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## Evaluation and Selection of Coding Machines and Determination of Priorities in Urban Transportation Systems

**Ramin Jahanshahi<sup>1</sup>, Hamidreza Motamedi<sup>2</sup>, Hamid Goodarzi<sup>3</sup>, Samad Khaledian<sup>4</sup>, Omid Fanaei Niya<sup>5</sup>, Mahdi Mirzaei<sup>6</sup>**

1. Bachelor of Civil Engineering, Bahonar University of Kerman and Master of Industrial Engineering, Engineering Management, Isfahan University of Technology.
  2. Bachelor of Industrial Engineering and Master of Industrial Engineering majoring in Engineering Management
  3. Bachelor's, Master's and PhD in Civil Engineering Master's student in Industrial Engineering, Engineering Management
  4. Bachelor of industrial safety and industrial engineering in engineering management
  5. Bachelor of Industrial Management and industrial engineering in Engineering Management
  6. Bachelor of Industrial Engineering, Isfahan University of Technology Master of Industrial Engineering, Engineering Management, Isfahan University of Technology
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### ABSTRACT

In this study, in order to enhance and expand the application of the Analytic Hierarchy Process (AHP) in solving complex multi-criteria decision-making problems, two independent case studies that have been previously investigated using the AHP are combined and re-evaluated. The first study deals with the optimal selection of a coding machine based on technical and economic criteria, while the second study examines the prioritization of urban transportation options by considering different stakeholder perspectives. The main objective of this study is to demonstrate the flexibility and power of the AHP in integrating the results of separate studies and also to examine how the integration of these studies affects the finalization of decisions. In this regard, the mathematical modeling of the AHP is explained in detail and its solution method is presented in detail. Also, in order to assess the depth and accuracy of the initial studies, a literature review of both articles is presented separately on two pages. Finally, the results of combining these two studies will be discussed in a separate section, and a summary and general conclusion will be presented regarding the benefits of this combined approach

## **Introduction**

Decision-making in many scientific and practical fields is complicated by the existence of multiple objectives, different and sometimes conflicting evaluation criteria, and a large number of alternative options. In this study, we consider two multi-criteria decision-making problems that have been previously investigated using the Analytic Hierarchy Process (AHP) method, and our main goal is to combine the approaches and results of these two studies.

**Problem 1:** Selection of an encoding machine, this problem deals with how to optimally select an encoding machine in an industrial or research environment. The process of selecting such a machine usually involves evaluating a set of available options based on a set of criteria. These criteria can include technical aspects (such as speed, accuracy, reliability, compliance with standards) and economic aspects (such as purchase cost, operating cost, maintenance cost, return on investment). The goal is to identify the machine that performs best across all of these criteria and provides the greatest utility to the decision maker.

**Issue 2:** Determining urban transportation priorities, this issue addresses the process of prioritizing transportation projects or strategies in a city. In this area, options can include building new subway lines, expanding the bus system, improving cycling infrastructure, implementing traffic plans, or investing in intelligent transportation technologies. The evaluation criteria in this issue are usually multifaceted in nature and may include things like traffic reduction, improving air quality, accessibility for different segments of society, safety, operational cost, and economic and social impacts. In this study, the emphasis is on considering the perspectives of different stakeholders (such as citizens, city officials, transportation experts), each of whom has different priorities.

The overall goal of this research is not to simply examine these two issues separately, but to focus on the integration of the (AHP) approach in these two studies. This integration is done to achieve the following goals:

- \* Comprehensive review of modeling (AHP): A deeper understanding of how hierarchical structuring is done in two different application areas.
- \* Methodological comparison: Assessing how pairwise comparisons are applied, weights are calculated, and consistency is achieved in both studies.
- \* Integration of results: Examining how to combine or compare results from separate studies to reach a larger conclusion or identify common patterns.
- \* Decision-making enhancement: Showing how integrating the results of studies (AHP) can help decision-makers make more comprehensive and informed decisions.

In other words, by carefully examining the structure, methodology, and results of two independent (AHP) studies, we intend to provide the basis for a better understanding of the potential of (AHP) in combining knowledge from different sources.

### **2. Problem classification**

Multi-criteria decision-making problems can be classified according to different dimensions. In this research, considering the two studies examined, the following classification can be presented: 1-2. Based on the nature of the decision:

**Choice:** Both problems under consideration have aspects of choice. In the first study, the optimal selection of an encoding machine from among the available options. In the second study, the selection or prioritization of transportation projects or strategies.

**Prioritization:** The second study specifically examines the problem of prioritizing transportation options, which is a subset of multi-criteria decision-making.

