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Application of a multi-criteria analysis method for the selection of a priority public transport mode for investment: case of the West Algiers region

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Abstract:
This article aims to develop a methodology in which alternative projects are prioritized and selected using appropriate methods of multi-criteria decision-making in organizations responsible for managing and developing transportation modes. This study addresses a particular gap in implementing a systematic methodology for prioritizing and selecting transportation modes for investment. The developed methodology proposes an approach based on the multi-criteria decision support method AHP (Analytical Hierarchy Process). The problem was implemented using the ExpertChoice software, which allows for the effective integration of decision-makers in the decision-making process to identify potentially profitable and beneficial transportation modes for the community.

Keywords: transportation modes, project selection, multi-criteria decision support, Analytical Hierarchy Process (AHP), AHP.
JEL Classification : : R400 ; R420 ; C830 ; C880

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1- Introduction

In recent years, Algeria has witnessed rapid urbanization, marked by an expansion in both size and number of cities. The issue of urban mobility has become a significant concern in the country's large cities due to their high population density and strategic positioning. Specifically, the city of Algiers has experienced rapid population growth, partly driven by a high growth rate and migration. As the country's economic capital, Algiers has always been a magnet for migrants. The population increase has led to a growing demand for transportation, necessitating improvements in both quantity and quality of transport infrastructure and facilities. The arrangement of jobs, businesses, residences, and other urban functions within the city generates urban movements.

Despite the presence of various modes of transportation such as public transport, private cars, trains, metro, and tramways, the western part of Wilaya is characterized by a deficit in urban transport compared to the eastern part. In this context, the state seeks to enhance the transportation sector in these communities, with sector managers aiming to launch a new project in the region. Therefore, selecting the priority mode of transport for investment is crucial to improve residents' quality of life and stimulate economic development in the area. For this purpose, the research question is formulated as follows: How can the selection of the priority mode of transport for investment in West Algiers be optimized, taking into account various relevant criteria and the needs of all stakeholders involved in the transportation process?

The objective of this study is, firstly, to analyze the transportation sector in the West Algiers region, particularly urban transport, to identify its strengths, weaknesses, and key influencing factors. Secondly, the study aims to assist decision-makers and sector leaders in selecting the most prioritized project for investment in the region, using a decision support model based on the Analytic Hierarchy Process (AHP) multicriteria method.

The transportation sector in Algeria has undergone significant evolution, transitioning from the absence of public policy to its development and regulation (BOUBAKOUR, 2012). Significant initiatives have been undertaken to address urban transport issues, including launching significant investment projects and allocating substantial budgets (Santos Rodrigues, Mendes dos Reis, & Sivanilza, 2022).

Project selection is fundamentally a complex and challenging issue in the decision-making process. To address this problem, we propose utilizing the multicriteria analysis AHP developed by (Saaty, The Analytic Hierarchy Process, 1980) to systematically organize interdependent factors and provide a relatively straightforward solution to decision-making problems (Skibniewski, 1992).

The current literature encompasses several studies focused on project selection using multicriteria analysis. For instance, (Akhrouf, 2022) employed AHP in the healthcare domain to devise a decision support model for selecting the most effective health infrastructure projects. (Fenniche, 2018) applied AHP in the financial services sector of commercial banks to establish a more viable system for evaluating commercial bank performance in the local market. Lahrache and Khedache introduced a multicriteria method in the procurement process to enhance the evaluation and selection of enterprise suppliers (Lahrache & Khedache, 2015).

2- Methodology

Multicriteria analysis methods, or more precisely, multicriteria decision aid methods, are relatively recent techniques that are continually evolving. According to Ben Mena, "these procedures appear to better facilitate moving towards a sound compromise rather than an often-outdated optimum". (Ben Mena, 2000)

2-1- Presentation of the AHP method

The Analytic Hierarchy Process (AHP) is a multicriteria decision aid method based on an analytical approach, invented by mathematician Thomas Saaty in the 1970s (Saaty, 1980). This method enables the decomposition of a complex problem into its various components, which are then organized in a hierarchical structure.

2-2- Principle of the AHP

The principle of AHP is based on a systematic approach to structure complex decision problems and incorporate decision-makers preferences. It is widely used in various fields, including urban planning, project management, supplier selection, and strategic decision-making.

