Chapter 4

Transport Sustainability Assessment

4.1 Introduction

When evaluating transportation projects and determining which of them will be carried out from a set of projects, several criteria need to be considered in the decision. Standard evaluation practices imply the aggregation of impacts into one utility function. Multi-criteria techniques can explicitly deal with different measuring units, however, they are not suitable to model interdependence relationships of projects that share a common characteristic (same route, location or target population, for instance).

The conventional techniques used for evaluation of transport projects, takes into consideration sustainability indicators, can be classified as follows:

- Multi-Criteria Decision Analysis (MCDA)
- The Analytical Hierarchy Process (AHP)

4.2 Multi-Criteria Decision Analysis (MCDA)

Multi-Criteria Decision Analysis is one of the established branches of Decision Theory. It is especially useful when making preference-based decisions over available alternatives based on criteria that are characterized by multiple, usually conflicting, attributes; i.e. “more is better” and “less is better” criteria (Pérez, Carrillo, & Montoya-Torres, 2014), and (Ananda & Herath, 2009). Unlike single-objective decision-making techniques, such as benefit-cost or cost/effectiveness analysis, MCDA techniques can take into account a wide range of differing criteria (Zietsman, Rilett, & Kim, 2006). The MCDA techniques are often applied for evaluating alternatives based on quantitative criteria; expressed in monetary terms. These techniques can also be used for qualitative impacts during the evaluation process (Sipahi & Timor, 2010).

In general, the methodology consists of seven steps (Figure 4). The first step consists of identifying the possible alternatives and their impacts submitted from a transportation study to achieve defined planning objectives. These alternatives can take different forms according to the problem situation. They can be different technological solutions (e.g.; bus or light rail), possible future scenarios, etc. There should be minimum two alternatives to be compared.

In the second step, the various relevant stakeholders are then identified, and their key objectives are specified. The stakeholders are people who have an interest in the concerns of any decisions taken; e.g. traffic and transport operators, transport users, local residents and businesses, land and property owners, as well as environmental and non-governmental organizations (NGOs).