### **2-2. Based on the number of decision-makers:**

**Single decision-maker** (assuming that each study is conducted by a single decision-maker): Ideally, if we assume that each study is conducted by a single individual or group of decision-makers, the problem is initially modeled as a single decision-maker.

**Multiple decision makers** (if views are combined): The second study explicitly refers to the different perspectives of stakeholders, indicating the multi-decision-maker nature or at least the

consideration of different perspectives. Combining studies can lead to more complex modeling, if necessary, taking into account agreement or disagreement between decision makers.

2-3. By application area:

Industrial/Technical: The problem of selecting a coding machine falls within the industrial domain and focuses on technical and economic criteria. Urban/Social: The problem of urban transportation falls within the domain of urban and social planning and deals with multiple social, economic and environmental criteria.

2-4. Based on the problem-solving approach:

Hierarchical structure: Both studies use the AHP method, which inherently defines a hierarchical structure for the problem (objective, criteria, options)

Paired comparisons: What both studies have in common is the use of paired comparisons to measure the relative importance of elements at different levels of the hierarchy.

5-2. Based on the type of criteria:

Quantitative and qualitative: The criteria of both studies are likely to be a combination of quantitative (such as cost, speed) and qualitative (such as ease of use, general satisfaction) criteria, which AHP has the ability to combine both.

By combining the two studies, the main problem of this research can be classified as follows:

Study integration: The AHP aims to integrate the results and approaches of two independent studies that used AHP.

Comparative and comparative: By comparing the structure, methodology, and results of both studies, similarities, differences, and integration capabilities are examined.

Applied: Both main studies had operational goals in their application areas, and their integration also seeks to improve practical decision-making processes.

Methodological: This research focuses on the methodological aspects of AHP and shows how this method can be used in more complex and integrated scenarios.

This classification helps us identify the different dimensions of the issues under consideration and provides a framework for analyzing and integrating them.

### .3Mathematical modeling

In this section, we outline the mathematical modeling of the Analytic Hierarchy Process (AHP). We assume that the problem is defined as a hierarchical structure with a goal (G), m criteria,  $(C_1, C_2, \dots, C_m)$  and n options  $(O_1, O_2, \dots, O_n)$ . If necessary, sub-criteria can also be considered, in which case the hierarchical level increases.

Pairwise comparison matrix:

For each level of the hierarchy, a pairwise comparison matrix is formed. The size of this matrix depends on the number of elements at that level.

Criteria-to-goal comparison matrix: Let the pairwise  $A_C$  comparison matrix be m criteria-to-goal G. This matrix is obtained from pairwise comparisons between criteria by the decision maker.

$$(1) A_C = \begin{bmatrix} w_{11} & w_{12} & \dots & w_{1m} & w_{21} & w_{22} & \dots & w_{2m} & \vdots & \ddots & \vdots & w_{m1} & w_{m2} & \dots & w_{mm} \end{bmatrix}$$

where  $w_{ij}$  represents the assessment of the relative importance of the criterion  $C_i$  relative to  $C_j$ .

Matrix of comparison of options relative to each criterion: For each criterion, a matrix of pairwise comparisons of option  $C_j$   $A_{O_j}$  comparisons relative to that criterion is formed.

$$A_{O_j} = \begin{bmatrix} o_{11}^{(j)} & o_{12}^{(j)} & \dots & o_{1n}^{(j)} & o_{21}^{(j)} & o_{22}^{(j)} & \dots & o_{2n}^{(j)} & \vdots & \ddots & \vdots & o_{n1}^{(j)} & o_{n2}^{(j)} & \dots & o_{nm}^{(j)} \end{bmatrix} \quad (2)$$

where  $o_{ik}^{(j)}$  represents the assessment of the relative importance of the option  $O_i$  to the alternative  $O_k$ .

### 3-2. Calculating weights (priority vector):

To extract the weights from the pairwise comparison matrix A, the eigenvector method is used. The weight vector w is obtained by solving the equation  $Aw = \lambda_{\max} w$ , which  $\lambda_{\max}$  is the largest eigenvalue of the matrix A.

Criteria Weight: After calculating the original eigenvector for the matrix  $Wc = [w_1, w_2, \dots, w_m]^T$  (which is established), this vector  $A_c \sum_{j=1}^m w_j = 1$  shows the relative weight of the criteria relative to the target.

Weight of options relative to each criterion: For each criterion  $C_j$ , the main eigenvector is  $w_{o_i} = [o_1^{(j)}, o_2^{(j)}, \dots, o_n^{(j)}]^T$  calculated for the matrix  $A_{o_j}$ ,  $\sum_{i=1}^n o_i^{(j)} = 1$  which is established. This vector shows  $C_j$  the relative weight of  $A_{o_j}$  the options relative to the criterion.