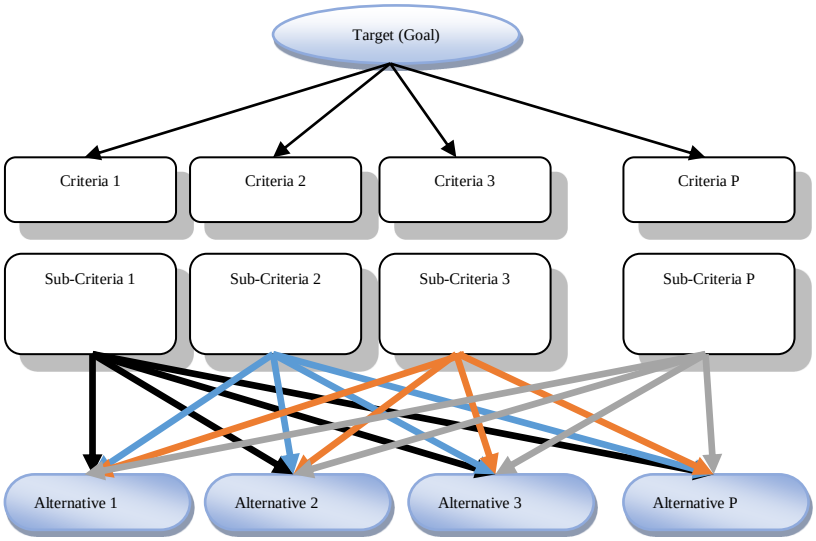
2-3- Steps of AHP

This method is based on Saaty's experience during his management of research projects for the American Arms Control Agency (FENNICHE, 2019). It has been developed straightforwardly to understand and implement a simplified methodology for making complex decisions. Additionally, a software called "Expert Choice" was designed by Saaty as a digital version of this technique (Guesdon, 2011). The AHP method can be summarized as follows:

2-3-1- Definition of the Hierarchy

The decision-making process breaks down the problem into distinct key components, established in a hierarchy that includes: the goal (objective), the main criteria, secondary criteria (if applicable), and alternatives. This constitutes the essential and innovative part of the decision-making process.

Figure 1 General hierarchy of AHP



Source: (Saaty, 1980)

2-3-2- Pairwise comparisons

Once the hierarchy is established, pairwise comparisons are conducted to assess the relative importance of elements at each level of the hierarchy. For instance, decision-makers might be asked to compare two criteria or two options at a time and determine which one is preferred. These comparisons are typically done using rating scales or comparison matrices.

Table 1: Binary comparison scale of the AHP method

Degree of importance	Definition	Explanation
1	The equal importance of both elements	Two elements contribute equally to theproperty
3	Low importance of one item overanother	Personal experience and appreciation slightly favor one element over another
5	The strong or decisive importance of one element over another	Personal experience and appreciation strongly favor one element over another
7	Demonstrated the importance of one element over another	An element is strongly favored and itsdominance is attested in practice
9	The absolute importance of one elementas over another	Evidence favoring one element over another isas convincing as possible
2, 4, 6, 8	Intermediate values between two neighboring assessments	A compromise is necessary between the two assessments
Reciprocal	If element i is assigned one of the previous digits C_{ij} when compared to element j, then C_{ji} has the reciprocal value $1/C_{ij}$ when compared to I (the inverse of the number).	

Source: (Saaty, 1980)

2-3-3- Construction of comparison matrices

Pairwise comparisons are used to construct comparison matrices. A comparison matrix is a structured representation of the relative preferences between elements at each level of the hierarchy. These matrices are typically square in size, with the elements to be compared on both rows and columns. The pairwise comparison matrix is structured as follows (Brunelli, 2015):

$$A = (a_{ij})_{n\times n} = \begin{bmatrix} a_{11} a_{12} & \cdots & a_{1n} \\ a_{21} a_{22} & \cdots & a_{2n} \\ \vdots \quad \vdots & \ddots & \vdots \\ a_{n1} a_{n2} & \cdots & a_{nn} \end{bmatrix}$$

