Optimization of choices in urban transport planning: a multicriterial model

E. Musso, C. Ferrari

Dipartimento POLIS, Università di Genova, Stradone S. Agostino 37, 16123 Genova, Italy

Abstract

In most socio-economic systems, decisions concerning urban transport planning, namely in the short run, may induce unoptimal choices, due to two major problems:

- who has to take the decisions concerning priority and relative importance of the different goals;
- the process through which decisions are taken.

Both problems have clearly a political nature, but could be satisfactorily faced by using multicriterial analysis techniques. A model derived from these techniques is proposed in this paper, in the aim of:

- allowing comparison and ranking among non-homogeneous options;
- monitoring a given set of indexes, referring to relevant features of urban transit and environment, for a given group of cities, thus allowing comparisons over space (among cities) and over time;
- widening the process of selection of priorities, by involving in goal-weighing either a greater number of subjects or a sample of resident households and/or firms;

The model is based on two sets of grids, stating (i) the links among instruments and goals, and (ii) the evaluations concerning priorities among them.

The eventual aim of the model is to optimize the choice of policy instruments with respect to the links between goals and policies. While it is impossible to make "impartial" the choice among different goals, yet it should be possible to make impartial - and thus more understandable and acceptable - at least the decision-making process in urban transport policies.

Some further advantages of the proposed technique are: easy implementation, flexibility with respect to goals and indexes, possibility of
setting networks of cities with respect to monitoring, and potential connection with environmental assessment evaluations.[1]

1 Some emerging trends in urban mobility policies

In recent years, planning concerning urban areas has more and more shortened its temporal horizon. This trend can be framed into the more general crisis of public choices and into a planning evolution from the "comprehensive planning" towards horizons of greater flexibility and "incremental planning".

In addition, the cronic (and growing) lack of adequate funds for long run planning projects has affected the infrastructural equipment of cities and a greater (possibly excessive) emphasis on short run interventions derived, although the latter should have not a supplementary, but a substitutive function.

Short-term transport planning requires planning activities aimed at a better and more efficient use of existing facilities, or at implementing capital works that are relatively inexpensive.

In the field of urban mobility short run action is concentrated on traffic regulation. It seems that such actions are just "symptomatic therapies" unable to produce durable effects and changes. On the other hand, it should also be stressed that, in the past, long run transportation planning had often been far away from foreseeing the main problems arising from the evolution of urban mobility. So, the greater attention paid to the direct effects, and to their prevention through short run policies concerning urban traffic, is not off the point, unless it should not be an occasion for giving up a long run vision of urban and metropolitan mobility and of its government.

There is also an increasing need for "transparency" in public decision-making, especially where political options are at stake.

Furthermore, in a period of increasing attention for the protection of natural environment, falling back on short run policies, especially if justified by the lack of funds for greater interventions, allows a low degree of involvement of the decision-maker into the evaluation of the negative and positive externalities arising from projects; and a lower "political cost" of decisions.

Thus, in recent years, public intervention is becoming "lighter", both financially and technically, based on short run policies, more sensitive to environmental values (or more sensitive to voters' sensitiveness for environmental values), more flexible with respect to goals, aiming at the efficient use of available resources.

2 Some requirements connected to new trends

The emerging trends concerning mobility policies need some specific requirements.

First, if long run planning was based on descriptive and anticipatory transport demand analysis - with the economical and technical problem of reliable estimates - short run policies need more detailed and complex
Urban Transport and the Environment 167
evaluation models. Besides, plans should be self-amending - through the appropriate feed-backs - on the basis of satisfaction of goals, rather than unchanging and subject to a quick ageing.

This requires the use of monitoring systems for traffic, consumption, safety, pollution and congestion, with different unit of measure and repeated over time, in order to evaluate short run policies effects and feed-backs on goals.

These tools should support assessment and political decisions about mobility. As these systems are in a multi-criterial and multi-objective context, they must select priorities on the basis of goals' achievement, in order to allow the decision-making process to be objective, or at least "transparent" (i.e., both more understandable and less subject to possible illegal behaviours), when strictly based on political options.

3 A multicriterial method

The above mentioned topics could be satisfactorily faced by using multicriterial analysis techniques. In the following pages, a multicriterial technique is proposed in the purpose of:

- allowing comparisons and ranking among non-homogeneous options;
- monitoring a given set of indexes, referring to relevant features of urban transit and environment for the cities, and allowing comparisons over space (among cities) and over time;
- widening the process of choice, by involving in goal-weighing either a greater number of subjects or a sample of resident households and/or firms;
- allowing a constant monitoring and evaluation of effectiveness of mobility policies.