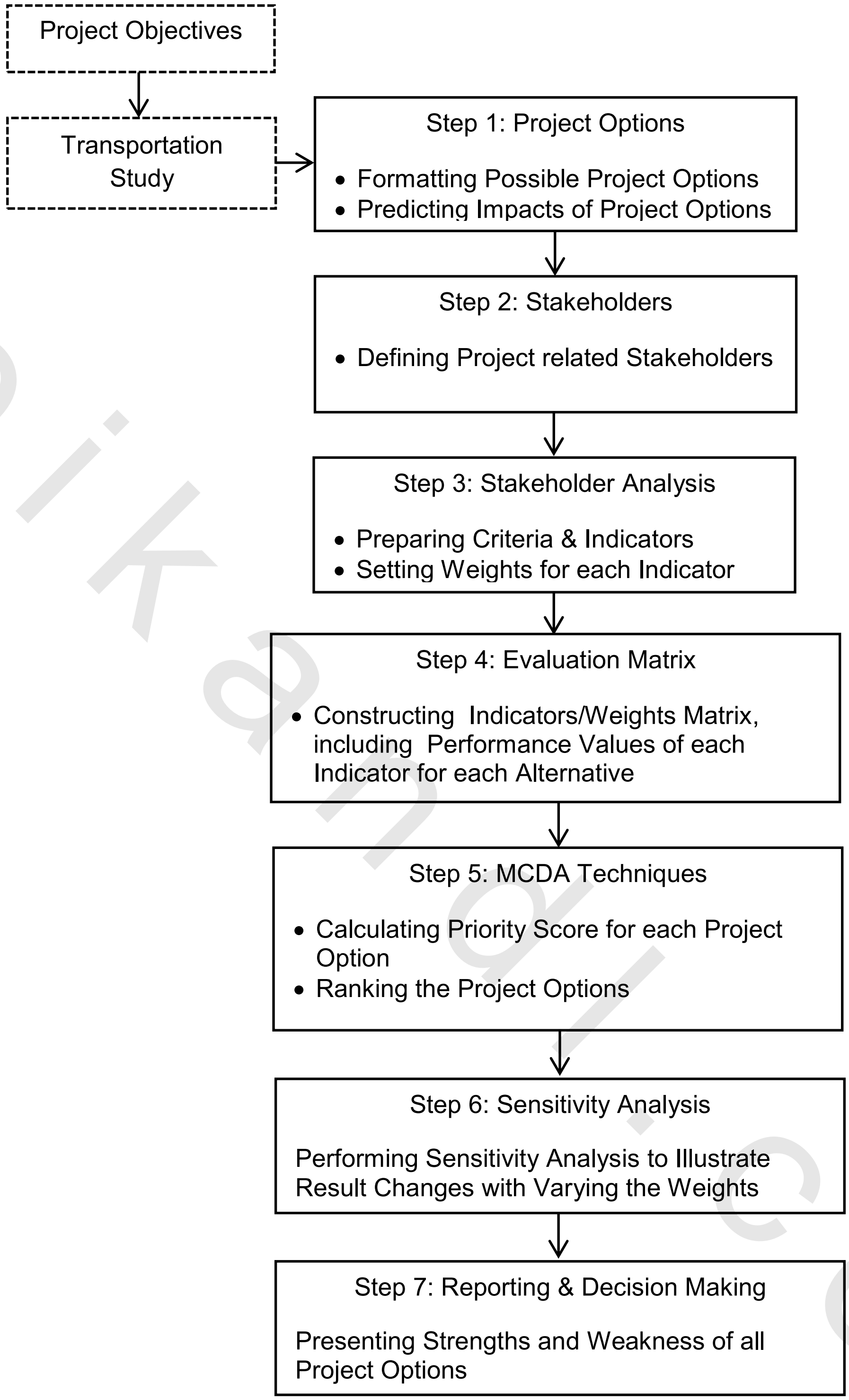

Figure 4: The Process of the Multi-Criteria Decision Analysis

In the third step, the particular objectives of each stakeholder are translated into criteria. The evaluation criteria are the impacts of the project arranged according to technical, economic, social, and environmental issues. Each criterion may include one or more indicators. An indicator is a measure or a scale of the effect of a project option regarding a certain criterion. For instance, the indicators of the environmental criteria may be noise level, Carbon dioxide (CO_2) reduction, Greenhouse Gases (GHG) reduction, water pollution, etc.

The indicators can be expressed explicitly in qualitative or quantitative, absolute or relative terms, in one of the following forms, however possible (Sayers, Jessop, & Hills, 2003):

- Quantitative (performance values; e.g. level of service, average speed, average time, etc.)
- Qualitative (description of impacts; e.g. good or bad, support or contradicts of objectives)
- Rating (A to F, 1 to 10, or high/medium/low, etc. for criteria with values that are difficult to express in quantitative terms)
- Monetization (use monetary unites to measure the value of impacts)

Each stakeholder gives then weights of each indicator. This weight represents the importance that a stakeholder allocates to the considered indictor. The average of the weights of all stakeholders regarding a given indicators can be used to present the importance of this indicator taking into account all stakeholder's side of views. In addition, the stakeholders might also give new ideas on the alternatives that have to be taken into account.

In the step 4, for each stakeholder, an evaluation matrix is constructed aggregating the impacts of each alternative to the weights given by the stakeholder regarding the particular indicators (Gühnemann, Laird, & Pearman, 2012).

Different MCDA techniques are used to calculate a single evaluation priority score for each project option. Therefore, the 5th step, including the calculation of the evaluation score and the ranking of the various alternatives, is the core element of the multiple criteria decision making (Buselich, 2002).

Due to the expected uncertainty embedded in the dataset (qualitative and quantitative nature of data inputs), the stability of this ranking can be accessed through a sensitivity analysis in step 6, to determine the transparency of the final decision output (Carbone, De Montis, De Toro, & Stagl, 2000). A sensitivity analysis is performed in order to see if the result varies, when the weights are changed.