With a_i, $j > 0$ expressing the degree of preference of xi to x_j, the criterion in row i is preferred over the criterion in column j if the value of the element (i,j) is greater than 1, otherwise the criterion in column j is preferred. Automatically, the inverse of the assigned number is associated with the $(j, i)^{th}$ position according to the following rule (Chang, 2007):

$$a_{ij} \succ 0, a_{j,i} = \frac{1}{aij}, \quad a_{i,j} = 1 \ \forall i$$

2-3-4- Calculation of the weights

The relative weights of criteria and options are computed from the comparison matrices. These weights are derived using mathematical methods to aggregate pairwise comparisons and determine the eigenvalues and eigenvectors of the matrix. The weights reflect the relative importance of elements and enable their prioritization.

2-3-5- Consistency analysis

Consistency analysis is a crucial step in the Analytic Hierarchy Process (AHP). Its purpose is to assess the reliability of decision-makers' judgments when establishing comparisons between different options and criteria. The Consistency Index (CI) is calculated as follows:

$$IC = (\lambda_{max} - n)/(n-1)$$

Where λ_{max} is the maximum eigenvalue of the judgment matrix, and n is the number of criteria.

The Consistency Ratio (CR) is derived by comparing the CI value to the Random Consistency Index (RI). This ratio gauges the level of error introduced in judgment formulation. Generally, if the CR value is less than 0.1, errors are deemed relatively low, indicating a high degree of relative consistency in responses. In such cases, the final estimation can be accepted. Conversely, if the CR value exceeds 0.1, the decision-maker should carefully scrutinize element comparisons to identify sources of inconsistency. The value of RI is related to the matrix order, that is the number of considered criteria, and is derived from the following Table 2 (Jeddou M.B., 2015).

Table 2: Random Consistency Indices

Matrix dimension	1	2	3	4	5	6	7	8	9	10
Random consistency	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Source: (Saaty, 1980)

2-3-6- Analysis of results

Once the weights are calculated, they are used to evaluate and compare different decision options. Options can be ranked based on their weighted scores, enabling the determination of the best choice or making informed decisions according to established goals and criteria.

3- Construction of the model for selecting a priority mode of transport for investment

When making decisions about investing in transportation, it's important to consider multiple criteria. To start, we've listed all the available modes of transport and identified both quantitative and qualitative criteria and sub-criteria that will help us make an informed decision. This step is crucial in ensuring that the results we obtain are relevant.

3-1- Goal identification

The objective of the research is to develop a framework for choosing the best and most efficient transportation options to meet the travel requirements of the Alger-West area. The study is focused on offering useful insights and suggestions to support informed decision-making while adopting and utilizing a new mode of transportation, considering various limitations and preferences.

3-2- Criteria and sub-criteria identification

The selection criteria for this study were based on extensive literature reviews. Each criterion identified the crucial factors that influence the decision-making process when selecting a transportation mode for investment. Through this process, we identified six (06) criteria and thirteen (13) sub-criteria, which are presented in Table 3 below.

Table 3: Descriptive table of criteria and sub-criteria

CRITERIA	SUB-CRITERIA	DEFINITION
Geographical criterion		Topographic characteristics or any other relevant geographical element. It is used to assess how a mode of transportation meets the travel needs in a given region, taking into account the specific geographical features of that region.
	Reliefs	It's the topographic and geographical characteristics of a given area. It is a quantitative sub-criterion that we measured by the maximum slope of the modes.
	Geographical coverage	It indicates the geographic areas served by this specific mode of transport, and it is a quantitative criterion that we measured by coverage radii.
Sociodemographic criterion		The sociodemographic criterion refers to the analysis of the characteristics of the population and society in a given region.
	Population	This criterion directly influences the demand for transportation; the larger the population, the greater the transportation needs.
	Number of travellers	It is a quantitative measure that represents the number of people using a specific mode of transportation over a specific period. This is a key indicator used to assess the popularity, capacity, and efficiency of a mode of transportation.
Financial and Economic criterion		It encompasses elements such as operating costs, fares, required investments, and overall profitability of the mode of transportation.
	Budget	It encompasses costs related to feasibility studies, land acquisition, infrastructure construction, vehicle or equipment purchase, operational expenses, maintenance, as well as other aspects related to the implementation and proper functioning of the mode of transportation.
	Job creation	These are the jobs created as a result of the introduction of a new mode of transportation. These jobs can be temporary during the construction phase, while others are sustainable and necessary for the operation, maintenance, and ongoing management of the transportation system.
Organizational criterion		This criterion measures the quality of transportation services.
	Security	It is crucial to ensure the safety of users and to mitigate the risks of accidents and injuries.
	Comfort	It has a direct impact on user experience, fatigue reduction, accessibility, space management, as well as the attractiveness and adoption of the mode of transport.
	Frequency	It is important to consider it when choosing a new mode of transport. It ensures accessibility, reduces waiting times, promotes smooth mobility, meets demand needs, and encourages communal use.
Technical criterion		It is the set of characteristics of each mode of transport.
	Sustainability	It is essential to consider the sustainability of the mode of transport to ensure that this investment will be profitable in the long term and provide better reliability and stability in the continuity of service
	Commercial speed	It directly influences the travel time of passengers
	Carrying capacity	Refers to its capacity to carry a sufficient number of passengers.
Environmental criterion		It is the action of pollution prevention, and it contains only one sub-criterion: "pollution risk."