The proposed method is based on the definition and treatment of a grid of indexes suitable for measuring the attainment of possible goals of mobility policy. A connection between goals and policies is clearly established, so that the level of indexes can measure both the attainment of goals and the effectiveness of policies. It must be stressed that most indexes need data which are usually found in statistics available for medium and large sized cities, so that little or no additional cost is brought by the setting up of the grid.

The grid of indexes can be used by a network of cities: all indexes are found out for each city at given times, so that effectiveness of mobility policies adopted by each of them can be compared with the achievement of goals, for each city and at different times.

4 The selection of goals

The goals of urban mobility policies can be relevant either from the point of view of land use or from the point of view of urban transport economics. The most important ones are:

1. increase in spatial accessibility;
2. reduction of differences in accessibility;
3. land costs reduction;
4. increase of opportunities connected to urban, suburban and (indirectly) interurban mobility;
5. increase in access to mobility;
6. efficacy of transport system (reduction in congestion levels and travel times, increase in reliability);
7. efficiency of transport system;
8. increase in safety;
9. reduction of transportation system vulnerability;
10. reduction of environmental impacts (acoustic and air pollution).

Indexes 1 to 3 have a spatial nature, indexes 4 to 10 have a transport-economic one.

If short run planning is the object of the analysis, infrastructural framework will be given. Therefore, only some of the above mentioned goals can be satisfactorily pursued. In a temporal horizon of four-five years, long run economic and territorial goals can hardly be considered achievable because they are strictly function of the infrastructural framework. With regard to the latter, however, accessibility should be included into phenomena concerning short run policies.

As goals are selected, there is the necessity of a priority order. This order can be obtained by using one of the many rating processes existing in the economic literature. It is important that a sample of resident households and/or firms is involved in the selection of priorities. This clearly aims at gaining consensus around plan and increasing its chances of successfulness. [2]

5 Definition of indexes

Once the goals that can effectively be achieved in the short run have been selected, the definition of grid of indexes is needed. It must be pointed out that the above mentioned goals do not allow a total or "absolute" fulfilment, but only a higher or lower fulfilment level.

Indexes proposed in next pages allow comparisons over space (among cities) and over time. None of the indexes' values has a "satisfactory" threshold value by itself. Instead of fixing discretionary thresholds values, a permanent monitoring of average values among different cities involved is here proposed.

The the following indexes are grouped in four great goals: efficacy, consumptions and costs reduction (efficiency), traffic and safety, environmental safeguard.

5.1 Efficacy

The efficacy of a transportation system is essentially measured by users' cost. This cost should be measured by a generalized cost, i.e. an index measuring the "out of pocket" cost, the value of the travel time and the non-monetary cost of discomfort due to moving.

Usually, generalized cost expressions like the following are used:
where $M$ is the out of pocket cost, $T$ the time spent and $v$ the time value. In these expressions discomfort is left out. In a similar way, expressions measuring the generalized time may be formulated:

$$GT = T + M/v$$

Here, however, putting monetary costs in the indexes' group of efficiency seems more suitable. First, because in urban transit there is only a thin link between the real cost of production of transport service and price, and any possible reduction of consumptions or maintenance expenses does not produce a reduction in users' costs. Even in private car mobility, monetary costs and their variations are largely underestimated by users, so that they should not be included in an efficacy index. Beside, the most significant changes in this sector depend on the kind of vehicle and on infrastructural framework; both of them are beyond short run planning.

As a consequence, the indexes about efficacy will centred on the measurement of time.

5.1.1 Indexes concerning travel times

The most important roads are subject to a periodical check about travel times. The index is a congestion index such as:

$$C = \frac{rt}{tt}$$

where $rt$ is the real time spent by vehicles, $tt$ is the "theoric time" resulting by covering the distance at the "free speed" (i.e. when there are no other constraints but the speed-limit).

The index can be determined either for the private traffic or the existing bus lines. It can be calculated for morning and evening peak hours and for different days.

In this context, "theoric time" $tt$ is calculated considering all the elements which are beyond this level of planning.