In the last step of this process (Step 7), due to the complexity nature of the MCDA, trade-offs analysis between advantages and disadvantages of each project option can be applied by decision makers for the final judgment. It is, therefore, increasingly being considered by decision-makers in order to (i) evaluate priorities, preferences, values and objectives; (ii) improve the quality of decisions by making choices more clear, and (iii) capture non-quantitative impacts through qualitative assessment (Ho, Xu, & Dey, 2010).

MCDA techniques are widely diverse. (Lai, Liu, & Hwang, 1994) classified MCDA procedures according to the weighted sum model (WSM), the weighted product model (WPM), and the Multifactor Evaluation Process (MFEP).

All these techniques start with construct a matrix that contains the values of each criterion for all alternatives, as well as the relative weights of the different criterion.

let A = {1 to x} be the set of m alternative projects, and n the number of criteria from which to consider each project, and let Cj(xi) be the action consequent to each project xi, of the criterion j.

	C_1	…	C_j	…	C_n
Alternative 1					
Alternative i			Cj(*x*i)		
Alternative m					
Weights	w_1		w_j		w_n

4.2.1 Weighted Sum Model (WSM)

The Weighted Sum Model (WSM) is the best known and simplest MCDA method for evaluating a number of alternatives in terms of a number of decision criteria. In general, if a given MCDA problem is defined on m alternatives and n decision criteria and all the criteria are benefit criteria (more is better), then the higher the values are, the better it is. If w_j denotes the relative weight of importance of the criterion C_j and a_{ij} is the scaled performance value of alternative A_i when it is evaluated in terms of criterion C_j. Then, the total importance of alternative A_i, denoted as $A_i^{WS\text{-}score}$, is defined as follows:

$$A_i^{WS-score} = \sum_{j=0}^{n} w_j \cdot a_{ij}, \text{ for } i= 1,2,3,\ldots, m. \qquad (15)$$

For the maximization case, the best alternative is the one that yields the maximum total performance value.

Illustrative Example 1
For a simple numerical example suppose that a decision problem of this type is defined on three alternatives A_1, A_2, A_3 each described in terms of four criteria C_1, C_2, C_3 and C_4. Furthermore, let the numerical data for this problem be as in the following decision matrix:

Alternatives	Criteria			
	C_1	C_2	C_3	C_4
A_1	25	20	15	30
A_2	10	30	20	30
A_3	30	10	30	10
Weights	0.20	0.15	0.40	0.25

The relative weight of the first criterion is equal to 0.20; the relative weight for the second criterion is 0.15 and so on. Similarly, the value of the first alternative (i.e., A_1) in terms of the first criterion is equal to 25; the value of the same alternative in terms of the second criterion is equal to 20 and so on.

When the previous formula is applied on these numerical data the WSM scores for the three alternatives are:

$$A_1^{WS\_score} = 25 \text{ x } 0.20 + 20 \text{ x } 0.15 + 30 \text{ x } 0.25 = 21.50$$

Similarly:

$$A_2^{WS\_score} = 22.00, \text{ and } A_3^{WSM\_score} = 22.00$$

Thus, the best alternative is alternative A_2 (because it has the maximum WS score which is equal to 22.00). Furthermore, these numerical results imply the following ranking of these three alternatives: $A_2 = A_3 > A_1$ (where the symbol ">" stands for "better than").

In case that some criteria are “more is better” criteria and others are “less is better” criteria, then the following procedure is applied:

1. Determine the minimum and the maximum value of each criterion, and calculate the deference between them.
2. Create a scaling matrix (non-negative):
   - In case of criteria with more is better, set 0 for the minimum value and 1 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1; and
   - In case of criteria with less is better, set 1 for the minimum value and 0 for the maximum value for each criterion, and the other values of this criterion in a linear scale between 0 and 1.

   The scaled matrix contains, then, the relative importance of each criterion for each project option in a scale between 0 and 1, i.e. a_{ij} (i = from 1to m, and j= 1 to n).
3. Calculating the Weighted Sum Score for each Project Option.
4. Ranking the project options according to their scores.

