Cost Benefit Analysis to assess urban mobility plans. Consumers' surplus calculation and integration with transport models.

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Abstract

Transport mobility plans, especially at the urban scale, are commonly produced by administrations. However, the decisions involved are often taken on a qualitative basis or, at best, by setting some indicators and verifying how much a plan or a scenario reaches the politically decided targets (e.g. "increasing by 10% the use of bike"). However, given that decisions on plans involve relevant public investments and may also determine radical changes in users' costs, a more quantitative and comprehensive approach to the evaluation is needed.

Cost Benefit Analysis is the tool commonly used to assess public expenditure, but its application to mobility plans introduces further practical and theoretical complexity.

The aim of the paper is to discuss how CBA can be used to assess complex and multi-modal mobility plans (involving for example both infrastructural investments and lighter sustainable mobility policies). Firstly we will discuss which are the complexities involved by plan assessments vs. infrastructure assessments. Secondly, we will revise the available approaches, namely the Generalised Costs comparison approach, the Rule of Half and the *logsum* functions for the perfect integration between CBA and transport models. Thirdly, we will comment the main advantages and problems of the last approach, namely, the *logsum*, clarifying why it is the most suitable for the assessment of plans made of a broad range of policies and actions. Finally, we will outline an ongoing application for the assessment of the SUMP (Sustainable Urban Mobility Plan) of Milan's municipality.

Highlights

➢ Why traditional CBA evaluations may fail in evaluating complex transport plans

➢ At least three ways to approach the calculus of surplus exist: the generalised costs comparison method, the Rule of Half, the use of *logsum* function.

➢ *Logsum* is the only method, which, together with a calibrated transport model, gives totally exhaustive and coherent results. However, it also presents some limits (transparency).

➢ What a CBA of a mobility plan must include and how to do it integrating transport models with CBA assessment.

1. Introduction: evaluating transport plans

The economic evaluation of transport investments is usually intended as the assessment of transport infrastructure. However, infrastructure investments are only one way to approach transport problems and needs, and the possible actions a public planner can implement now include, more and more, other kinds of softer policies. The construction of a modern transport plan should then foresee single investments, but also improvements of existing transport services and implementation of sustainable mobility policies, such as city walkability, development of bike transport, road pricing, park pricing, technological investments on networks, vehicles and communications, smart mobility, vehicle sharing projects, incentives, redefinition of fares structure, mobility credits, etc. (EC, 2013; Eltis, 2013; Banister, 2008)

In this articulated context, the evaluation tools commonly used to support the design of mobility plans and the consequent public decisions are:

- Traditional *Cost Benefit Analysis,* practically everywhere required to allocate public money for infrastructure investments, i.e. in cases where the public decision is dominated by the alternative allocation of lump sums;
- *Multicriteria analyses* or *Indicators-based assessments,* used to "visualise" and clarify the goals and the (possibly positive) effects of the actions of a plan, such as the foreseen decrease in car ownership or pollutants concentrations.

However, in the assessment of a plan made of both "hard" (infrastructural) investments and "soft" policies whose effects are not concentrated in time, both traditional approaches may fail. In particular, a rigid CBA may be not be able to catch all the effects of a plan and, in addition, provides too synthetic outputs to support the dialogue with public opinion and stakeholders. On the other side, indicators and MCA are, by definition, not able to measure the efficiency of public expenditure, which represents a key element of public decisions. For example, MCA cannot discriminate between a new metro line (which costs a lot to be built and gives localised transport cost advantages in the future) and, say, the setting of incentives to the change of old cars with low emission ones (which cost less but gives spread positive effects only in the field of external costs reduction).

In addition, one must consider that the "typical" scheme of lump sum public costs versus distributed private benefits is not always the case, especially with pricing or limitation policies. In these cases, the effect is to give both advantages to some groups and disadvantages to others. Some policies are not, in fact, simply additive and this must be taken into account in the evaluation (Beria et al., 2012). For example, the closure of a city centre to private cars benefits the inhabitants because reduces pollution and improves the urban environment (positive effects that can be measured with appropriate indicators). At the same time, however, it generates also costs to other citizens which are now forced to switch from the private car (which was their best option before, maybe also because not paying for its external costs) to walking or to public transport (which costs more to them, for example in terms of travel time and flexibility). Then, a decision on this kind of policy should obviously take into account not only the benefits, but also the public *and* the private costs necessary to obtain them.

When the existence of complex cost and benefit structures in the assessment of plans is recognised, practical problems rise. As already mentioned, approaches using indicators and MCA are not satisfactory to evaluate the trade-offs of public expenditure. At the same time, the CBA in the "simple" form suggested by numerous guidelines is not sufficiently complex to handle the previously mentioned problem and, in addition, fails in representing effectively the distribution of effects, especially for non *win-win* policies.

