EuroEconomica
Issue 2(34)/2015 ISSN: 1582-8859

Comparative analysis multiple criteria for the choice of a common transport system in Rabat (Morocco)

Badreddine EL GOUMI[1], Mohammed El KHOMSSI[2], Ghizlane CHAIBI[3]

[1]*University Sidi Mohamed Ben Abdellah, badreddinegoumi@gmail.com*

[2]*University Sidi Mohamed Ben Abdellah, khomsixmath@yahoo.fr*

[3]*University Sidi Mohamed Ben Abdellah, ghizlane.chaibi@usmba.ac.ma*

Abstract. The choice of a transport system is a complex and difficult job. Different systems may seem to offer equivalent services to users while often lack the information necessary to better distinguish the differences between a particular systems. We present a comparative analysis of public transport systems in Rabat-Sale to better guide the selection of communities, in the context of promoting urban transport meeting the challenges of sustainable development. We analyzed, presented the criteria and characteristics of each system, proposed and discussed a multi-criteria method to the weighted sum to propose the best adapted system with knowledge and clarity. We close this work with the results showing the fact that the tram has a special place in relation to the bus in the majority of scenarios.

Keywords: transport system, comparative analysis, multi-criteria method, weighted sum.

1 Introduction

Multi-criteria analysis is technical science devoted to clarification of understanding a decision problem and its resolution. It becomes multi-criteria when the problem has several objectives, often contradictory. An analysis that seeks to explain a coherent family of criteria to permit to conceive justify and transform preferences in a decision process.

According to this definition, we present, first, a few selection methods including multi-criteria analysis, the most used for the selection of an action or an alternative to a problem. Then we perform a multi-criteria comparative analysis of public transport systems in Rabat[1] while adopting the method of the weighted sum.

2 Analysis methods multicriteria

Basic methods (elementary)

a) categorical method (Borgers and Timmermans, 1986)

The categorical method is to do a performance evaluation of each action in relation to each criterion, and by assigning a "grade": a categorical single term, such as "good", "unsatisfactory" "neutral." Is carried out in a second step the sum of ratings of each action to obtain an overall score per action.

[1] *The capital and fourth largest city of Morocco with an urban population of approximately 620,000 (2004)*

The categorical method is simple to treat a selection problem, and easy to implement. However, it requires judgments based on memory and experience of the decision maker.

b) Method of the weighted sum (Borgers and Timmermans, 1986)

Is to establish a set of criteria and rank them by assigning each of them a weight. The method of the weighted sum is as follows:

- ✓ Step 1: Identify appropriate criteria to the problem, C_i
- ✓ Step 2: Assign weights to the criteria listed, reflecting the relative importance of the criteria, P_i
- ✓ Step 3: Evaluate each action on each of the criteria
- ✓ Step 4: Calculate the total score (weighted ratings) for each action

$$S(A_i) = \sum_{i=1}^{n} P_i . C_i \quad (1)$$

The method of weighted sum is one of the most used methods. It has the advantage of being easy to understand and implement. However, the difficulty resides in the definition of qualitative evaluations conversion procedures in quantitative evaluations.

c) Method "Maxmin" (Guitouni and Martel, 1998)

The "Maxmin" method is used to select an action considered the best action from a set of actions.

The term "maxmin" indicates that the procedure trying to select the maximum (depending actions) minimum ratings (according to criteria). Thus, the overall performance of an action is determined by its worst performance. This procedure is suitable in the case where the decision-maker has a pessimistic attitude.

Methods of Mathematical optimization Multi-criteria

The mathematical optimization methods are the most used in the field of scientific research, to address the selection problem. The problem is often formalized in the form of one or more objective functions and a set of constraints to be respected.

The resulting models can be linear or nonlinear depending on the problem to formalize. The mathematical optimization methods are often exploited in two stages.

- ✓ Step Modelling: it is to formalize the problem studied in an optimization model
- ✓ Step resolution: it consists in solving the proposed model.

The problem is Multi-criteria selection in the sense that the evaluation of an action is often done by considering several criteria at once. In this case, we limit the presentation of mathematical optimization methods for the integration of several criteria. This integration is done in three different ways:

- ✓ Aggregation criteria in one objective function (Compromise Programming, Goal Programming, and method of global criterion ...).
- ✓ Optimizing a criterion in the objective function and the integration of other criteria within the constraints of the model (ε-Constraint Method)
- ✓ The formulation of the problem in a mathematical multiple objective program.