4.2.2 Weighted Product Model (WPM)

The Weighted Product Model (WPM) is a popular MCDA method. It is similar to the WSM. The main difference is that instead of addition in the main mathematical operation, this method is based on multiplication. If a given MCDA problem is defined as follows:

- m alternatives and n decision criteria,
- all the criteria are “more is better” criteria,
- w_j denotes the relative weight of importance of the criterion C_j,
- a_{ij} is the performance value of alternative A_i and it is evaluated in terms of criterion C_j,
- and, if one wishes to compare the two alternatives A_K and A_L (where $m \geq K, L \geq 1$),

The following product has to be calculated:

$$P(A_K / A_L) = \prod_{j=1}^{n} (a_{kj}/a_{Lj})^{wj}, \text{ for K, L} = 1, 2, 3\ldots \text{ m.} \quad (16)$$

If the ratio $P(A_K/A_L)$ is greater than or equal to the value 1, then it indicates that alternative A_K is more desirable than alternative A_L (in the maximization case).

Illustrative Example 2

This simple decision problem is based on three alternatives denoted as A_1, A_2, and A_3 each described in terms of four criteria C_1, C_2, C_3 and C_4. Next, let the numerical data for this problem be as in the following decision matrix:

Alternatives	Criteria			
	C_1	C_2	C_3	C_4
A_1	25	20	15	30
A_2	10	30	20	30
A_3	30	10	30	10
Weights	0.20	0.15	0.40	0.25

From the above data we can easily see that the relative weight of the first criterion is equal to 0.20, the relative weight for the second criterion is 0.15 and so on. Similarly, the value of the first alternative (i.e., A_1) in terms of the first criterion is equal to 25; the value of the same alternative in terms of the second criterion is equal to 20 and so on. However, now the restriction to express all criteria in terms of the same measurement unit is not needed. That is, the numbers under each criterion may be expressed in different units.

When the WPM is applied on the previous data, then the following values are derived:

$$P\ (A_1/A_2) = (25/10)^{0.20}\ x\ \ (20/30)^{0.15}\ x\ \ (15/20)^{0.40}\ x\ \ (30/30)^{0.25} = 1.007\ > 1$$

$$P\ (A_1/A_3) = 1.067\ > 1$$

Similarly:

$$P\ (A_1/A_3) = 1.067\ > 1$$
$$P\ (A_2/A_3) = 1.059\ > 1$$

Therefore, the best alternative is A_1, since it is superior to all the other alternatives. Furthermore, the ranking of all three alternatives is as follows: $A_1 > A_2 > A_3$ (where the symbol ">" stands for "better than").

The Weighted Product Model (WPM) has some weakness. Firstly, the values in the matrices should be non-zero. Secondly, Decision-aiding techniques do not overcome the problem associated with incomparable quantities ((Munda, 2004)); i.e. criteria with different identities (combination of “less is better” criteria and “more is better” criteria).

4.2.3 Multifactor Evaluation Process (MFEP)

The Multifactor Evaluation Process (MFEP) is also close to the WSM. It is appropriate when an individual, a group, or an organization faces a number of factors in a decision-making situation. With the MFEP, a decision maker assigns an importance weight to each factor.

In general, if a given problem is defined on m alternatives and n decision criteria and all the criteria are "more is better" criteria, and if w_j expresses the relative weight of importance of the criterion C_j, then a_{ij} is the performance value of alternative A_i when it is evaluated in terms of criterion C_j.

MFEP starts by listing the performance value of alternative (a_{ij}) and the relative importance of each criterion (weights) on a factor scale from 0 to 1 in an evaluation matrix. The sum of each column j is calculated, and each value of the column is divided by its column sum to generate a normalized matrix. The sum of each column will be 1.

The factor weights are multiplied by each factor in the evaluation normalized matrix for a given alternative and summed. The alternative with the highest overall priority score is selected.

Illustrative Example 3
For a numerical application, three alternatives A_1, A_2, A_3 are defined beside four criteria C_1, C_2, C_3 and C_4. The relative weights of the criteria are also defined. Then, let the numerical data for this problem is described as in the following decision matrixes:

Alternatives	Criteria				SUM
	C_1	C_2	C_3	C_4	
A_1	25	20	15	30	90
A_2	10	30	20	30	90
A_3	30	10	30	10	80
Weights	20	15	40	25	100

In the next Table, each value is equal to the corresponding value in the previous table divided by sum of the same row.