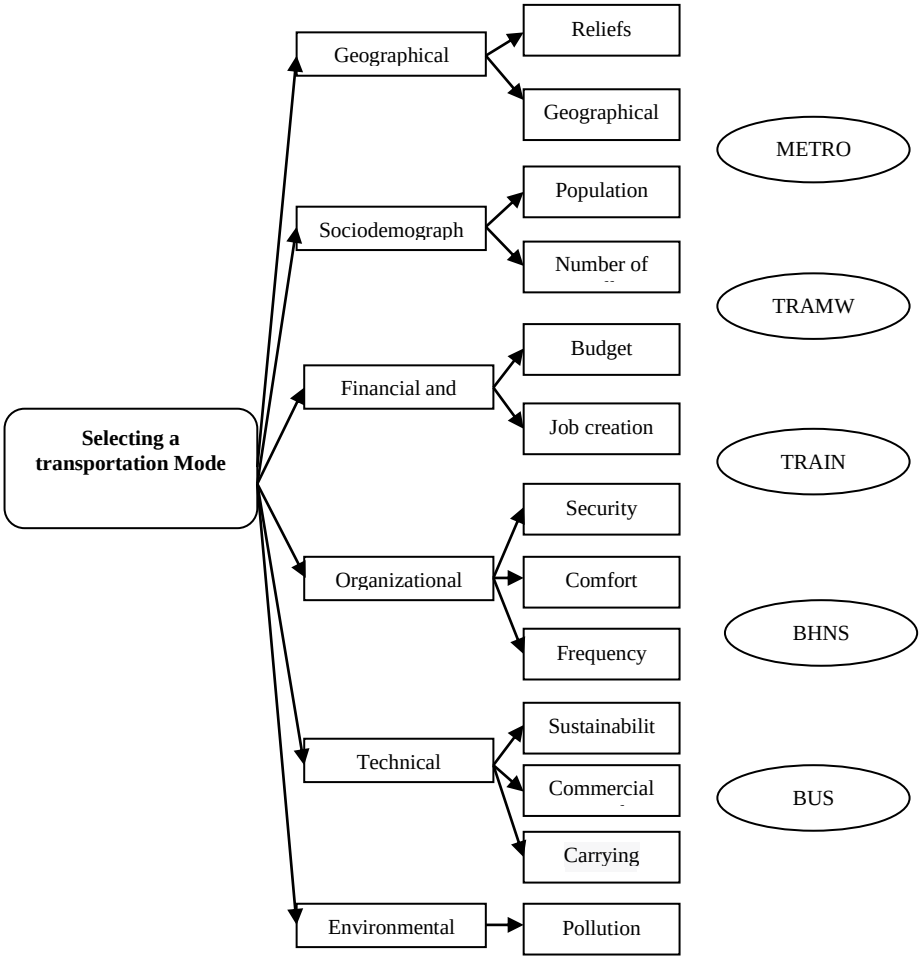
3-3- Identification of alternatives

In our case, the alternatives are the five modes of transportation as follows: METRO, TRAMWAY, TRAIN, Bus-ETUSA, and BHNS defined in Table 4