For such reason, in the paper we will discuss how a Cost Benefit Analysis of a mobility plan could be implemented, focusing initially on the key theoretical and practical issue to be solved: the calculation of consumers' surplus. As we will show, while the other costs and benefits can be

represented as usual and in an intuitive way (investment costs, running costs, environmental benefits, taxation, etc.; see for example DG Regio, 2008), the consumers' surplus requires to be calculated with a transport simulation model and using the *logsum* method, to avoid significant computational and theoretical errors. Secondly, we will discuss the further benefits of the integration between the transport model and the assessment, in terms of disaggregation and representation of results. For example, in this way benefits can be represented geographically and not only in an aggregate way. This kind of representation may be a useful complement to the aggregate CBA indicators (NPV, NBIR, B/C, IRR; DG Regio, 2008) in the due consultation phase and ultimately to take better decisions. Aside to the strengths of the *logsum* method, we will comment its drawbacks, which mainly belong to the issue of transparency of the calculations.

The paper is structured as follows. The following Section 2 discusses three ways to calculate consumers' surplus: the Generalised Cost comparison approach, the Rule of Half, the *Logsum* function. The literature on them is theoretically mature, but does not appear conclusive from the point of view of practical applications, where some ambiguities still exist. Section 3 goes more in deep with the less used approach: the *logsum* function method. We will comment when it is recommended, as other methods fail, but also its main limits. Section 4 discusses how the *logsum* can be practically calculated by means of a transport simulation model, when articulated plans are assessed. Section 5 presents an advanced application of CBA for the assessment of a complex plan, namely the Milan Sustainable Mobility Plan. Section 6 concludes.

2. Calculating the consumers' surplus

Theory and guidelines indicate three approaches to calculate the consumers' surplus. However, the range of application of one method or another is seldom discussed, leaving the analyst the responsibility of choosing. Nevertheless, as we will show in the present section, the three methods are not perfect substitute. In particular, the simplest approach, the Generalised Cost comparison, results to be adequate only under very specific conditions, very seldom present. The other two methods are more general, but give different levels of precision and robustness and require different amounts of data to be applied.

2.1 A dangerous method: the Generalised Costs comparison approach

We define the consumers' surplus as the difference between the willingness to pay of each user to make that trip and the "price" he has to "pay" to make it (Stiglitz, 2000). In transport, the "price" a user has to pay to make a trip is expressed by the so-called *Generalised Cost* (GC), that is the monetary effort that the user associates to his overall trip experience, including out-of-pocket expenses (tolls and fares), operating costs of the vehicles (in private transport) and consumed time. Other factors like discomfort, crowding, beauty of the landscape and more personal attitudes can also reduce or increase the GC of the same trip for different users.[1]

We can calculate the variation in consumers' surplus by multiplying the average unit reduction in GCs (from initial situation 1 to the final situation 2, after the investment) by the number Q of users (Equation 1).

$$\Delta S = Q \cdot (GC_1 - GC_2)$$

Equation 1

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[1] In the paper we refer to the calculation of users' surplus in terms of perceived (or private) costs, which – as we discussed in a former paper (Grimaldi & Beria, 2013) – requires some corrections to balance transfers (e.g., taxes and fares) among different parts of the society. Another relatively widespread approach, especially when the GCs comparison is used, is to calculate the variation in users' surplus directly in terms of social costs. The considerations made in this paper remain valid.

However, this can be done consistently only under very strict conditions, typical of simple problems only: single mode appraisals and rigid demand, that is when we expect no induced users from other modes or paths.

In less simple cases or in any multimodal appraisal, instead, we expect a certain amount of users to shift from other modes (or paths, time of the day, etc.) to the one influenced by the new project. In this case, we cannot calculate the surplus variation of the shifting users as the sum of the reduction in the weighted sum of time, costs, discomfort and so on - that is in their GCs – because it is practically impossible to know GCs for every user and non-user before and after the scheme is implemented. This ignorance makes it impossible to calculate the effect for the users whom change mode or path in consequence of the scheme.

More realistically, when available, we can use a transport model to obtain the average generalised costs of groups of users (see section 4.2), also in a very detailed way. Apparently, we could calculate the benefit of the scheme referring to the average GCs of the groups, if a model simulates for us the GCs of all groups. However, also this approach introduces errors in the estimation of the benefits, because shifting users are exactly those having the highest distance from the average value of their group. In other words, the difference between average values of GCs of groups of users is (too) different from the benefit of individuals.