Method of Multi-criteria Analysis:

a) Methods of multi-criteria decision

Mathematical programming methods for handling a selection problem with constraints, in other words, a selection problem where solutions are not known a priori. However, methods of multi-criteria decision that we present in the following assume that the solutions are known a priori. The method of choosing the best solution is conditioned by the way in which the decision maker expresses his preferences. In decision theory, this stage of the treatment of the problem is called preference modelling stage. We consider it a key point that distinguishes the elementary aggregation methods and mathematical optimization multi-objective methods of help multi-criteria decision.

The help multi-criteria Process Decision can generally be seen as a recursive process (iterative), nonlinear, composed of 4 principal stages (Guitouni and Martel, 1998):

- ✓ The definition of problems and the structuring of the situation (problem) decision.
- ✓ The modelling of preferences at each point of view (modelling of local preferences).
- ✓ The aggregation of these local preferences to establish one or more relational systems of global preferences.
- ✓ The recommendation after exploiting aggregation

As stated before, we assume that facing a decision-making context, the decision maker (the person with knowledge of the actions, criteria ...) will be helped by a man of study (expert, rational person master the process of help the decision).

b) Complete aggregation method: synthetic approach to the single criterion

- ✓ *TOPSIS Technique for Order by Similarity to Ideal Solution (*Hwang and Yoon, 1981*)*

The basic idea of this method is to select a solution that is closest to the ideal solution (better on all criteria) and away as possible from the worst solution (which degrades all criteria).

Step 1: Normalize performance according to a predefined formula (*E '*)

Step 2: Calculate the standard product performance by relative importance coefficients of the attributes (e''_{ij})

Step 3: Determine the ideal profile *(a*)* and anti-ideal $(\bar{a})$

Step 4: Calculate the Euclidean distance to profiles a^* and $\bar{a}$ (*Di* et *Di*)*

Step 5: Calculate a coefficient measuring the ideal profile of the combination *(C *)*

Step 6: Store the actions according to the decreasing values of *Ci **

The TOPSIS method lets arrange actions. His great contribution was the introduction of notions of ideal and anti-ideal. It is easy to apply. In addition, it is sensitive to the will of the decision maker. However, some limitations characterize this method: attributes must be of cardinal nature, preferences are fixed a priori. Moreover, if all actions are bad, the method offers the best action among the poor

- ✓ *SMART: Simple Multi-Attribute Technical Rating (*Edwards, 1971*)*

The SMART method is to use the additive form for aggregation evaluations on different criteria. This approach is justified by the fact that in some cases, also obtained good approximations with the additive form with other non-linear shapes which are much more complex.

The SMART method is as follows:

Step 1: Set the criteria in descending order of importance.

Step 2: Determine the weight of each criterion.

Step 3: Normalize the relative importance coefficients between 0 and 1: summing the importance coefficients and dividing each weight by this sum.

Step 4: Measure the location of each share on each criterion $u_j(a_i)$. The valuations of actions are on a scale ranging from 0 (least likely) to 100 (maximum plausible).

Step 5: Determine the value of each action by the following weighted sum:

$$U(a_i) = \sum_{j=1}^{n} \pi_j u_j (a_i), \quad i = 1,2, \dots\dots\dots, m . \tag{2}$$

Step 6: Rang the actions in descending order of $U(a_i)$.

The SMART method is easy to operate. It requires a priori articulation of preferences, and stock evaluation on a single scale (cardinal scale). The SMART method uses the additive form.

3 Selection criteria of common transport system in Rabat

The choice of criteria is a major challenge to better appreciate more or less objectively the possibilities of systems in the urban context. We use the following criteria for the possibilities and differences of a transport system to another.

Criteria related to the performance and services rendered.

Deemed necessary to ensure proper functioning of transport systems[2], are often linked to the quality of services provided to users, punctuality and accessibility.

✓ Capacity (Cp)

It is a value that represents the maximum provision of transport of a means of transport. *(Number of persons / vehicle where 4per / m²).*The following table shows the capacity of a vehicle of each transport system on own site:

Table 1 Capacity of a vehicle

Vehicle	**Vehicle (number of passengers)**
Tram	560
Bus (Stareo)	175

✓ Frequency (Fr)

Frequency is the number of vehicles travelling on a route on a regular schedule per time unit. In practice, this is the time observed between passing vehicles regularly and successively in one place. Thus, the frequency in practice should not be long for not disadvantage the level and quality of service.