### 3-3. Calculation of the consistency index:

The consistency index (CI) is calculated for each matrix A:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \tag{3}$$

Where  $\lambda_{\max}$  is the largest eigenvalue of the matrix A and n is the matrix dimension. The inconsistency ratio (CI) is obtained by comparing CI with the random index (RI) proportional to the matrix size:

$$CR = \frac{CI}{RI} \tag{4}$$

To accept comparisons,  $CR \leq 0.1$ .

Calculating the final weight of the options:

The final weight (or overall priority) of each option  $O_i$  is calculated by combining its relative weights with respect to each criterion  $W_o = [W_1, W_2, \dots, W_n]^T$ . The final weight vector of the options is obtained as follows:

$$W_o = A_o \times Wc \tag{5}$$

where is a  $A_o$  matrix who's each row contains the weights of the options relative to a criterion. (i.e.,  $A_o$  it is a matrix  $n \times m$  whose column  $j$  is equal to  $W_{o_j}$ , so  $A_o = [W_{o_1} | W_{o_2} | \dots | W_{o_m}]$ ). More precisely, the final option  $O_i$  weight is equal to:

$$W_i = \sum_{j=1}^m w_j \times o_i^{(j)} \tag{6}$$

This final weight  $O_i$  indicates the overall priority by considering all criteria and their weights to the overall goal. The options are ranked based on this final weight.

This mathematical framework forms the basis for modeling and solving problems using the (AHP) method, and in future studies, these models will be developed in more detail based on the structure and criteria specific to each study.

#### 4. Problem-solving methods

The solution method in the AHP framework involves the step-by-step implementation of the steps defined in the mathematical modeling. These steps are implemented systematically and using computational tools (such as specialized AHP software or manual calculations/using spreadsheets). In this section, we will generally discuss the solution method in this study.

1-4. Understanding and reconstructing the AHP models of two studies:

The first step in solving the integration problem is to fully understand the AHP model of each of the two independent studies. This includes:

Identifying the objective: What was the main objective set in each study?

Identifying the criteria and sub-criteria: What criteria were used to evaluate the options? Is the hierarchy deeper?

Identifying the alternatives: What options were presented for decision-making?

Reviewing the pairwise comparison data: This data was collected through questionnaires, interviews, or other methods.

Reviewing the results: The relative weights of the criteria, the relative weights of the options relative to the criteria, the final weights of the options, and the final ranking.

Checking the consistency: The CR values reported in each study.

2-4. Implementing the AHP model (if reconstruction or verification is needed)

If access to raw data of pairwise comparisons of each study is available, or if we want to use newer software or more accurate methods (e.g. eigenvector), it may be necessary to reimplement the AHP model for each study. This includes:

1- Construction of pairwise comparison matrices: Based on existing or reconstructed data.

2- Calculation of eigenvector (or other weighting methods): To extract the relative weights of criteria and options.

3- Calculation of CI and CR: To verify or reassess the consistency of comparisons.

4- Calculation of the final weight of options: For the final ranking.

3-4. Solution method for combining studies:

Combining these two studies can be done in different ways, each of which is considered an aspect of the solution method for the combination problem:

4-3-1. Comparative comparison of models and results:

Comparison of hierarchical structure: Examining the degree of similarity or difference in the depth and breadth of hierarchies, categorizing criteria and options.

Comparison of sets of criteria: Identifying common criteria (with similar names or concepts) and unique criteria in each study.

Comparison of weights of criteria: Examining the relative importance of common criteria in two studies. Does a criterion have a high weight in one study and a low weight in the other?

Comparison of option rankings: Comparing the rankings of options (in case of common options or similarity of their concepts) or comparing the overall results.

4-3-2. Combining common criteria:

If there are similar criteria in both studies, their relative weights can be compared or combined (after standardization). This can lead to a better understanding of the importance of these criteria at different levels of decision-making.

4.3.3. Build a combined AHP model (if possible and justified):

This step is more complex and requires that a common or understandable goal can be defined for both problems.

Define a higher-level goal: If a more general goal can be defined that both studies are subsets of.

Merge criteria into a new structure: Define a new hierarchy that includes criteria from both studies. This may result in a very large and complex model.

Combine weights: Use weights obtained from previous studies as input for a higher-level model (e.g. in a broader AHP process).

4.3.4. Analyze overlaps and gaps:

Identify strengths and weaknesses: Examine which study has provided stronger results due to specific criteria or a different approach.

Identify missing knowledge: Does combining the two studies shed light on aspects that were overlooked in each study alone?