Alternatives	Criteria			
	C_1	C_2	C_3	C_4
A_1	0.28	0.22	0.17	0.33
A_2	0.11	0.33	0.22	0.33
A_3	0.38	0.13	0.38	0.13
Weights	0.20	0.15	0.40	0.25

In the following Table, each value of the criteria is equal to the corresponding value multiplied by weight of the same column.

Alternatives	Criteria				
	C_1	C_2	C_3	C_4	SUM
A_1	5.56	3.33	0.07	0.08	9.04
A_2	2.22	5.00	0.09	0.08	7.39
A_3	7.50	1.88	0.15	0.03	9.56

According to this method, the best alternative is alternative A_3 (because it has the maximum SUM score which is equal to 9.56). Furthermore, these numerical results imply the following ranking of these three alternatives; A_3, then A_1 and A_3 respectively.

In case that some criteria are "more is better" criteria and the others are "less is better" criteria, then the following procedure is applied:

- Construct a performance value matrix (a_{ij}) and allocate only the performance values of "less is better" criteria to be 1 divided by the corresponding performance value.
- Create a new matrix, in which each value equals the corresponding value in the previous matrix divided by SUM of the same ROW.
- Multiply the factor weights by each factor in the matrix for a given alternative and summed. The sum of a row presents the evaluation priority score of the corresponding alternative.
- Rank the project options according to their priority scores.

MCDA in Group Decision Making

As a decision affects several persons, MCDA has been adapted in order to be applied in group decisions. Consulting several experts avoids unfairness that may be present, when the judgments are considered from a single expert.

The vote is used, when a homogenous group is concerned and not a collection of individuals. On the judgments level, this method requires an absolute agreement on the value of each entry.

An absolute agreement is usually difficult to obtain with increasing the number of participants and related discussions. In order to bypass this difficulty, the vote can be postponed after the calculation of the priorities of each participant. An aggregation after the calculation of priorities allows decision-makers from different boards to discuss any further disagreement (Escobar & Moreno-jiménez, 2007).

4.2.4 Conclusion

In the illustrative examples 1 to 3, despite the use of the same input data, the results of the different techniques are totally varied, as follows:

MCDA Procedures	Rating of Alternatives		
	1	2	3
WSM	A3=A2	A3=A2	A1
WPM	A1	A2	A3
MFEP	A3	A2	A1

Moreover, MCDA also have a number of weaknesses:

- Decision makers often use subjective qualitative assessment and charge weights to assumptions, which may lead to subjective and non-transparent results (Annandale & Lantzke, 2000).
- MCDA may lead to doubt the results, due to the complexity nature of the methodology. Methods for explicitly incorporating uncertainty are not yet well developed, which may disadvantage stakeholders who are not willing to accept trade-offs, particularly where there are resource and time constraints (White & Lee, 2009).

4.3 Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a decision making tool helping decision-maker facing a complex problem with multiple criteria. AHP is used to integrate qualitative and quantitative information into a single output (Global priority). It contains six phases (Ishizaka & Labib, 2011):

- Structure of the Decision Problem under Consideration
- Judgment Scales
- Priorities Valuation
- Consistency Test
- Priorities Aggregation
- Sensitivity analysis

Phase 1: Structure of the Decision Problem

As with all decision-making processes, the allocation of the weights of criteria and project alternatives takes a long time and associated with difficult debates and different points of views. AHP has the advantage of permitting a hierarchical structure of decision problem under consideration. This structure provides users with a better analysis of all elements, when allocating the weights. This phase is important, because a different structure may lead to a different final ranking (Anjali Awasthi & Chauhan, 2011).

(Brugha, 2004) has provided a complete guideline to structure a problem hierarchically. When setting up the AHP hierarchy with a large number of elements, the decision maker should attempt to arrange these elements in groups so they do not differ in extreme ways. Figure 5 presents the AHP structure hierarchy, starting from the top (the goal) through the intermediate levels (criteria) to the lowest level (alternatives).