Let us consider an example of a group of users Q, having the same characteristics (origin-destination, travel purpose, etc.). When a new project is implemented, it reduces the average GC of a sub-group of Q_a users initially using the mode a from $GC_{1,a}$ to $GC_{2,a}$ (say from 106 to 98, that is a reduction of 8). These users do not use the alternative mode b because it is more costly for them (say higher than 106). The benefit of the project for those users is simply given by the unit benefit of $GC_{1,a}$ - $GC_{2,a}$ (say 8) multiplied by the amount Q_a of the users themselves (Table 1).

Q_a existing users	Before		After		
	$GC_{1,a}$	$GC_{1,b}$	$GC_{2,a}$	$CG_{2,b}$	Benefit
Average values	**106**	>106	**98**	>106	
Total benefit					$Q_a \cdot (GC_{1,a} - GC_{2,a})$ $= Q_a \cdot 8 \ (106\text{-}98)$

Table 1. Calculation of the benefits for existing users on the mode 'a'.

A second sub-group of users Q_b was using mode b before the project was implemented, because for them mode b had a lower average GC with respect to a. A transport model suggests, for example, that a part of the users of the group will shift to the mode a after the scheme is implemented thanks to the reduction of GC_a.

Calculating the benefit in the apparently intuitive way, that is calculating the difference between the average GCs of the mode those users used before and the mode they will use after ($GC_{1,b}$ - $GC_{2,a}$), we actually obtain misleading or even absurd results. In fact, this way of calculating the benefits of shifting users does not consider the distribution of users around the known average values.

For example (Table 2), let us say that a group of 3 non-users of mode a before the investment has an average cost of 106 on mode a and 100 on mode b, thus choosing mode b. After the investment, the average generalised cost improves of 8 units on mode a, falling to 98. If we know (from the choice model) that just 2 of them change mode, we could calculate the benefit of the investment as the difference between the average GC of the mode used before (100) and after (98), multiplied by two switching users.

Shifting users $k \cdot Q_b$ (method 1)	Before		After		Benefit*
	$GC_{1,a}$	$GC_{1,b}$	$GC_{2,a}$	$GC_{2,b}$	
Average	106	100	98	100	
Total benefit					$k \cdot Q_b \cdot (GC_{1,b} - GC_{2,a})$ $= 2 \cdot 2 \, (100\text{-}98) = 4$

*: calculated as the difference between the GC of the modes used before and after.

Table 2. Calculation of the benefits for two users shifting from mode 'b' to mode 'a', as a consequence of the project, with the average GC comparison approach.

However, if we could know the individual GCs of the three non-users of mode *a*, we would discover that the correct total benefit is different (higher in this case) from the one calculated as the difference of average GCs. The example in Table 3 shows that the average value does not correctly represent the individual values and cannot be used.

	Before		After		Benefit*
	$GC_{1,a}$	$GC_{1,b}$	$GC_{2,a}$	$GC_{2,b}$	
Potential shifting user 1	102	**100**	**94**	100	6 (100-94)
Potential shifting user 2	104	**100**	**96**	100	4 (100-96)
Potential shifting user 3	112	**100**	104	**100**	0 (no shift)
Total benefit					6+4+0 = 10

*: calculated as the difference between the GC of the mode used before and after.

Table 3. Calculation of the benefits for two users shifting from mode 'b' to mode 'a', as a consequence of the project, comparing the GCs of every single user

The explanation for this inconsistency is that the average GC of the group on the mode they used before was not their actual GC, but just the average value of the group they used to belong (same origin-destination pair, same trip purpose, same hour of the day, etc. depending on the level of detail of the model we have). Those who shift transport mode are usually the marginal part of the group, that is the ones who had a cost that was already close to the mode they will shift to.

In conclusion, we can affirm that, also when a transport model is available, the surplus calculated using the difference of average GCs of shifting users introduces errors. The entity of these errors depends on the homogeneity of the users of the groups considered.

Moreover, often a transport model is not fully available to the evaluator (or does not exist at all) and the evaluator has to construct his own estimations of GCs based on values taken from the literature. In this case, evaluating the benefits using this approach is even more misleading.

In fact, when we estimate GCs without using a calibrated transport model, we have to focus basically on the monetisation of time spent travelling, usually using Values of Time from the literature or guidelines, operating costs and the out-of-pocket expenses. If other GC components exist and we ignore them (for example, the interchange discomforts), the GCs obtained may result inconsistent with the current choices of the users and this can lead to completely paradoxical results (Grimaldi & Beria, 2013).[2]

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[2] This is true for any modelling exercise. However, when a transport model is available, it is usually a *calibrated* transport model, which already analysed and included all the relevant cost components, and estimated the parameters capable to reproduce observed figures.