4-3-5. Using study results as input for higher-level decision making:

Instead of building a completely new AHP model, the results (relative priorities) from each study can be considered as input (weights) for a subsequent decision-making stage.

6-3-4. Tools used:

Specialized software: AHP such as Expert Choice, Super Decisions, AHP-OS. These software automate the process of building the model, making comparisons, calculating weights, and checking consistency.

Spreadsheets (such as Microsoft Excel): To implement mathematical calculations, AHP especially for problems with a limited number of elements.

Programming languages (such as Python with NumPy and SciPy libraries): To implement computational algorithms, especially for more advanced analyses.

The main solution approach in this research will involve an in-depth analysis and comparative comparison of two AHP studies, re-engineering the models (if necessary), and then providing a framework for integrating the results and insights from this integration. Focusing on how this integration can be done and what insights can be gained from it will form an important part of the solution approach.

Literature Review

The Analytic Hierarchy Process (AHP) method has been used in recent decades as one of the most widely used multi-criteria decision-making methods for solving complex problems with diverse and sometimes conflicting criteria. A review of previous studies shows that this method has demonstrated a high ability to structure the problem and prioritize options, especially in situations where human judgments and expert opinions play a central role.

In the first study, the AHP method was used to select a coding machine in the pharmaceutical industry. The main objective of this research was to identify and weight the criteria affecting machine selection and ranking of different suppliers. The decision-making structure in this study includes goal definition, determination of technical and economic criteria, and evaluation of options through pairwise comparisons. The main strength of this study is the transparency of the hierarchical structure and the ability to quantify expert judgments, which has enabled the extraction of the final priority of the options. However, the results are highly dependent on the accuracy and consistency of the initial judgments, and the assumption of independence of criteria is also raised as an inherent limitation of the AHP method in this study.

The second study examines the application of the AHP method in the field of determining urban transportation priorities. In this study, the preferences of citizens and different stakeholders in choosing transportation modes are analyzed based on a set of social, economic, and service criteria. The distinctive feature of this study is the attention to the diverse perspectives of stakeholders and the attempt to achieve a comprehensive ranking in a multidimensional and sometimes conflicting decision-making environment. This approach shows that AHP, in addition to technical and industrial issues, has a high ability to analyze complex social and urban service issues.

A comparison of these two studies shows that despite the difference in the field of application, the methodological structure of both studies is the same. Both studies used the definition of decision hierarchies, pairwise comparisons, extraction of criteria weights, and prioritization of options. Their main difference is in the type of criteria and the nature of decision-making; the first study focuses more on technical and economic criteria, while the second study emphasizes social and preference criteria.

In summary, the literature review shows that the analytic hierarchy process, as a single framework, is adaptable to decision-making problems in different domains. Combining these two studies indicates that the AHP can be used simultaneously to analyze managerial decisions at the organizational level and strategic decisions at the urban level, provided that the limitations of the method, especially the dependence on expert judgments, are properly considered.

Table 1 - Comparison of studies

Several decision makers	Correlation or assumption of independence	Multi-product	Group / Individual	Multiple choice	Multi-regional	Year	Author/Authors
✓	Assumption of independence of criteria	✓	Group	✓	✗	2023	Novrisal & Mahmudah
✓	Assumption of independence of criteria	✗	Group	✓	✓	2024	Sekmen et al.

**Conclusion**

This study aimed to combine and analyze two independent studies based on the Analytic Hierarchy Process (AHP), one of which focused on the selection of a coding machine in an industrial environment and the other on prioritizing urban transportation modes. The results showed that despite the substantive differences between the two problems, both studies use a common and coherent decision-making framework and the AHP method has a high ability to model multi-criteria decision-making problems at different levels.

The findings indicate that AHP is a flexible tool that can be applied from operational and organizational issues to strategic and urban decision-making. However, the difference in the level of decision-making, the nature of the criteria, and the diversity of stakeholders are the main challenges in the process of combining the two studies. The first study was more structured, focusing on technical and economic criteria, while the second study showed more complexity in the decision-making process, considering multifaceted criteria and diverse stakeholder perspectives.

In the integration section, a comparative comparison of the structure, criteria, and role of stakeholders in the two studies showed that it is possible to integrate the results through a higher-level hierarchical model; one that can use weights and priorities extracted from previous studies as input. This integrated approach provides the basis for achieving a more comprehensive understanding of the relationship between decisions in different areas and identifying gaps that may have been overlooked in individual studies.

Overall, the results of this study emphasize that success in applying the AHP method depends on precise problem definition, correct hierarchical structuring, and attention to the role of expert judgments, and that integrating studies based on this method can lead to more comprehensive and coherent decision-making.