure that can withstand future challenges, such as climate change and resource scarcity (Solangi et al., 2021). This involves designing buildings and systems that are durable and adaptable to changing environmental conditions. For example, using materials that are resistant to extreme weather helps ensure that structures remain safe and functional over time (Ahmad & Tahar, 2014). Economic viability is another important consideration. Sustainable development must balance environmental benefits with economic realities. This means finding cost-effective solutions that also offer long-term savings. Energy-efficient buildings, for example, may have higher initial costs but lower operating costs due to reduced energy consumption. By focusing on these long-term savings, sustainable development ensures that investments in green practices are economically justified (Solangi et al., 2021). Lastly, social benefits play a significant role. Sustainable development considers the impact on communities, aiming to enhance quality of life through healthier living environments and equitable access to resources. Engaging local stakeholders in the planning process ensures that projects meet community needs and contribute positively to societal well-being. By integrating social considerations, sustainable development helps build more supportive and inclusive communities (Elliott, 2012).

IV. MATERIALS AND METHODS

A. Region Overview

Khorasan Razavi Province, located in northeastern Iran, is a part of the larger Khorasan province. The region experiences moderate and relatively average rainfall and humidity. According to the 2011 national census, the population of Khorasan Razavi was 5,996,602, showing an average annual growth rate of 1.4% compared to the 5,593,079 reported in 2006. Additionally, the urbanization rate in the country increased from 68.5% to 71.4% between 2006 and 2011 (Ghalam, 2013).

Mashhad is a major city situated in the northeastern part of Iran and serves as the capital of Khorasan Razavi Province. Covering an area of 351 km², Mashhad is the second-largest city in Iran after Tehran in terms of area and population, according to the 2016 census. The city lies in the Mashhad plain, between the Khasht Rud River and the Binalud and Hezar Masjed mountain ranges. Mashhad has a variable climate, characterized as mild, with hot, dry summers and cold, humid winters. It is divided into 13 municipal districts and features an international airport, a railway station, and three bus terminals, facilitating connectivity with other cities. Internal transportation within Mashhad is managed by a network of taxis, buses, and a metro system. The city's economy heavily relies on religious tourism, particularly focused on the shrine of Imam Reza (Zanganeh et al., 2013).

B. Geology of the Region

The Mashhad Plain is a vast valley extending over 100 km in length and averaging about 25 km in width, with a total area of approximately 2,500 km². From a geological perspective, the Mazurian Formation within this plain is significant for groundwater resources. This formation, composed of hard

carbonate sediments, has karstic spaces capable of hosting groundwater reservoirs. The Khasht Rud River is one of the surface water sources in the Mashhad Plain (Moteahd et al., 2019). In addressing environmental pollution, significant initiatives have been undertaken in Mashhad. One major effort includes the use of eco-friendly technologies and the establishment of the largest solar power plant in the country. This solar plant features a solar tracking system that boosts electricity production by 20%. Additionally, Mashhad inaugurated its first biogas power plant in 2009, which has contributed positively to the environment by capturing and burning ozone-depleting gases to generate electricity. A third biogas plant is planned for the near future. Moreover, Mashhad has become the first city in the region to produce granulated sulfur-containing organic fertilizers at its compost plant, which supports environmental conservation and sustainable agriculture (Ghalam, 2013).

The city faces significant air quality issues, with over 800,000 vehicles operating daily, contributing to 70% of the city's air pollution. There are approximately 4.2 million daily trips within Mashhad, with 1.2 million passengers transported. Currently, only 50% of these trips utilize public transportation. Each year, about 40,000 new vehicles enter the city's road network, adding to traffic congestion and pollution. Additionally, around 6% of urban trips are made by bicycle, reflecting an effort to promote more sustainable modes of transport. Mashhad is addressing its environmental and transportation challenges through various sustainable practices and infrastructure projects. These efforts aim to improve air quality, manage resources efficiently, and enhance overall urban sustainability while supporting the city's significant role as a major religious and economic center.