Table 4: Definition of Alternatives (Modes of Transportation)

Modes of Transportation	Definition
METRO	Abbreviated as "Subway," it is a railway network that operates within a city, sometimes in the open air but always on a dedicated track.
TRAMWAY	It's a mode of public transportation that operates on dedicated railway tracks, typically in urban areas. It consists of connected carriages or trains and is powered electrically.
TRAIN	It's a means of transportation consisting of vehicles on rails, designed for the conveyance of passengers or goods.
BUS-ETUSA	It's a mode of transportation in Algeria used for passenger travel in urban and suburban areas. It is a road vehicle adapted for collective passenger transport, providing seating and standing places.
BHNS	The BHNS (High-Level Service Bus) is a mode of public transportation that combines the advantages of a bus and a tramway. Unlike traditional buses, the BHNS has a dedicated lane and specific facilities to ensure smoother and more regular traffic flow.

Figure 2 Hierarchical structure for the selection of a priority public transportation mode for investment



4- Results and Discussion

Once the hierarchy is established, experts in the field of urban transportation perform pairwise comparisons. Our respondents include the following individuals: • Director of Studies and Development at the Urban Transport Authority-Algiers (UTA-A) • Head of Public and Private Transport Division (UTA-A) • Department Head of Infrastructure at the Urban Transport Study Office (UTSO) • Department Head of Urban Transportation (UTSO) • Operations

Manager at the Algiers Metro Company (AMC) • Expert in Management-Transport-Logistics.

Pairwise comparisons are used to create comparison matrices, from which the relative weights of criteria and options are calculated using the ExpertChoice software. Since our study relies on a group of experts, to include all of their information in the software, we calculated the average for each response using the geometric mean as it helps minimize errors (Ishizaka, 2011).

4-1- Evaluation of the relative importance of Criteria

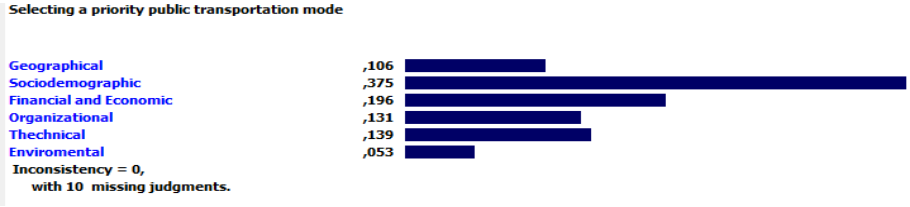
Each of the criteria and sub-criteria does not hold the same level of importance in their ability to contribute to the solution of the alternative selection problem. Evaluators or relevant experts will be asked to compare the relative importance of all criteria pairwise (binary comparison).

The interactive decision support system facilitated by the ExpertChoice software automatically calculated the relative importance of each criterion represented in Table 5.

Table 5 : Relative Weighting of the Priority of Main Criteria

Ranking	Criteria	Relative weighting
1	Sociodemographic	0.375
2	Financial and Economic	0.196
3	Technical	0.139
4	Organizational	0.131
5	Geographical	0.106
6	Environmental	0.053
Inconsistency ratio = 0.03		

Figure 3 Priorities and weighting of criteria (data provided by Expert Choice software)



When designing a mode of transport, it's important to consider factors such as population density, geographical distribution, travel habits, transportation demands, social constraints, and more. By taking into account these sociodemographic aspects, it's possible to create a mode of transport that effectively meets the specific needs and requirements of the population it serves. Overall, the sociodemographic criterion is critical in ensuring that the mode of transport is suitable for the social and demographic realities of the region in question. It should be noted that the most important sub-criteria in order are as follows:

- Number of passengers
- Required budget
- Capacity to accommodate people
- Safety
- Geographic coverage
- Risk of pollution

4-2- Analysis of Consistency of the Entire Judgments

The following table presents the consistency index of all criteria and sub-criteria.