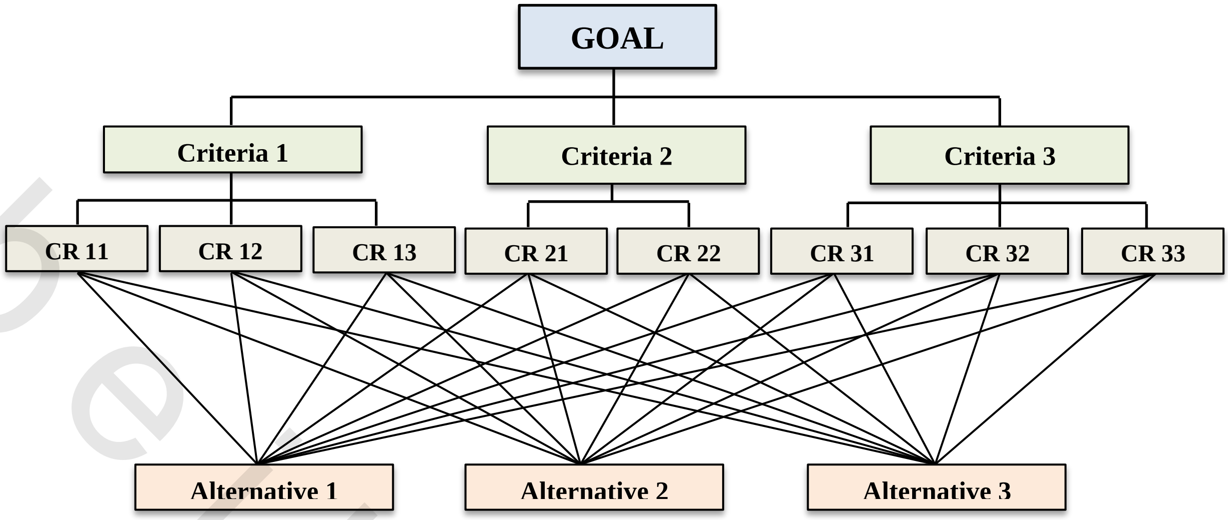

Figure 5: AHP Structure Hierarchy

Phase 2: Judgment Scales

AHP hierarchy method is based on pairwise comparisons between alternatives (or criteria). AHP uses a ratio scale (Table 5). It is a linear scale that contains integers from one to nine and their reciprocals. It requires no units in the comparison. The judgment is based on relative values, either for quantitative or qualitative criteria and indicators. One of AHP's strengths is the possibility to evaluate the comparison elements on the same preference scale (Saaty, 2006). The use of this scale is practically attractive, user-friendly and more common than numbers.

Table 5: AHP Preference Scale (Saaty & Vargas, 1998)

AHP Scale of Importance for pairwise comparison	Numeric Rating	Reciprocal (decimal)
Extreme Importance	9	1/9 (0.111)
Very strong to extremely	8	1/8 (0.125)
Very Strong Importance	7	1/7 (0.143)
Strongly to very strong	6	1/6 (0.167)
Strong Importance	5	1/5 (0.200)
Moderately to Strong	4	1/4 (0.250)
Moderate Importance	3	1/3 (0.333)
Equally to Moderately	2	1/2 (0.500)
Equal Importance	1	1(1.000)

Phase 3: Priorities Valuation

This phase is based on four steps; see the following illustrative example, (Sipahi & Timor, 2010):

1. Constructing pairwise comparison matrices

2. Sum the elements of each column j
3. Divide each value by its column sum to generate normalized matrices. The sum of each column will be 1
4. Calculate the average of each row, which presents the Priority Vector of the row

A pairwise comparison matrix is a consistent matrix (n x n), in which comparisons are recorded. It takes the following form:

$$\begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ \frac{1}{a_{12}} & 1 & \dots & a_{2n} \\ \dots & \dots & 1 & \dots \\ \frac{1}{a_{1n}} & \frac{1}{a_{2n}} & \dots & 1 \end{bmatrix}$$

Where, a_{ij} is the comparison between element i and j.

To fill the lower triangular matrix, the reciprocal values of the upper diagonal are used. If a_{ij} is the element of row i column j of the matrix, then the lower diagonal is filled as $1/a_{ij}$.