C. Multi-criteria Decision-Making

Multi-criteria decision-making (MCDM) is rapidly evolving as a key approach in management evaluations globally. Among various decision-making methods, those grounded in scientific and mathematical principles have garnered the most attention. MCDM methods employ criteria, sub-criteria, and indicators to guide decision-making through various stages, including selecting the most preferred option, ranking alternatives based on their significance, and testing options to arrive at the final decision. In general, MCDM concepts, both dominant and non-dominant structures play crucial roles. They help decision-makers determine preferences based on the degree of dominance of each factor. Typically, there are several efficient optimal solutions that are considered as candidates for the final decision-making process. These methods are particularly valuable in complex scenarios where multiple, often conflicting, criteria must be weighed to reach a well-informed decision (Gyani et al., 2022).

Choosing the best option from various solutions requires a thorough understanding and evaluation of the relevant variables, necessitating continuous analysis and consideration of all aspects of the evaluation. Any shortcomings or lack of information can directly impact the risk associated with decision-making. In other words, an optimal decision should minimize risk and provide the highest level of confidence in the outcomes. This becomes particularly critical in management and planning for structured systems, where risks can lead to significant financial or operational losses for projects or organizations (Gyani et al.,

2022). Consequently, utilizing a multicriteria decision-making framework, such as the Analytic Hierarchy Process (AHP), is highly effective in these decision-making systems. The AHP method, introduced by Thomas Saaty in 1980, is one of the most comprehensive systems designed for decision-making with multiple criteria. This method is based on pairwise comparisons of criteria made by experts. It involves creating one or more comparison matrices to rank alternatives. After determining the relative importance of each criterion, the consistency ratio is calculated to ensure the reliability of the results (Asadabadi et al., 2019). In this study, the AHP method has been employed to assess the environmental impacts of the southern belt project in the city of Mashhad. This section outlines the methodology of AHP-MCDM, which provides a structured approach for evaluating and prioritizing multiple factors to support decision-making.

The AHP is a structured methodology designed for decision-making that involves multiple criteria. The architectural structure of AHP can be broken down into several key components (Gyani et al., 2022):

Problem decomposition: The first step in the AHP process is to decompose the complex decision problem into a hierarchical structure. This involves breaking down the problem into smaller, more manageable components. Typically, this hierarchy consists of three levels: the goal or objective at the top, the criteria and sub-criteria in the middle, and the decision alternatives at the bottom.

Pairwise comparisons: At the core of AHP is the pairwise comparison process. In this stage, decision-makers compare each pair of criteria, sub-criteria, or alternatives to assess their relative importance or preference. These comparisons are typically made on a scale of relative importance, often ranging from 1 (equal importance) to 9 (extremely more important).

Matrix formation: The results of the pairwise comparisons are used to form a series of comparison matrices. Each matrix represents the relative importance of criteria or alternatives with respect to the decision goal. These matrices are essential for calculating the priorities of each element in the hierarchy.

Calculation of weights: Using the comparison matrices, AHP calculates the priority weights for each criterion, sub-criterion, and alternative. This involves determining the eigen-values and eigenvectors of the comparison matrices to derive normalized weights, which reflect the relative importance of each element.

Consistency Check: A key aspect of AHP is the consistency check, which ensures that the pairwise comparisons are logically consistent. The consistency ratio is calculated to assess whether the comparisons are reasonably consistent. A low consistency ratio indicates that the comparisons are reliable, while a high ratio suggests inconsistencies that need to be addressed.

Aggregation and synthesis: Finally, the weights and priorities derived from the pairwise comparisons are aggregated to rank the alternatives. The weighted scores of each alternative are summed up to determine the overall ranking and to support the final decision-making process. This synthesis helps in identifying the most preferred alternative based on the criteria and sub-criteria.

The architectural structure of AHP ensures a systematic and rational approach to decision-making, allowing decision-makers to handle complex problems by breaking them down into

manageable parts and evaluating them in a structured manner (Toloie-Eshlaghy & Homayonfar, 2011).