Table 6 : The consistency indices of each level of the hierarchy

Criteria	Sub-criteria	Consistency index
Goal		0.03
Geographical		0
	Reliefs	0.02
	Geographical coverage	0.06
Sociodemographic		0
	Number of travelers	0.05
	Population	0.05

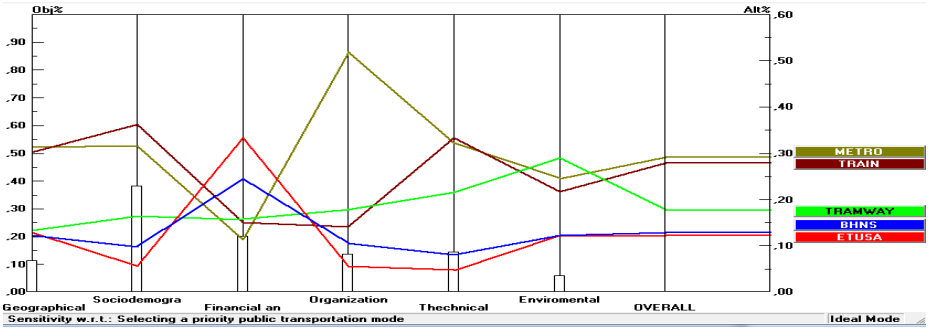
Financial and Economic		0
	Budget	0.05
	Job creation	0.00862
Organizational		0.00352
	Security	0.04
	Frequency	0.02
	Comfort	0.04
Technical		0.05
	Carrying capacity	0.07
	Commercial speed	0.07
	Sustainability	0.01
Environmental		_
	Pollution risk	0.01
Set ratio = 0.04		

In Table 6, it is evident that the inconsistency ratios obtained from the judgments provided by the respondents for each level of the hierarchy are consistent. The overall consistency ratio is 4%, which is less than 10%.

4-3- Evaluation of the Relative Importance of Transport Modes concerning Sub-Criteria

After establishing the priorities of the criteria, it is now possible to determine how each of the modes is evaluated about the chosen criteria. The transport modes are compared pairwise (two by two) considering all the established criteria. The overall ranking of the five transport modes according to all criteria is illustrated in Figure 4 below.

Figure 4 Overall Ranking of Transport Modes Concerning Main Criteria



The ranking of transport modes in different criteria depends on several factors specific to each context. Each mode of transport has its advantages and disadvantages that can influence its position in the ranking.

In the geographical criterion, trains and subways are often ranked at the top due to their ability to offer extensive coverage and efficient connectivity over long distances. They are particularly suitable for serving large urban areas and densely populated regions.

Regarding the sociodemographic criterion, the ranking can vary based on population density, travel habits, and specific needs of each region. For example, the subway might be favored in densely populated urban areas, while the tramway could better meet the needs of residential neighborhoods.

It's interesting to note that the financial criterion can reverse the ranking, where the subway might end up in the last position due to its high cost compared to other modes of transport like the tramway and train, which generally have lower construction and operating costs.

In the organizational criterion, the subway might take the top position due to its efficient organization, high frequency, and level of comfort. This makes it an attractive choice for many users.

On the other hand, Bus-ETUSA might end up in the last position in several criteria due to issues with inefficient operations management, frequent delays, service breakdowns, and poor schedule coordination.

Measures need to be taken to improve management, planning, and innovation within Bus-ETUSA to offer more reliable and efficient transport services.

Furthermore, in the technical criterion, the Bus-ETUSA might also occupy the last place due to its limited capacity, low commercial speed, and shorter lifespan compared to other modes of transport.

Therefore, responsible authorities need to consider these different criteria and implement appropriate policies and measures to select and improve transport modes based on the specific needs of each context.

In summary, each criterion has its implications and impacts on the efficiency, relevance, and quality of a given mode of transport. So, it's crucial to consider all these criteria in a balanced way and adapt them to the specifics of each situation to make informed decisions when choosing a new mode of transport. The ranking can vary based on the priorities and objectives of each project, and it's important to consider all aspects to arrive at an optimal and suitable transport solution.