Apart from the problems introduced in this section related to the use of the Generalised Cost comparison approach, there is a traffic component whose surplus change cannot be evaluated in any way by referring to this approach: generated traffic, that is the users who did not travel before. In this case, and to face correctly the problems mentioned above, most of the guidelines suggest using the so-called *Rule of Half.*

2.2 The Rule of Half

Traditionally the most robust and used method to calculate the variation in users' surplus is to hypothesise the demand function as linear on a graph between the points representing GC with respect to the amount of users (Q) before and after the investment, which are known (DG Regio, 2008; Grimaldi e Beria, 2013; Maffii e Parolin, 2013). This hypothesis translates into the so called *Rule of Half:* the variation in existing users' surplus is given by the area of the rectangle having base Q (the number of existing users) and height GC_1-GC_2 (the reduction in generalised costs, that is the unit benefit) and the new users' surplus is given by the triangle having base Q_2-Q_1 (the number of new users) and the same height (Figure 1).
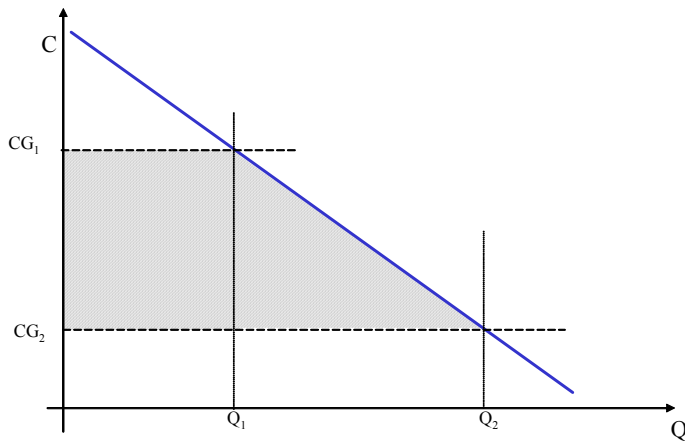
Figure 1. Representation of the Rule of Half (our elaboration).

The variation in users' surplus is thus given by the area of a trapezius and writeable as in Equation 2 (hence the name "of half").

$$\Delta S_{users} = (Q_1) \times (GC_1 - GC_2) + \frac{1}{2}(Q_2 - Q_1) \times (GC_1 - GC_2)$$

$$\Delta S_{users} = \frac{1}{2}(Q_1 + Q_2) \times (GC_1 - GC_2)$$

Such an approach is very widespread because of its simplicity and because it is the only way to calculate the variation in users' surplus knowing only the amount of users and the variation in generalised costs (and not their absolute values, a much more difficult task),[3] limitedly to the transport mode directly involved in the considered improvement.[4]

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[3] As we already mentioned before, the estimation of the absolute value of generalised costs is not a simple exercise without a transport model, especially in public transport and in active modes (walking and cycling). The related variation is instead usually made only of easily measurable items, like time savings and/or operating costs.

[4] This allows ignoring the value of the generalised cost on the mode of 'origin' for users shifting to the improved mode, to whom is simply given half the benefit introduced on the improved mode.

This method, by treating in the same way the whole induced users (that is, both generated and shifted from other modes, paths, time of the day, etc.) and not needing the absolute values of the GCs, avoids all the problems introduced in the former section.

Referring to the numeric example in Table 3, the Rule of Half would give a benefit for the improvement of mode *a* of 106-98 (the cost of travelling on mode *a* before and after) for the Q existing users and 1/2·(106-98) for each of the two shifting users. The benefit for shifters calculated is now 8 instead of 10. We still have an error, but lower, and this calculation is done without knowing the generalised cost of the origin mode *b* and, in principle, knowing just the difference between mode *a* before and after (equal to 8, without knowing that it is the result of 106-98).

2.3 The logsum function method

The Rule of Half refers again to average GCs, but at least assuming a certain distribution of users across it. Depending on the needed level of detail (and on the available data), we can minimise the error by disaggregating as much as possible users in homogenous groups, in terms of geography, trip purpose, etc. (i.e. making them more similar to the average values) and applying the Rule of Half to the groups separately.

This disaggregation, theoretically always feasible, can be very demanding in practice and requiring a detailed transport model. Nevertheless, when a transport model is available, it is possible to use another method to assess the variation in users' surplus, which overcomes some of the hypotheses behind the Rule of Half and gives a much more detailed representation of the benefits.

By measuring the variation in the composite utility (*logsum*) of all alternatives (modes) considered by the transport model, it is possible to obtain a more precise calculation of the variation in users' surplus (Cascetta, 1998). The higher precision derives from the fact that it takes from the calibrated transport model, not only the average values of the GCs, but also their implicit distribution among users through the coefficients of the logit formula used by the model itself.