The MCDM model is an advanced and practical approach used in decision-oriented analyses, offering a broad range of analytical methods to users in management, particularly for engineering and managerial issues. The high capability of this approach has made it one of the most important methods for decision-making analysis based on various evaluation variables. Unlike single-criteria optimization methods, MCDM employs a set of criteria for evaluation. Multi-criteria models are specifically used for designing and selecting optimal options (Toloie-Eshlaghy & Homayonfar, 2011). In the AHP-MCDM analysis, consider that A represents a fundamental matrix, which is expressed as Eq.1. Now, by employing expert input and decisions from specialized personnel for each row of the comparison matrix, the value S_k (which is a spatial function) is calculated as Eq 2.

$$A = \begin{bmatrix} 1 & M_{12} & M_{13} & \cdots & M_{1n} \\ M_{21} & 1 & M_{23} & \cdots & M_{2n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ M_{n1} & M_{n2} & M_{n3} & \cdots & 1 \end{bmatrix} \quad (1)$$

$$S_k = \sum_{j=1}^n A \times \left[\sum_{i=1}^m \sum_{j=1}^n M_{ij} \right] \quad (2)$$

where M represents the options for each decision criterion, i and j denote the indices, and A is the function for alternatives. In this method, after calculating S_k , the relative magnitudes of these values are determined.

D. Temporal and Spatial Scope

The spatial and temporal scope of the present study encompasses data related to construction in the context of civil engineering projects managed by construction and environmental companies involved in road construction. This information has been collected through a system of expert inputs, including surveys completed by specialized personnel, university professors, doctoral students, and consulting engineers involved in design and execution. The data collection process, using questionnaires, spanned six months for the southern ring road project in Mashhad. The thematic scope of this research focuses on examining and comparing project management methods in various civil engineering activities using the AHP-MCDM technique. The study utilizes the most recent version of AHP-MCDM, incorporating the latest updates and refinements to the multi-criteria decision-making analysis method.

E. Statistical Population

The statistical population of the research consists of individuals, characteristics, and objects that share at least one common attribute, which is used to establish a logical relationship between the information and the analysis process. The population for this study, based on their expertise in project management, includes 5 project managers, 5 university professors and lecturers in civil engineering and geological

engineering, 5 project experts, and 5 supervising engineers and technical office managers, totaling 20 experts. This broad selection of participants ensures a comprehensive and multi-faceted perspective. In this study, both field-based and library-based approaches were utilized to establish and complete the database for the evaluation context. Field methods involved gathering real-time data from practical environments, while library methods included reviewing existing literature and documents relevant to the subject matter. This dual approach ensures a comprehensive data set, combining practical insights with theoretical foundations. Once the initial data collection and database creation were completed, the data were analyzed using quantitative descriptions and computer programs. The aim of data analysis through various methods, including statistical, geostatistical, deterministic, or probabilistic approaches, is to identify a cognitive pattern in the data. In this study, techniques such as AHP-MCDM were employed using software tools like SPSS, ExpertChoice11, and Excel for data evaluation.

F. AHP-MCDM Model

To address the causes and factors contributing to environmental issues in the southern ring road project in Mashhad, a process-based hierarchical analysis model was implemented. The model, depicted in Figure 1, shows that specified levels based on criteria and sub-criteria were classified through the AHP process. Each sub-criterion was outlined with various indicators, as illustrated in Figure 2. By considering these strategic criteria, the model defines and prioritizes optimal management methods for strategic planning. The AHP-MCDM model facilitates the comparison of all variables at the sub-criteria level with n and $n+1$ variables, resulting in outputs categorized into four operational and practical levels. In this evaluation, each variable is assessed with equal importance, meaning that all evaluation variables are considered equally important. The results of these evaluations are provided as consistency coefficients for the matrices. In a hierarchical evaluation, the objective function refers to the outcome or goal of the studies, which, in this research, concerns the environmental impacts of a beltway. This objective function is interactive, based on the dependency of environmental indicators on the parameters that the beltway imposes on the surrounding environment.

As discussed in the previous chapter, every structure impacts its surrounding environment and must adhere to sustainable development guidelines to avoid causing environmental damage. Generally, sustainable cities should exemplify mechanisms that are in harmony with the environment. Any disruption in the balance between development and the environment can undermine environmental sustainability. Therefore, defining objective functions and evaluation indicators for these guidelines is crucial. The prioritization and preference of a factor over itself are considered parameters of independence, assigned a weight of 1. The principle of inverse relationships between factors and the preference of one factor over another are key properties in decision matrices, representing interactive factors. Interactive factors indicate the level of impact or importance of one factor relative to others. In pairwise analysis, this impact can be used as a relative importance factor for the criteria or alternatives. After comparing indicators, criteria, and sub-criteria in pairs, the information appears as decision matrices.