5.1.2 Accessibility indexes

For every one of $n$ zones in which an urban area can be divided, for the purpose of transport planning[3], a possible index evaluating the "inner" accessibility, i.e. with regard to the other zones, is

$$A_i = \frac{n}{\sum_{j=1}^{n} T_{i,j}}$$

Where the time $T$ can be either a real time (and in this case the accessibility index includes an evaluation of congestion level for any $i$-zone) or a theoretic time, as previously defined (and, in this case, evaluation of congestion effects is left to indexes specified in § 5.1.1).
Obviously, accessibility indexes will have higher values for the central areas and/or areas better served from the transport system; and lower values for the suburbs and/or worse served areas. Therefore they have two functions: on one hand monitoring, for each zone, the evolution of accessibility over time; on the other hand, allowing comparisons among accessibility of different zones (what helps in the assessment of interventions aiming at the reduction of accessibility disequilibria among zones).

From these indexes, a general index of “inner” accessibility for the whole city can be derived:

\[ GA = \frac{\sum_{i=1}^{n} A_i}{n} \]

This global accessibility index is important for comparisons among different cities over time. Increasing over time of index \( GA \) gives a measure of the aim’s achievement.

Another accessibility index consists in the ratio of the transport network length to the city’s surface[4].

### 5.1.3 Reliability indexes

In the short run reliability means reduction of delays. Delays measurement can be given using variance or standard deviation with respect to \( rt \):

\[ \sigma^2 = \frac{\sum_{i=1}^{n} (rt - \text{average} \, rt)^2}{n} \]

The index will be applied both to transport liners than to individual transport. In the latter case, the travel time should include the time spent in searching a parking.

### 5.2 Consumptions and Costs reduction - Efficiency

Since transport system efficiency is measurable only in terms of costs per production unit, the two goals of consumption and costs reduction and efficiency will be object of a single measurement system.

As far as transit is concerned, productivity indexes are necessary; namely:
- cost per passenger-Km;
- personnel cost per passenger-Km;
- number of passenger-Km per employed staff;
- average annual run / population;
- fuel cost per passenger-Km;
- consumable stores cost per passenger-Km.
These indexes which are usually calculated by urban mass transportation companies, should be considered both in their evolution over time and for possible comparisons with other urban areas with similar size and natural characteristics.

For private traffic, measurement of efficiency is not easy because users do not perceive exactly the level of consumptions and costs. Average fixed costs are inversely related to the distance covered, while variable costs are related to speed and variation in speed. Thus, the evaluation of costs should involve indexes (to be measured on a sample of vehicles) such as:

- the average speed in the urban area;
- the speed standard deviation in the urban area.

5.3 Traffic and safety

In the short run, factors influencing infrastructural capacity are: parking places, traffic flows intersections, two-ways and one-way regulations, road yards, and so on. These factors, and possibly other specific elements for each area, may be related with the road total surface or length, or with a measured time, giving indexes inversely related to traffic conditions. For example:

- on-street parking surface divided by total road surface;
- number of driveways per Km of carriage;
- Km of reserved way per Km of carriage;
- road yard surface (daily average) per kilometres of road surface.

For traffic safety, the following indexes can be usefully calculated:

- number of accidents per 1,000 resident vehicles;
- number of accidents involving dead or injured men per 1,000 resident vehicles;
- number of injured men per 1,000 inhabitants;
- number of dead men per 1,000 inhabitants.

These indexes allow both comparisons over time (for the same city or area) and comparisons with national statistics or with other similar urban areas.

5.4 Environment, Pollution, Land Use

Specification of acustic and air pollution indexes is referred to different national legislations.

As regards "land use", in the short run planning the recurrent inference of the following indexes seems suitable:

- number of cars per inhabitant;
- metres of lane per inhabitant;
- metres of lane in areas with traffic allowed to residents only, per inhabitant;
- residents in pedestrian precincts, per inhabitant;
- residents in areas with traffic allowed to residents only, per inhabitant;
- residents in areas with parking allowed to residents only, per inhabitant;
- metres of cycle track, per inhabitant,
- square metres of public parks and gardens, per inhabitant.