Most transport models, in fact, estimate the *p* share of users that will choose a transport mode *m*, on the origin-destination pair *od*, for the trip purpose *s*, using the following logit formula, where λ_s is the calibration parameter for the users travelling for the purpose group *s* (Equation 3).[5]

$$p_{od|s|m} = \frac{e^{\lambda_s \cdot GC_{od|s|m}}}{\sum_m e^{\lambda_s \cdot GC_{od|s|m}}} \qquad \text{\textit{Equation 3}}$$

The surplus of each group of user is the composite utility, that is given by the logarithm of the denominator of the logit formula (thus the name, "log-sum"), multiplied by the number of trips, plus a constant (Cascetta, 1998; de Jong *et al.*, 2005 and 2007). The variation in the *S* users' surplus is given by the difference between the surpluses calculated in the reference and in the intervention alternatives (this elides the constants) (Equation 4).

$$\Delta S_{od|s} = trips_s \cdot \left[\left(ln \sum_m e^{\lambda_s \cdot GC_{2,od|s|m}} \right) - \left(ln \sum_m e^{\lambda_s \cdot GC_{1,od|s|m}} \right) \right] \qquad \text{\textit{Equation 4}}$$

The sum of these variations for all the users' groups obviously gives the total variation of consumers' surplus associated to the scheme or policy.

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[5] If the model is based on a nested logit, this operation can be done on the first (higher) level of the logit. The GC represents the disutility of the trip.

Despite well discussed in the literature quoted above, the *logsum* function method has been barely faced from an applicative point of view, when real projects and plans must be assessed. The following of this paper tries to go more in deep in this direction.

3. Implications of the *logsum* function method

3.1 When the logsum *is recommended*

In general we can affirm that the *logsum* provides a better measure of surplus gains and losses, while the Rule of Half is, and will remain, the most used and widespread tool due to its simplicity and relative correctness. There are some situations, however, in which the direct use of the Rule of Half fails and the Logsum is recommended to correctly address the problem.[6]

1. A first case is the assessment of a completely new transport option (e.g., a radically new mode; Maffii *et al.*, 2012).[7] Since the option does not exist in the reference alternative, we have no "existing" users to refer the variation of costs to and we cannot apply the Rule of Half. An estimation of the absolute value of the GCs is thus needed;

2. A second case is when we want to take into account the benefits of non-dominant alternatives (Cascetta, 1998). Let us consider a new transport option that is not the best one for none of the groups of users we are considering. A transport model (by means of a logit) will allocate a small share of users on it anyway, but the Rule of Half would give zero (or even negative) benefit for it as its average GC is higher than an existing alternative. The Logsum is instead able to catch the true (small) benefit of this new option, considering the distribution of the generalised costs among group components and not only the average value.

3. A more significant case is when the variation in the GC is too high with respect to its absolute value and thus the area of the triangle of induced users – with all the approximations it represents – becomes comparable to the one of the rectangle of existing users. This happens for example when we remove big bottlenecks or missing links to the mobility (e.g., by building a bridge among two places that were connected before only via very long detours);

4. Finally, when we want to assess at the same time both additive and restrictive policies. In fact some actions give, at the same time, benefits for some users and costs for others, as it often happens in plans. In this case, it is impossible to know how much of the mode shift simulated happened because of the new costs on the origin mode or because of the benefits on the destination mode. The Rule of Half becomes then inapplicable in practice and introduces relevant double counting.

The third and the fourth case are the most problematic and both may extensively occur in a mobility plan where the actions are not simply new infrastructure but involve also other demand management tools, such as road pricing, large car free areas, etc.

3.2 Pitfalls and practical limits

As already mentioned, the main limit to the widespread application of the *logsum* is that it is very data demanding and feasible only with a calibrated transport model, which is not always available.

A second problem is that the method may lack of clarity for the unexperienced reader and does not allow the typical disaggregation of the outputs. Since the model calculates the composite utility for the users, it is not possible to specify costs and benefits of each transport mode and it is not possible to provide the components of the surplus variation in terms of time, costs, etc. In transport plans, which might entail actions that benefit some transport options and increase costs for others, this might

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[6] Actually, it is also possible to adjust the Rule of Half, obtaining a better estimation: Nellthorp and Hyman, 2001.

[7] In most cases new transport modes within the public transport sphere can be considered improvements of existing services (e.g., high speed rail with respect to conventional rail, or rail services with respect to bus ones).

represent a major readability issue. To cope with this limit, other ways to outline the distribution are needed. Some proposals in this direction will be given in the last section.