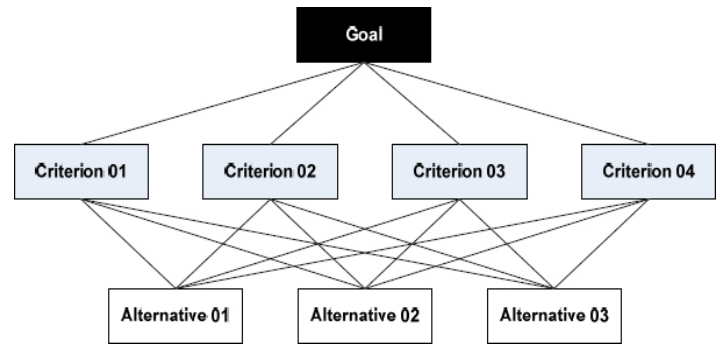


Fig. 1 Architectural structure of the AHP process

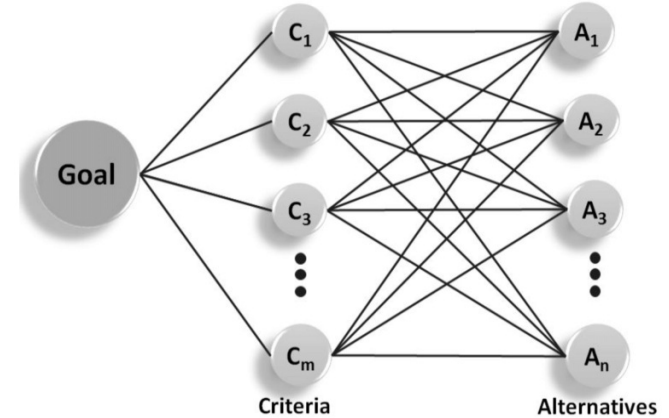


Fig. 2 A schematic MCDM system

These matrices represent the intermediate level of evaluation and its effect on the performance results or optimal decision. The matrices help determine the ranking of criteria based on their relative importance as influenced by their assigned weights. Based on the library and field studies conducted through questionnaires, the influential criteria have been identified and presented in Table 1. Additionally, Figure 3 displays the flowchart of the implementation and analyses.

Table 1 The indicators used in this research as main criteria

No.	Criteria	Sub-criteria
1	Human factors (C1)	Green personnel (M1) Green construction (M2) Green inspection (M3)
2	Local factors (C2)	Green user (M4) Contamination (M5) Construction disposals (M6) Noise and sound (M7)
3	Environmental factors (C3)	Air pollution (M8) Soil pollution (M9) Wastes (M10) Sewer (M11)
4	Management factors (C4)	Design quality (M12) Executive efficiency (M13) Mismanagement (M14) Legal conditions (M15)
5	Social factors (C5)	Social index (M16) Educational indicators (M17) General indicators (M18) Cultural indicators (M19)
6	Economic factors (C6)	Livelihood (M20) Development Index (M21) Employment (M22)
7	Political factors (C7)	Political pressure (M23) Idle function (M24)