6 Relationships between goals and indexes

Once chosen the short run goals, and the set of indexes measuring the degree of attainment of each goal, the $m$ indexes and $n$ goals can be put into a $m \times n$ matrix pointing out the link between each goal and the indexes measuring its attainment, as follows (a different "weight" of each link might also be used):

Table 1 - Links between goals and indexes

<table>
<thead>
<tr>
<th>goals =&gt; indexes</th>
<th>rt/tt</th>
<th>green sq.m./inhab.</th>
</tr>
</thead>
<tbody>
<tr>
<td>sign</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>limit</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>efficacy</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>efficiency</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>safety</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>environment</td>
<td>*</td>
<td>***</td>
</tr>
</tbody>
</table>

Another matrix reports the value of indexes for all cities involved in the monitoring network. It must be stressed that in order to allow full comparison between indexes their values must be normalized through the formula:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{n} x_{ij}^2}}$$

Table 2 - Normalized indexes for all cities

<table>
<thead>
<tr>
<th>Indexes</th>
<th>City 1</th>
<th>City 2</th>
<th>...</th>
<th>City p</th>
</tr>
</thead>
<tbody>
<tr>
<td>rt/tt</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>green sq.m./inhab</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

It must be specified that some indexes must be maximized and other must be minimized. In order to allow comparisons the latter should be multiplied by $-1$. 
7 Selection of goals and weighing groups of indexes

Indexes must now be weighed following the importance given to the goal they measure. There are two relevant problems here:

1. Who chooses the priority order among different goals, and the relative weights? Politicians are entitled to take this decision. Nevertheless, in many situations (private or lobby interests, imminence of elections) they can be induced to take non-optimal decisions. And in any case the complexity of choice, and frequent trade-offs between different goals may cause inefficient decisions. It would be probably better to involve in the decision transport planners and a sample of population.

Which procedure is used to take this decisions? A multicriterial technique can here be employed (even if the decision is taken only by politicians, namely if it is a collective body, like a city council). The procedure aims at weighing different goals. A square matrix of the \( n \times n \) objective is set up: each element \( ij \) involves a comparison between two goals, and each person interviewed will give values +1 or -1 if one of the objective is considered more important, or 0 if they are equally important. The sum of values obtained by each goal allows both a ranking of goals and a definition of a weight given by a cardinal number, as shown in the following example:

<table>
<thead>
<tr>
<th>Goals</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>Weights and Ranking</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-</td>
<td>+1</td>
<td>+1</td>
<td>+1</td>
<td>+3 (1)</td>
</tr>
<tr>
<td>2</td>
<td>-1</td>
<td>-</td>
<td>0</td>
<td>-1</td>
<td>-2 (4)</td>
</tr>
<tr>
<td>3</td>
<td>-1</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-1 (3)</td>
</tr>
<tr>
<td>4</td>
<td>-1</td>
<td>+1</td>
<td>0</td>
<td>-</td>
<td>0 (2)</td>
</tr>
</tbody>
</table>

A set of relative weights of the goals can be derived from the above, by the formula:

\[
k_j = \frac{w_j}{\sum w_j} \quad \text{where} \quad \sum k_j = 1
\]

A relative weight of each index can also be derived as:

\[
g_i = \frac{k_j}{m}
\]

where \( g_i \) is the relative weight of the index, \( k_j \) is the relative weight of the goal and \( m \) is the number of indexes related to that goal.

The problem of weighing goals among different cities involved in the monitoring process still remains. Two solutions are possible:

- weights given to each goal are the same for all cities; in this case, their definition may be given by politicians and/or residents of the different cities;
weights are different for each city, due to specific features; in this case, comparisons are always possible, but they measure the achievement of different "goal-vectors".

8 Measuring the effectiveness of policies

The periodical monitoring on indexes gives an overall assessment of the level of goals' achievement. For any city, the sum of all normalized values of indexes, each weighed by its relative weight, gives rise to an overall evaluation for effectiveness of transport policies.

The monitoring of each group of indexes gives an evaluation of effectiveness of policies related to a single goal.

These results provide data for an objective assessment of mobility policies adopted by different municipalities.

The proposed method is also a decision-making support for mobility policies since it allows to make them out which interventions have a real effectiveness over urban traffic, attaining goals' maximization.

Over time, the decisional process to select priorities among different goals has to be repeated because their achievement, even if partial, make it fall down in the list of priorities. So, the proposed monitoring model follows a "cycle": from specification of a priority goal, short run urban traffic policies are adopted, while policies able to modify the priority order make necessary the whole process to start again.

References

[1] §§ 1, 2, 3, 4 and 7: E. Musso; §§ 5, 6 and 8: C. Ferrari