Thirdly, since the calculation method is complicated, it might be difficult for an independent reader to fully reconstruct the calculations made, thus generating a 'black box' appraisal. This is a key point, especially when there is not a consolidated CBA framework and data to refer to. However, the difficulty for an independent reviewer to enter in the details of calculation of the *logsum* comes directly from the scarce permeability of transport models themselves and not of the CBA.

4. Evaluating a mobility plan

4.1 What makes a plan different from an infrastructural investment

As already discussed, the assessment of a plan entails the assessment of numerous and different policy actions, with different spatial and time boundaries of their effects. A sample is provided in Table 4.

Action/Policy	Costs	Benefits	Investment costs are dominant vs. other costs?
New infrastructure (public transport, roads capacity)	PU, T	pr, C, t	Yes
New/modified services on existing infrastructure	PU, t	pr, d, t	No
Innovative mobility (sharing, pooling, etc.)		pr, d, t	No
Bicycle lanes, bike parking, bike sharing	PU, T	pr, d, t	Yes/No
ITS, traffic management	PU, t	pr, d, t	No
Restrictive policies, car free zones, traffic calming	pr, d, t	d, t	No
Park and road pricing	pr, d, t	PU, pr, d, t	No
Public transport fares	PU/pr, d, t	Pr/PU, d, t	No

Symbols: "PU" public bodies, "pr" private users, "C" concentrated in space or limited to groups, "d" diffused in space or spread among many users, "T" punctual in time, lump sum, "t" continuous in time.

Table 4. Policy actions in a mobility plan and type of effect

In plans additive policies, such as new infrastructure, whose costs are public and concentrated in time, co-exist with restrictive policies such as traffic calming, pricing, etc., which change mobility patterns because rise the private costs. These two extremes must be assessed in a coherent way, but their effects and economic mechanisms are profoundly different.

Moreover, the effects act synergically, so that modal shift is the effect both of the improvement of the destination mode (e.g. public transport) and of the worsening of the origin mode (e.g. private road transport).

As said in the previous section, the Rule of Half, perfectly suitable for the assessment of new linear infrastructure (entailing punctual public investment to generate lower users costs on a given O-D pair), is not capable of catching the effect of mixed policies. In particular, it may incur in double counts, moreover if this occurs in different ways in different parts of a city.

4.2 Towards a consistent integration between planning, modelling and assessment

When a transport model is available, it is relatively easy to extract the GCs directly from the transport model, guaranteeing a complete consistency the model and the following cost-benefit analysis. The GCs derived this way can be used both with the Rule of Half and with the *logsum* method.

If the model does not provide the generalised costs of the mode alternatives, it is sufficient to extract the systematic utilities[8] used by the model, which is usually constructed like in Equation 5.

$$V_{od|s|m} = \beta_{s|m}^{Time} \cdot Time + \beta_{s|m}^{Cost} \cdot Cost + Other\_components \qquad \text{\textit{Equation 5}}$$

If we divide the systematic utility by the parameter related to its monetary component, we express it in monetary terms representing the monetary trade-off that users attribute to their trips, that is the GC (Equation 6).

$$GC_{od|s|m} = \frac{V_{od|s|m}}{\beta_{s|m}^{Cost}} \qquad \text{\textit{Equation 6}}$$

Some transport modes might be not associated to any direct monetary component (for example walking and cycling). There is a way to overcome the issue, though losing some consistency (see for example Castiglione *et al.*, 2003, or de Jong *et al.*, 2007). We divide the systematic utility by the time parameter (which is always present) instead of by the cost one, so deriving a *generalised time* instead of the *generalised cost* (Equation 7).

$$GT_{od|s|m} = \frac{V_{od|s|m}}{\beta_{s|m}^{Time}} \qquad \text{\textit{Equation 7}}$$

Then we multiply this generalised time by an exogenous Value of (in-vehicle) Time (VoT), obtaining the generalised cost (Equation 8).

$$GC_{od|s|m} = VoT \cdot GT_{od|s|m} \qquad \text{\textit{Equation 8}}$$

When the GCs are estimated, we can directly applying the formula of the surplus variation, discussed at the end of Section 2.3. It must be noticed that this passage is done at the highest level of disaggregation: per origin – destination pair (*od*), travel purpose (*s*) and mode (*m*). This is a computational burden, involving even millions of operations, if the study area is divided in hundreds of zones, like in urban areas. However, this disaggregation allows grouping the results as needed, for example maintaining the spatial structure of surplus variations, as shown in our case.

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[8] With systematic utility V we mean, according to the definition by Cascetta (1998), *"the mean or the expected value of the utility perceived among all the users with the same choice context"*. The perceived utility U is given by the sum of the systematic utility V and the random residual Ɛ (which represents the deviation of the single user with respect to the average value): U = V + Ɛ.