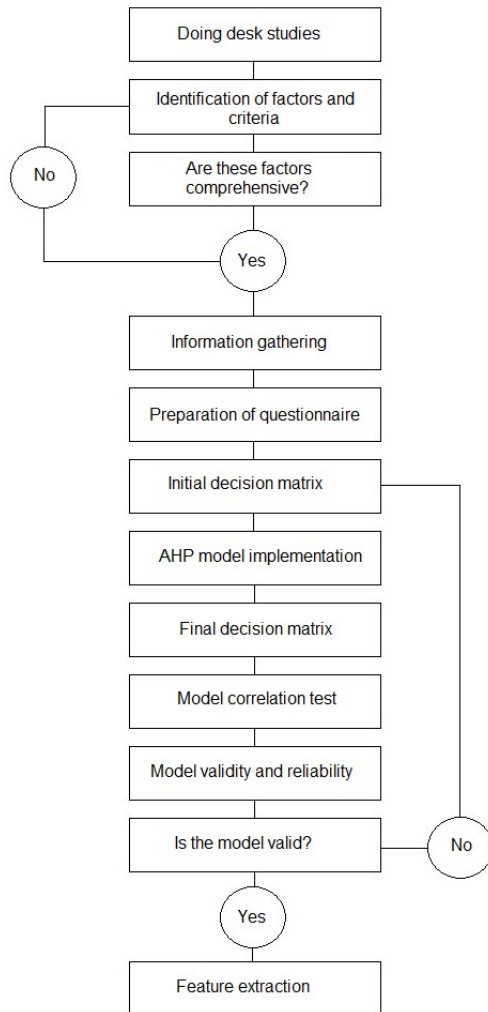


Fig. 3 AHP analysis flowchart for this study

V. RESULTS AND DISCUSSION

This study utilized the AHP-MCDM approach to ensure effective decision-making and optimal prioritization of criteria. AHP was chosen over alternative methods like TOPSIS, BWM, and PROMETHEE because it offered more precise and consistent results, especially in complex decision scenarios. The key advantage of AHP lies in its ability to break down decisions into a structured hierarchy, making it easier to evaluate different criteria and sub-criteria. By incorporating expert opinions and minimizing user bias through a descriptive-survey method, the outcomes were more reflective of real-world conditions. This led to the development of decision matrices that accurately mirrored the actual project environment, a significant outcome of this research. One of the primary contributions of the AHP model was its ability to handle complex matrices and convert qualitative data into measurable, quantitative insights. This was especially important for the project under study, where various factors interacted in complicated ways. Through the AHP process, the study identified eight key factors that influenced the project: human, environmental, ecological, managerial, social, economic, and political factors. Each of these major factors could be further broken down into more specific sub-factors, providing a

comprehensive view of the elements affecting the project. This categorization helped clarify the interrelationships between the factors, allowing for a more nuanced analysis.

The exploratory analysis performed using AHP allowed the research team to classify and rank the importance of these factors based on weighted coefficients. The results of this analysis showed that environmental and political factors had the highest influence on the project's ecosystem, underscoring the significance of sustainable environmental practices and the role of governance in large-scale infrastructure projects. On the other hand, economic factors, though present, had a lesser impact. This was an important finding, as it indicated that decisions regarding the project should prioritize ecological and political considerations to minimize harm to the environment. In evaluating the consistency of the model, the AHP results demonstrated that all decision matrices were aligned, indicating a high level of internal consistency and accuracy. This consistency is crucial in ensuring that the data inputs were properly integrated into the model, and that the results were reliable and reflective of the collected information. The agreement between input data and outcomes signified that the model successfully converged, reducing the likelihood of errors in decision-making processes.



Fig. 4 A view of the studied project (north section)



Fig. 5 A view of the studied project (south section)

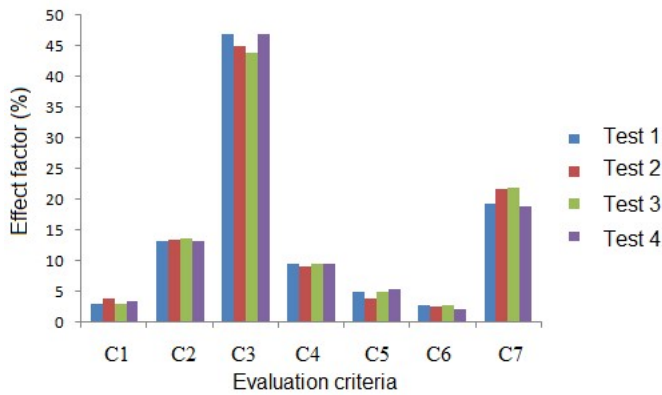


Fig. 6 Sequential variations chart for evaluation of criteria

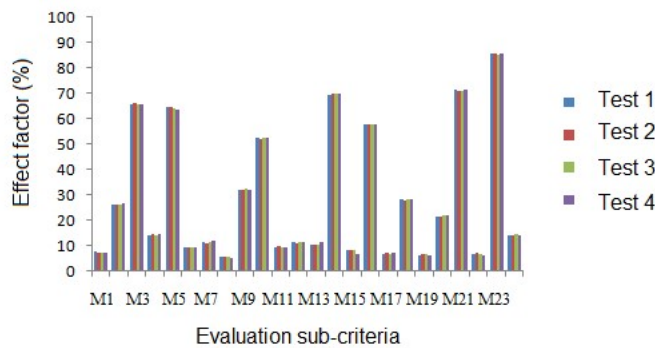


Fig. 7 Sequential variations chart for evaluation of sub-criteria

Case Processing Summary			
		N	%
Cases	Valid	74	100.0
	Excluded ^a	0	.0
	Total	74	100.0

a. Listwise deletion based on all variables in the procedure.