Table 2 Frequency of vehicle

Vehicle	**Mean frequency (min)**
Tram	9
Bus (stareo)	20

[2] *All data sources are taken by the company of Tramay Rabat-Sale (STRS) Morocco*

✓ Commercial speed (C.S)

The commercial speed is needed to know the efficiency of a line and the quality of public transport service. It can be obtained by the following calculation:

$$V_c = \frac{l}{T_t} \quad (3)$$

where:

V_c: commercial speed,

l : length of the line,

T_t: Total travel time.

The mean commercial speed of each system is given by the following table:

Table 3 Commercial speed of different transport systems

Transport system	Commercial speed (km / h)
Tram	18,25
Bus	12

✓ Punctuality (Pu)

Punctuality is a feature of which is in conformity with the predetermined exploitation hourly. It is related to quality of service because it influences the waiting time of the judgment to users.

Life in big cities such as Rabat is stressful, delays in traffic are not acceptable by travelers. Punctuality, therefore, may be one of the necessary criteria, which acts on the level and quality of service. Punctuality can therefore result by the percentage:

Table 4 Punctuality

Transport system	Guidance	Punctuality(%)
Tram	Yes	97
Bus	No	70

Criteria related to costs:

Financial items are very present in the decisions and choices of transport systems, so buying a ticket and the global cost of a project of a public transport system are essential elements that influence the choice of a transport solution.

✓ Investment Cost (I.C)

The cost of the global investment project to Stareo bus mobilize 2 billion DHS TTC in 15 years.

The global investment cost of the tram project is established at May 2013 in 3.814 billion DHS TTC (Excluding price revision).

✓ Ticket price (T.C)

The cost of Tramway ticket is 6 DHS TTC.

The cost of bus ticket is 4 DHS TTC.

Criteria related to the environmental aspects: Greenhouse Gases (EGG)

Greenhouse gases are simply a gas that affects climate change. The table representing emissions of greenhouse gases of each transport system:

Table 5 Greenhouse gas emissions

Vehicle	Emission CO2 (gCO2/vehicule·km)	Total emission (tCO2/vehicule/year)	Coût total (DH/year)
Tramway	0	0	0
Bus	480	781	4266660

After studying the table, so we held that greenhouse gas emissions is zero for the tram and the bus is 480 g CO2 / km-vehicle. This means that the number of the tram that uses electricity is much better in terms of pollution.

4 Weights weighting

In this part, as there is no reference method, firstly we will try to choose the reference weight for each given criteria, these weights are fixed and then varies the common sense to see if this allocation is valid.

We have already selected the criteria in three categories: Performance, Cost and Environment. So we will fix the choice of the total score to a value for example 300. Then it is natural to think of to affect weight to classify the categories compared to the other two. However, there are, in practice, the criteria considered more important than others. The method we will follow is to give more weight on the most important criteria, other criteria being defined in a complementary manner to achieve the set score.

Thus, we will give weights that seem to be different from the reference weight and weight values each one of the criteria of the performance or cost or the environment, and in the table below, we will try to allocate weight for each criterion:

Table 6 Weight criteria

Criteria	Reference Weight	Weight 1	Weight 2	Weight 3
Capacity (Cp)	40	50	30	30
Frequency(Fr)	40	55	25	30
Commercial speed (C.S)	30	40	20	20
Punctuality(Pu)	40	55	25	30
Subtotal	150	200	100	110

Criteria	Reference Weight	Weight 1	Weight 2	Weight 3
Investment costs(I.C)	50	35	80	45
Ticket costs(T.C)	50	35	80	45
Subtotal	100	70	160	90
Environment Greenhouse gases(EGG)	50	30	40	100
Total	300	300	300	300

5 Application of the method of weighted amount and study of scenarios

We adopted the method of weighted sum because it is one of the most used methods. It has the advantage of being easy to understand and implement, and is known by its mathematical accessibility.

Scenario Study 1: Reference Weight

- **Mathematical formulation**

$$S(A_j) = \sum_{i=1}^{n} P_i . C_{ij} \qquad \forall j \in [1,2] \tag{4}$$

with;

P_i: Vector weights i∈ [1,8]

A_j : The actions (tram and bus)

C_{ij}: Criteria

- **Data Transformation**
  - ✓ Normalization of all C_{ij} criteria, $\forall i$, to maintain the proportionality between values.
  - ✓ Normalization of weights (the sum of weights = 1).
  - ✓ Implementation of the weighted sum method.