5. An example: Milan 2015-2025 urban mobility plan (SUMP)

5.1 The CBA model

For the assessment of new Milan's Sustainable Urban Mobility Plan (SUMP, or PUMS in Italian) we interfaced the simulation model developed by the transport authority (AMAT, developed in Cube©) with the assessment procedures, developed in Access© and Excel©. A schematic representation of the algorithm developed is depicted in Figure 2. The model has been used extensively in the past years to plan all transport decisions in the city and can rely on solid datasets of observations, used for the calibration.
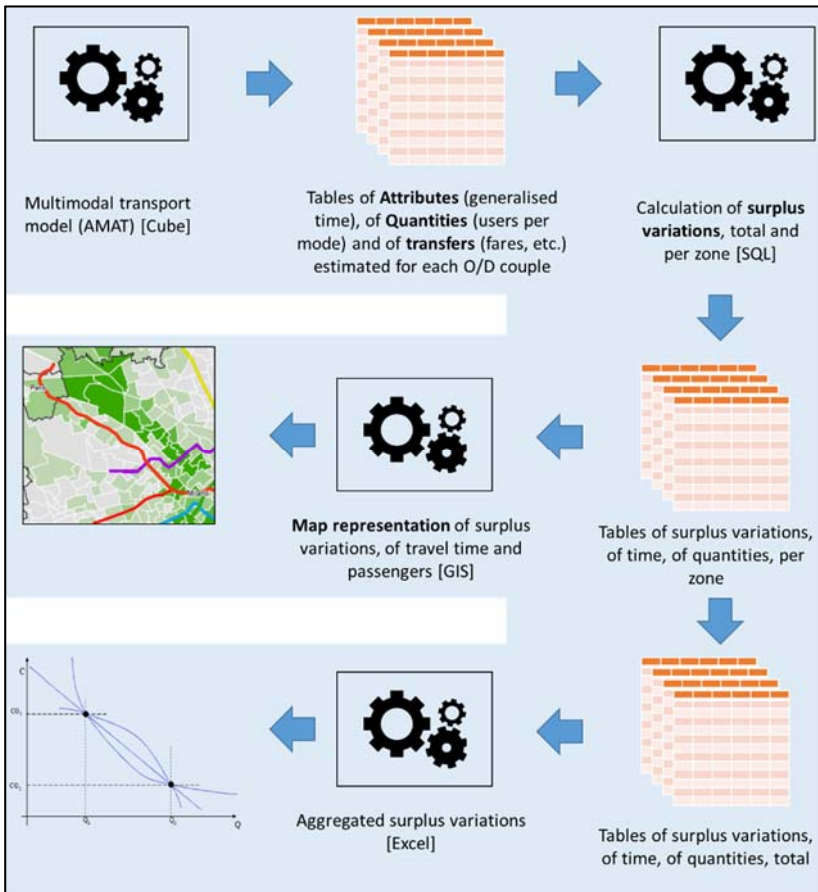

Figure 2. The assessment procedure implemented for the Milan's sustainable urban mobility plan (SUMP).

The transport model provided us the generalised cost components of each origin – destination pair for six different travel purposes (plus the "return home" purpose) and for the four modes considered: car, motorbike, public transport, active modes. Each segment of the simulated mobility is associated to a set of calibrated beta coefficients (Equation 5), including the values of time (per trip purpose and per mode). To manage the fact that some transport modes does not have any monetary component, we transformed the generalised costs into a generalised time, as explained in section 4.2. In addition, the model gives the quantities, in passengers during the peak hour, for every mode on each OD pair, allowing us to calculate the users changing mode. Finally, the model output includes also the data used to correct the transfers, in particular the paid fares, the parking tolls, the road pricing tolls, the driven km (useful to calculate the fuel duties paid).

Overall, the output consists of an Access file with tables of attributes (generalised time), quantities (amount of users) and transfers (fares, tolls and taxes) per 390,452 origin-destination pairs and 24 (4·7) mode and travel purpose combinations. In Access, with SQL procedures, we estimated the surplus variation using both the *logsum* method (as described in the previous sections) and the *Rule of Half* method. It must be noticed that the core calculations are done at the highest disaggregation level, i.e. per OD pair, mode and travel purpose and, only later, we proceeded with the aggregation

of the results in 829 origin and destination zones, using the same zoning of the model. The same thing has been done for all attributes, quantities and transfers.

Once the aggregation has been done, the datasets become more manageable with other software. The procedure has been then interfaced with Excel© for the CBA properly said (briefly described below) and with ArcGIS© to produce cartographical representations of the main variables.