After constructing the pairwise comparison matrix, a normalized matrix can be generated by totaling the numbers in each column. Each entry in a column is then divided by the column sum to yield its normalized score. The sum of each column is 1.

$$x_{ij} = \frac{a_{ij}}{\sum_i^n a_{ij}} \quad (17)$$

The form of the normalized matrix (n x n) is as follows:

$$\begin{bmatrix} x_{12} & \dots & \dots & x_{1n} \\ \dots & \dots & \dots & \dots \\ \dots & x_{ij} & \dots & \dots \\ \dots & \dots & \dots & x_{in} \end{bmatrix}$$

Where, x_{ij} is the normalized score of the comparison value between element i and j.

Then, the average of each row is calculated to determine the Priority Vector of the row. The result will be a (n x 1) matrix that includes a set of relative priorities P_n of the criteria from criterion 1 to criterion n, as follows:

$$\begin{bmatrix} P_1 \\ \dots \\ P_i \\ \dots \\ P_n \end{bmatrix}$$

Illustrative Example:

Criteria	Pairwise Comparison Matrix		
	a	b	c
a	1	4	2
b	1/4	1	0.5
c	1/2	1/0.5	1
SUM	1.75	7	3.5

Normalized Matrix		
a	b	c
0.57	0.57	0.57
0.14	0.14	0.14
0.29	0.29	0.29
1	1	1

Average
Priority Vector (P)
0.57
0.14
0.29

Phase 4: Consistency Test

Having made all the pairwise comparisons, a consistency test should be applied. Priorities can make sense only if they are derived from consistent or near consistent matrices (Alonso & Lamata, 2006). The consistency test is carried out in 6 steps (see also the following example):

1. Multiply each column of the pairwise comparison matrix by the corresponding weight (Priority Vector) to calculate the Weighted Sum Vector WSV.

$$\mathrm{WSV}_{ij} = \sum_{1}^{n} \mathrm{a}_{\mathrm{ij}}.\,\mathrm{P}_{\mathrm{i}} \tag{18}$$

2. Divide of sum of the row entries by the corresponding weight to determine Consistency Factor CF.

$$\mathrm{CF}_{\mathrm{i}} = \frac{\mathrm{WSV}_{\mathrm{i}}}{\mathrm{P}_{\mathrm{i}}} \tag{19}$$

3. Compute the average of the values from step 2, denote it by λ.

4. Determine the Consistency Index CI.

$$\mathrm{CI} = \frac{\lambda - \mathrm{n}}{\mathrm{n} - 1} \tag{20}$$

   Where, n is the matrix size

5. The consistency ratio, the ratio of CI and RI, is given by:

$$CR = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{21}$$

   Where, RI is the random index and it can be driven from the following Table:

n	1	2	3	4	5	6	7	8	9	≥ 10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.44	1.45

Notes: n is the matrix size

6. In case of perfectly consistent, λ will equal n and therefore, the CI will be equal to zero and so will the consistency ratio CR. If CR is less than 10%, then the matrix can be considered as having an acceptable consistency. Otherwise the weights should be reviewed and improved.

Illustrative Example

Pairwise Comparison Matrix			
Criteria	a	b	c
a	1	4	2
b	0.25	1	0.5
c	0.50	2.00	1
SUM	1.75	7	3.5

Normalized Matrix		
a	b	c
0.57	0.57	0.57
0.14	0.14	0.14
0.29	0.29	0.29
1	1	1

Average
Priority Vector
0.57
0.14
0.29

Weighted Sum Vector	Consistency Factor	λ	CI	CR
1.710	3.000	3.00	0.00	0.001
0.428	3.054			
0.855	2.948			

Phase 5: Priorities Aggregation

The pairwise comparison is carried out several times:

- Pairwise Comparison between each two alternatives concerning one specific criterion in a pairwise comparison matrix. After normalizing the performance values in this matrix, formulate a normalized matrix. The average of each row in the normalized matrix presents the priority vector P_i of this alternative regarding this criterion. Carry out such pairwise comparison regarding the other criteria.