Reliability Statistics	
Cronbach's Alpha	N of Items
.748	74

Fig. 8 The result of the Cronbach's test on the data

Further analysis of the AHP model involved calculating the impact coefficients for each of the eight factors. The results showed that environmental factors had the largest influence on the project, with a coefficient of 47%. This was followed by political factors, which held an influence of 19.4%. These findings emphasize the need for environmental and political considerations to be at the forefront of decision-making for the Mashhad Southern Beltway project. The lesser influence of economic factors, in this case, suggests that while economic efficiency is important, it should not overshadow the need for ecological and political responsibility. To ensure the accuracy and reliability of the model, four iterations of the AHP process were conducted to test consistency. The results showed minimal variation across the iterations, indicating that the model was stable and that the calculated impact coefficients were reliable. Additionally, to validate the performance of the AHP model, both validity and reliability tests were applied. The convergent

validity model yielded a high correlation coefficient of 0.89, which confirmed the credibility of the evaluations. The Cronbach's alpha coefficient was also satisfactory at 0.748, indicating that the measurement tools used in the study were consistent and reliable. Together, these findings underscore the robustness of the AHP model and its ability to generate reliable and accurate results in complex decision-making environments.

VI. CONCLUSION

This study employed a MCDM approach using the AHP to achieve optimal decision-making and prioritize key criteria. AHP outperformed other methods like TOPSIS, BWM, and PROMETHEE by providing more accurate and consistent results. The use of a descriptive-survey method, coupled with expert input, minimized user bias, allowing the results to better reflect real-world conditions. This led to the development of accurate decision matrices that aligned with the actual project environment. The AHP model effectively managed complex matrices, translating qualitative data into measurable, quantitative results. Eight main factors were identified, including human, environmental, ecological, managerial, social, economic, and political factors, each with various sub-factors. Exploratory analysis using AHP revealed that environmental and political factors had the greatest influence on the project's ecosystem, while economic factors had the least. The final model demonstrated high consistency, showing minimal variation across four test iterations, reflecting the accuracy of the implementation. Additionally, the model's validity and reliability were confirmed through convergent validity and Cronbach's alpha tests, which yielded coefficients of 0.89 and 0.748, respectively, indicating strong evaluation accuracy and reliability. Environmental factors emerged as the most significant, contributing 47% of the impact, followed by political factors at 19.4%.

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AUTHORS' CONTRIBUTIONS

Ali Saedi and Mohammad Soltani Asl conducted the main data analysis, contributed to the data collection, preprocessing, and interpretation, and were responsible for drafting the initial manuscript. Mohammad Soltani Asl and Armin Jarahi assisted in the development of the methodology and performed validation checks, provided supervision, conceptual guidance, and critical revision of the manuscript. All authors read and approved the final manuscript.

CONFLICT OF INTEREST

The authors have not disclosed any competing interests.