Subject of the Decision: The most optimal transport system

- **Consider the following 8 criteria:**

C1: Capacity: This criterion is to maximize

C2: Frequency: This criterion is to minimize

C3: Commercial speed: This criterion is to maximize

C4: Punctuality: This criterion is to maximize

C5: Capital cost: This criterion is to minimize

C6: Ticket Price: This criterion is to minimize

C7: EEG: This criterion is to minimize

References weight values are given in the table below (our choice):

Table 7 References to weights values

Criteria	Description	Reference Weight
1	Capacity	40
2	Frequency	40
3	Commercial speed	30
4	Punctuality	40
5	Investment cost	50
6	Ticket Price	50
7	Greenhouse gas	50

The matrix of decisions (performance chart) is as followings:

Table 8 The Decision Matrix

Transport System	Cp	Fr	C.S	Pu	I.C	T.C	EGG
Tramway	560	9 mn	18.25 km/h	97%	3.814 BDH	6 DH	0
Bus	175	20 mn	12 km/h	70%	2 BDH	4 DH	480 gCO^2

In order to have a coherent weighted sum, it is necessary to consider only the criteria to be maximized. However, criteria to minimize exist. A transformation of these data is then necessary to obtain those criteria to maximize. An appropriate transformation is as follows:

$$C'_{ij} = \max_i \left(C_{ij}\right) - C_{ij} \qquad \forall j, \qquad (5)$$

This transformation maintains the gaps and keeps a veritable zero, and exchange the order to be considered a criterion to be maximized.

The matrix of decisions or performance to which the weighted sum method can then be applied:

Table 9 The matrix of decisions after transformation

Transport System	Cp	Fr	C.S	Pu	I.C	T.C	EGG
Tramway	560	11 mn	18.25 km/h	97%	0 BDH	0 DH	480 gCO^2

Bus	175	0 mn	12 km/h	70%	1.814 BDH	2 DH	0

We then apply the method of Weighted Sums while going through normalization procedures Normalization of C_{ij} , $\forall i$:

We chose as the normalization procedure the following relationship:

$$v_{ij} = \frac{c_{ij}}{\sum_j c_{ij}} \qquad \forall i \in [1,8] \tag{6}$$

After we calculate the following results:

Table 10 The matrix normalize of decisions

Transport System	Cp	Fr	C.S	Pu	I.C	T.C	EGG
Tramway	0.76	1	0.60	0.58	0	0	1
Bus	0.24	0	0.4	0.42	1	1	0

Weights normalization

Table 11 The values of the normalized of weight

Criteria	Description	Reference Weight
1	Capacity	0.133
2	Frequency	0.133
3	Commercial speed	0.100
4	Punctuality	0.133
5	Investment cost	0.166
6	Ticket Price	0 .166
7	Greenhouse gas	0.166

Implementation of the weighted sum method

We finally perform the operation for each transport system to be tram or bus:

$$S(A_j) = \sum_{i=1}^{n} P_i . C_{ij} \qquad \forall j \in [1,2] \tag{7}$$

Once this is done calculates, interpretation of results is required. It then sorts the resulting weighted sums in ascending order, thus achieving a ranking of the transport systems.

Here is the ranking of Rabat transport systems via the weighted sum method:

Table 12 Classification of transport systems in Rabat

Preferences	Sys. Transport	Weighted Sum
1°	Tramway	0.537
2°	Bus	0.46

It is important to note that the weighting was provided by our decision. Other weights would give different results[3].

Indeed, according to the result of the weighted sum of the weight method references, we find tram in the first row in second place the bus, so it is clear that we first chose the tram because it is considered more efficient and adequate at the time of the decision of a transport system in Rabat, and after the bus as the second transport solution.

Scenario Study 2: Weight1 favouring the performance criterion

In the following, we will introduce weight1 who value performance criteria, then we will do the previous procedure of data transformation.

The weight1 criteria before the normalization:

Table 13 The values of weight1

Criteria	Description	Weight 1
1	Capacity	50
2	Frequency	55
3	Commercial speed	40
4	Punctuality	55
5	Investment cost	35
6	Ticket Price	35
7	Greenhouse gas	30

Normalization of weight1

Table 14 The values of standard weight1

Criteria	Description	Weight 1
1	Capacity	0.166
2	Frequency	0.183

[3] *The resulting classification depends on the weight and normalization procedure.*

Criteria	Description	Weight 1
3	Commercial speed	0.133
4	Punctuality	0.183
5	Investment cost	0.116
6	Ticket Price	0.116
7	Greenhouse gas	0.1

✓ **Implementation of the weighted sum method**

The operation is performed for each transportation system tram or bus:

$$S(A_j) = \sum_{i=1}^{n} P_i . C_{ij} \qquad \forall j \in [1,2] \qquad (8)$$

Here is the ranking of Rabat transport systems via the weighted sum method according weight1 that promote the performance criteria for the same values C_{ij}criteria:

Table 15 Classification of transport systems in Rabat-Salé

Preferences	Sys. Transport	Weighted Sum
1°	Tramway	0.595
2°	Autobus	0.402

From the result, we note that tram still holds lead the standings, so it is obvious that the first chosen at the time of the decision.