4-4- Summary of Overall Mode Priorities

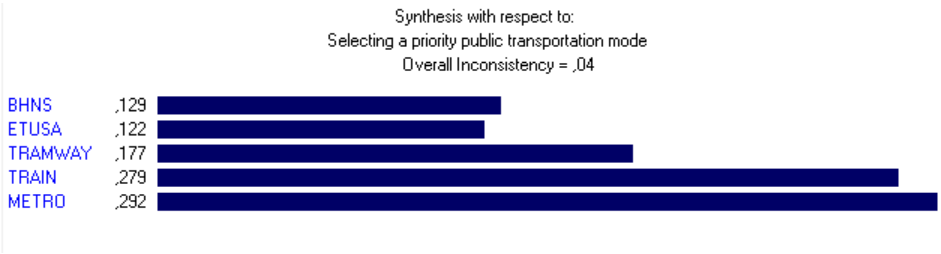
The result provided by the ExpertChoice software shows that the "METRO" mode of transport is the one that has achieved the highest level of alignment in selecting priority transport modes for investment. The following table presents the summary of overall mode priorities.

Table 7: The overall mode priorities

Ranking	Transportation mode	Relative weighting
1	METRO	0.292
2	TRAIN	0.279
3	TRAMWAY	0.177
4	BHNS	0.129
5	Bus-ETUSA	0.122
Inconsistency ratio =0.04		

The ranking results of the alternatives are summarized in Figure 5 below.

Figure 5: Overall Summary of Transport Modes Priorities



In conclusion, the results reveal that the metro ranks in the first position with a percentage of 29.2%, closely followed by the train with 27.9% and the tramway with 17.7%. On the other hand, the BHNS and Bus-ETUSA obtained similar percentages, estimated at 12.9% and 12.2% respectively.

4-5- Sensitivity Analysis

Sensitivity analysis of the alternatives (transport modes) ranking was conducted using ExpertChoicev.11 software. This analysis is useful for understanding the effect of changing the weights of the main criteria on the ranking of modes.

To do this, we decided to vary the relative weights of certain criteria in different ways as follows: • Using larger variations around the weights of socioeconomic, as well as economic and financial criteria, as these are more relevant to the overall objective. • Using smaller variations around the weights of organizational criteria.

We considered three different scenarios: • Scenario 1: Sensitivity analysis regarding the sociodemographic criterion • Scenario 2: Sensitivity analysis regarding the financial and economic criterion • Scenario 3: Sensitivity analysis regarding the organizational criterion

The following Table 8 represents the variations in relative weights of the main criteria for each scenario.

Table 8 : Sensitivity analysis scenarios (data provided by Expert Choice software)

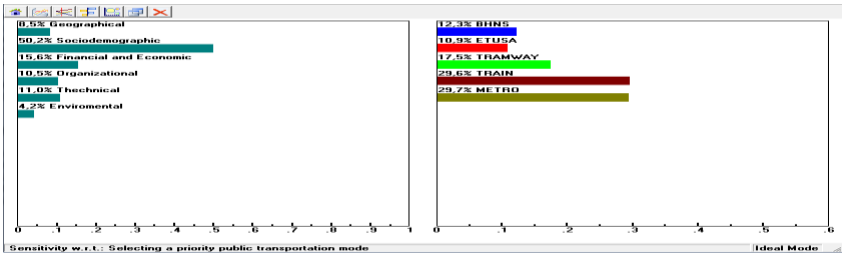
Criteria	Initial	Scenario 1	Scenario 2	Scenario 3
Sociodemographic	**0.375**	**0.501**	0.296	0.082
Financial and Economic	0.196	0.156	**0.501**	0.138
Organizational	0.131	0.105	0.062	**0.501**
Transportation Mode weighting results				
BHNS	0.129	0.123	0.173	0.118
ETUSA	0.122	0.109	0.201	0.094
TRAMWAY	0.177	0.175	0.168	0.184
TRAIN	0.279	0.296	**0.237**	0.214
METRO	**0.292**	**0.297**	0.222	**0.390**

Examining the preceding table shows that when the weight of one criterion is increased, the majority of the weights for the other criteria become lower.

Scenario 1: Sensitivity Analysis Regarding the Sociodemographic Criterion

By varying the weight of the sociodemographic criterion increasingly to reach a value of 50% of the relative importance to the objective, we observe that the ranking of transport modes remains unchanged compared to the initial scenario. The METRO still maintains its first position with a priority of 29.7%.