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REFERENCES

- Ahmad S., Tahar R.M. (2014). Selection of renewable energy sources for sustainable development of electricity generation system using analytic hierarchy process: A case of Malaysia. *Renewable Energy*, 63, 458-466. <https://doi.org/10.1016/j.renene.2013.10.001>.
- Asadabadi M.R., Chang E., Saberi M. (2019). Are MCDM methods useful? A critical review of analytic hierarchy process (AHP) and analytic network process (ANP). *Cogent Engineering*, 6(1), 1623153. <https://doi.org/10.1080/23311916.2019.1623153>.
- Azizpour A., Azarafa M., Akgun H. (2020). The impact of municipal waste disposal of heavy metals on environmental pollution: A case study for Tonekabon, Iran. *Advances in Environmental Research*, 9(3), 175-189. <https://doi.org/10.12989/aer.2020.9.3.175>.
- Blewitt J. (2012). *Understanding sustainable development*. Routledge, New York, USA.
- Boccia F., Ianuario S., Samo V. (2013). The Italian Environmental Performance: The Role of Ecosystem Vitality. *Quality-Access to Success*, 14 (137), 95.
- Carley M., Christie I. (2017). *Managing sustainable development*. Routledge, New York, USA.
- das Neves Almeida T.A., García-Sánchez I.M. (2016). A comparative analysis between composite indexes of environmental performance: An analysis on the CIEP and EPI. *Environmental Science & Policy*, 64, 59-74. <https://doi.org/10.1016/j.envsci.2016.06.011>.
- Elliott J. (2012). *An introduction to sustainable development*. Routledge, New York, USA.
- Ghalam S.J. (2013). Providing a Model for Measuring the Sustainable Development in Cities (Case Study: Mashhad city). *Research Journal of Environmental and Earth Sciences*, 5(10), 556-566.
- Gyani J., Ahmed A., Haq M.A. (2022). MCDM and various prioritization methods in AHP for CSS: A comprehensive review. *IEEE Access*, 10, 33492-33511. <https://doi.org/10.1109/ACCESS.2022.3161742>.
- Jabareen Y. (2008). A new conceptual framework for sustainable development. *Environment, Development and Sustainability*, 10, 179-192. <https://doi.org/10.1007/s10668-006-9058-z>.
- Kaymaz Ç.K., Birinci S., Kızılkın Y. (2022). Sustainable development goals assessment of Erzurum province with SWOT-AHP analysis. *Environment, Development and Sustainability*, 24(3), 2986-3012. <https://doi.org/10.1007/s10668-021-01584-w>.
- Londoño-Pineda A., Cano J. A., Gómez-Montoya R. (2021). Application of ahp for the weighting of sustainable development indicators at the subnational level. *Economies*, 9(4), 169. <https://doi.org/10.3390/economies9040169>.
- Mitlin D. (1992). Sustainable development: A guide to the literature. *Environment and Urbanization*, 4(1), 111-124. <https://doi.org/10.1177/095624789200400112>.
- Moteahd F.S., Hafezi Moghaddas N., Lashkaripour G.R., Dehghani M. (2019). Geological parameters affected land subsidence in Mashhad plain, north-east of Iran. *Environmental Earth Sciences*, 78, 1-12. <https://doi.org/10.1007/s12665-019-8413-y>.
- Nuong B.T., Kim K.W., Prathumratana L., Lee A., Lee K.Y., Kim T.H., Duong B.D. (2011). Sustainable development in the mining sector and its evaluation using fuzzy AHP (Analytic Hierarchy Process) approach. *Geosystem Engineering*, 14(1), 43-50. <https://doi.org/10.1080/12269328.2011.10541329>.
- Oțoiu A., Grădinaru G. (2018). Proposing a composite environmental index to account for the actual state and changes in environmental dimensions, as a critique to EPI. *Ecological Indicators*, 93, 1209-1221. <https://doi.org/10.1016/j.ecolind.2018.06.009>.
- Parris T.M., Kates R.W. (2003). Characterizing and measuring sustainable development. *Annual Review of Environment and Resources*, 28(1), 559-586. <https://doi.org/10.1146/annurev.energy.28.050302.105551>.
- Poveda C.A., Lipsett M.G. (2013). Weighting sustainable development indicators (SDIs) for surface mining operations using the analytical hierarchy process (AHP). *International Journal of the Analytic Hierarchy Process*, 5(2), 200-222. <https://doi.org/10.13033/ijahp.v5i2.199>.
- Singh A., Malik S.K. (2014). Major MCDM Techniques and their application-A Review. *IOSR Journal of Engineering*, 4(5), 15-25.
- Solangi Y.A., Longsheng C., Shah S.A.A. (2021). Assessing and overcoming the renewable energy barriers for sustainable development in Pakistan: An integrated AHP and fuzzy TOPSIS approach. *Renewable Energy*, 173, 209-222. <https://doi.org/10.1016/j.renene.2021.03.141>.
- Szabo Z.K., Szádóczki Z., Bozóki S., Stănculescu G.C., Szabo D. (2021). An analytic hierarchy process approach for prioritisation of strategic objectives of sustainable development. *Sustainability*, 13(4), 2254. <https://doi.org/10.3390/su13042254>.
- Toloie-Eshlaghy, A., & Homayonfar, M. (2011). MCDM methodologies and applications: a literature review from 1999 to 2009. *Research Journal of International Studies*, 21, 86-137.
- Zanganeh M., Varesi H.R., Zangiabadi, A. (2013). Strategic housing planning through sustainable development approach in Iran Metropolitans: Case study of Metropolitan Mashhad. *Journal of Basic and Applied Scientific Research*, 3(9), 180-188.