  For Criterion j

Alternatives	Normalized Matrix					AVR
	Alternative 1		Alternative i		Alternative k	Priority Vector (P_i)
Alternative 1						
			Performance Value			
Alternative i						
Alternative k						

Priority Vector P_{ij}, for alternative i (i=1 to i=k) regarding criterion j (j=1 to j=n)

	Criterion 1		Criterion j		Criterion N
Alternative 1					
			P_{ij}		
Alternative i					
Alternative k					

- Calculate the Local Priority Vector (LP) of each alternative:
  - ➢ In case of a "more is better" criterion, the priority vector P_i of alternative i presents the local priority vector (LP_i) of a particular criterion.
  - ➢ In case of a "less is better" criterion, the priority vector P_i of alternative i regarding this criterion should be regulated to calculate the local priority vector LP_i, as follows:

Alternatives	Priority Vector (P)	Regulation (R)	Local Priority (LP)
Alternative 1	P_1	$R_1 = 1 - P_1$	
Alternative i	P_i	$R_i = 1 - P_i$	$LP_i = Ri/\sum_{i=1}^{k} R$
Alternative k	P_k	$R_k = 1 - P_k$	
SUM		$\sum_{i=1}^{k} R$	

- Pairwise comparison between each two criterion to determine the weighted vector (W_i) for each criterion.

Criteria	Normalized Matrix					AVR
	Criterion 1				Criterion N	Weighted Vector (W_i)
Criterion 1						W_1
Criterion i						W_i
Criterion N						W_n

- Construct a Matrix that includes Local Priority (LP_{ij}) of all alternatives against all criteria, as well as the weighted vector (W_i) for each criterion.

Alternatives	Criterion 1				Criterion N
Alternative 1					
Alternative i			LP_{ij}		
Alternative k					
W_i (from 1 to N)			W_i		

The last step is to combine the local priorities across all criteria in order to determine the global priority for rating of alternatives. The AHP approach adopts an additive aggregation with normalization of the sum of the local priorities to unity (Ishizaka, Balkenborg, & Kaplan, 2011):

$$GP_i = \sum_{j}^{n} W_i \cdot LP_{ij} \qquad (22)$$

Where, GP_i is the Global Priority of the alternative i; LP_{ij} is local priority from criterion i to criterion j; W_i is weighted factor of the criterion i.

Alternatives	GP_i
Alternative 1	
Alternative i	$\sum W_i \cdot LP_{ij}$
Alternative k	

Phase 6: Sensitivity Analysis

The last step of the decision process is the sensitivity analysis, where the input data are slightly modified in order to observe the impact on the results. If the ranking does not change, the results are said to be strong, otherwise it is sensitive. However, an interactive graphical interface allows a better visualization of the impact of the changes (Sipahi & Timor, 2010).

AHP in Group Decision Making

As a decision affects several persons, AHP has been adapted in order to be applied in group decisions. Consulting several experts avoids unfairness that may be present, when the judgments are considered from a single expert.

The vote is used, when a homogenous group is concerned and not a collection of individuals. In this case, the hierarchy of the problem must be the same for all decision-makers. On the judgments level, this method requires an absolute agreement on the value of each entry in a matrix of pairwise comparisons.

An absolute agreement is usually difficult to obtain with increasing the number of comparison matrices and related discussions. In order to bypass this difficulty, the vote can be postponed after the calculation of the priorities of each participant. An aggregation after the calculation of priorities allows to detect decision-makers from different boards and to discuss further any disagreement (Escobar & Moreno-jiménez, 2007).

If an agreement is difficult to achieve (e.g. with a large number of persons or distant persons), the geometric mean of individual evaluations is used as elements in the pairwise matrices and then priorities are computed. The geometric mean method must be used instead of the arithmetical mean. For example, if person A enters a comparison 9 and person B enters 1/9, then the geometric mean should be $\sqrt{9\,.\,1/9}$ = 1, while the arithmetical mean is (9+1/9)/2 = 4.56. If the group is not homogenous, further discussions are required to reach an agreement (Saaty & Vargas, 2007). As individual identities are lost with an aggregation in group decision, (Condon, Golden, & Wasil, 2003) have proposed the visualization of the decision of each participant and the detection of extreme values.