Scenario Study 3: Weight2 favouring cost criterion

Now let's introduce weight2 who value the cost criterion, then we will do the previous procedure of data transformation. The weight2 criteria before the normalization:

Table 16 Values weight2

Criteria	Description	Weight 2
1	Capacity	30
2	Frequency	25
3	Commercial speed	20
4	Punctuality	25
5	Investment cost	80
6	Ticket Price	80
7	Greenhouse gas	40

The ranking of Rabat transport systems via the weighted sum method according weight1 that promote cost criterion for the same values C_{ij}criteria:

Table 17 Classification of transport systems in Rabat- Salé

Preferences	Sys. Transport	Weighted Sum
1°	Bus	0. 61726
2°	Tramway	0.3797

From the result of the weighted sum method according weight2 that promote investment cost criterion, we see that the bus leads the ranking, so this comes from the fact that Tramway spent too much money in its investments.

Scenario Study 4: Weight3 favouring environmental criteria

The weight3 criteria before the normalization:

Table 18 Values Weight3

Criteria	Description	Weight 2
1	Capacity	30
2	Frequency	30
3	Commercial speed	20
4	Punctuality	30
5	Investment cost	45
6	Ticket Price	45
7	Greenhouse gas	100

The classification of Rabat transport systems via the weighted sum method according Weight3 that promote environmental criteria for the same C_{ij}values:

Table 19 Classification of transport systems in Rabat-Salé

Preferences	Sys. Transport	Weighted Sum
1°	Tramway	0.6066
2°	Autobus	0.3924

From the result of the table we see the dominance of the tram that leads the ranking, so it is obvious that the tram is not polluting and respecting the environment in emissions of greenhouse gases.

6 Conclusion

We finally concluded that the analysis of multi-criteria comparative Rabat-Salé transport systems made following the criteria and assigning different weights, has allowed us to see that we must think first of the tram and after other systems transportation because it shows the dominance in the weighted sum method compared to the bus. However many limitations exist in this method, due in particular to the interpretation weights that take into account the relative importance of criteria and the influence of normalization.

7 References

Borgers, A. & Timmermans, H. (1986). A Model of Pedestrian Route Choice and Demand for Retail facilities within Inner-City Shopping Areas. *Geographical Analysis*, 18(2), pp. 115-128.

Edwards, W. (1971). Social Utilities. in *Engineering Psychologist. Proceedings of the Symposium on Decision and Risk Analysis Series.* U.S. Naval Academy, M.D.

Guitouni, A. & martel, J.-M. (1998). Tentative guidelines to help choosing an appropriate MCDA method. *European Journal of Operational Research,* 109(2), pp.501-521.

Hwang, C.L. & Yoon, K. (1981). *Multiple Attribute Decision Making Methods and Applications*. Springer-Verlag, Berlin.

Jeong-hwa, N. (2011). The choice of a sustainable transport system: Comparative analysis of surface guided transport systems. Doctorate thesis: Université Paris-Est.

Lehoux, N. & Vallée, P. (2004). Multi-criteria analysis..

Berkoune, D. (2005). Approche d'évaluation pour les problèmes d'ordonnecement multicritères: Méthode d'agrégation avec direction de recherche dynamique. SMC, pp.276-281.

Henriet, L. (2000). Système d'évaluation et de classification multicritères. Paris: Université Paris Dauphine.

Mammeri, M. (2013). Une approche d'aide multicritère à la décision pour l'évaluation du confort dans les trains. Paris. Thèse.

Talbi, E. (1999). Métaheuristiques pour l'optimisation combinatoire multi-objectif. Paris: Tutorial, *Journée Evolutionnaires Trimestrielles*, Paris.

Vincent, C. (2004). Approche systèmatique et méthode multicritère pour la définition d'un système d'indicateurs de performance. Thèse.

*** (2007). Master Plan of transport and traffic of the agglomeration of Rabat-Sale-Temara. Rabat-Sale Tramway Society, pp. 54-70..