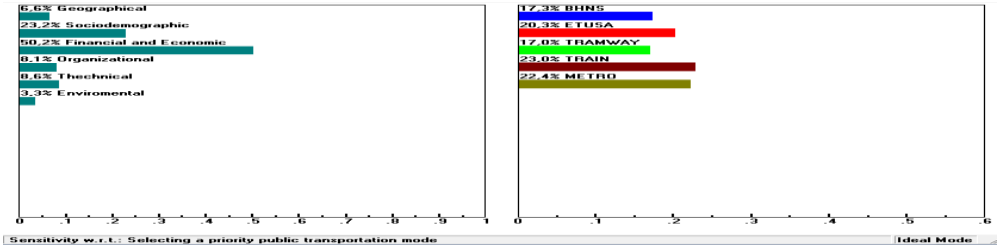
Figure 6 Sensitivity analysis - Scenario 1 (data provided by Expert Choice software)



Scenario 2: Sensitivity Analysis Concerning the Financial and Economic Criterion

By varying the weight of the Financial and Economic criterion in the increasing direction to reach the value of 50% of the relative importance to the objective, we observe a change in the ranking of the modes of transport compared to the initial scenario. The TRAIN is now ranked first with a priority of 23.7%, followed by the METRO with a priority of 22.2%.

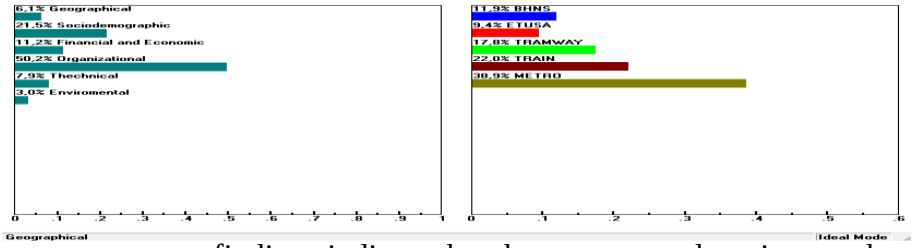
Figure 7 Sensitivity analysis - Scenario 2 (data provided by Expert Choice software)



Scenario 3 : Sensitivity analysis concerning the organizational criterion

By varying the weight of the Organizational criterion in the increasing direction to reach the value of 50% of the relative importance to the objective, we observe that the ranking of the modes of transport remains unchanged compared to the initial scenario. The METRO is still ranked first with a priority of 39%.

Figure 8 Sensitivity analysis - Scenario 4 (data provided by Expert Choice software)



In summary, our findings indicate that there were no alterations to the rankings compared to our original assessment, except for two instances. Firstly, in Scenario 2, the METRO did not claim the top spot due to its expensive cost, resulting in BHNS and Bus-ETUSA ascending in the rankings due to their more cost-efficient nature. Secondly, in Scenario 3, we observed that the rankings remained unchanged, with only a switch between the train and the metro.

5- Conclusion

Choosing a mode of transportation requires careful consideration of various criteria, each with its implications and priorities depending on the context and specific needs. To assist stakeholders in the transportation sector with making informed decisions during project implementation, we ranked different modes of transport based on six criteria and thirteen sub-criteria. Our decision support model, which utilizes the Analytic Hierarchy Process (AHP), allows for sensitivity analyses and scenario creation to confirm information accuracy. Additionally, AHP facilitates communication between researchers and domain experts, promoting information sharing and increasing the usefulness of the decision model for all parties involved. This approach is crucial for studying decisions made by authorities.

This study aims to evaluate the transportation plan in the West Algiers area, specifically focusing on urban transport, and pinpoint its strengths, weaknesses, and main influencing factors. Moreover, it seeks to aid decision-makers and stakeholders in selecting the

investment project with the highest priority in the region. To accomplish this, we outlined the intricate challenges posed by this extensive network, necessitating ample time, significant financial resources, and profound expertise. The model we created allows for the genuine participation of the decision-maker in the decision-making process by incorporating their input to identify transportation projects with the greatest investment priority.

We strongly suggest that for future research, a thorough analysis of all transportation lines should be conducted to gain a better understanding of their unique features. Additionally, this approach can efficiently organize the current network by identifying factors that influence private transportation, without requiring new construction efforts. It would be intriguing for scholars to re-examine this issue using integrated multi-criteria decision-making methods like TOPSIS-AHP, which allows for the simultaneous consideration of multiple criteria.

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