The entire process has been applied for approximately fifty final scenarios. For this reason, we spent particular care to partially automatize the procedure with scripts but also to track all intermediate results in all passages to facilitate the debug. Some controls have been introduced intermediately to manually check the correctness of the results. The process showed also some local inconsistencies of the transport model, which were corrected.

The CBA properly said has been done in Excel, in the two variants of Economic CBA and Financial CBA. The elements included are listed in Figure 3 and the indicators calculated are the Net Present Value (NPV), the Net Benefit over Investment Ratio (NBIR) and the Benefit over Cost ratio (B/C). We further separate the results in two different sets of indicators, called "base" and "extended": the "extended" include the health benefits for active modes, the opportunity cost of public funds and an approximation of the possible wider economic effects. The reason is to keep separate the consolidated estimations of costs and benefits, from other less reliable estimations. In general, to be conservative, the SUMP used the "base" indicators to decide the actions to be included.

COST BENEFIT ANALYSIS

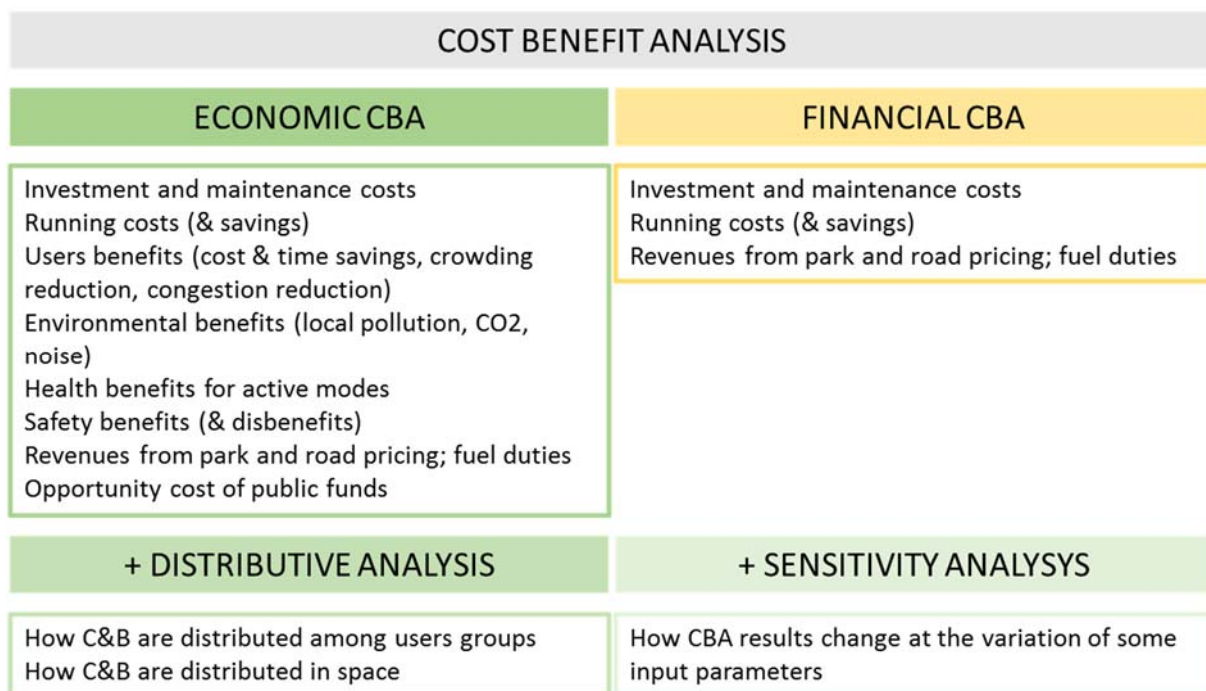| ECONOMIC CBA	FINANCIAL CBA
Investment and maintenance costs Running costs (& savings) Users benefits (cost & time savings, crowding reduction, congestion reduction) Environmental benefits (local pollution, CO2, noise) Health benefits for active modes Safety benefits (& disbenefits) Revenues from park and road pricing; fuel duties Opportunity cost of public funds	Investment and maintenance costs Running costs (& savings) Revenues from park and road pricing; fuel duties
+ DISTRIBUTIVE ANALYSIS	**+ SENSITIVITY ANALYSYS**
How C&B are distributed among users groups How C&B are distributed in space	How CBA results change at the variation of some input parameters

Figure 3. Cost Benefit Analysis components

In addition, we developed in the same environment also the Distributive Analysis module (disaggregating the costs and the benefits into six users' categories, plus the non-users, the State and the Local Administration) and a simple Sensitivity Analysis testing automatically the effect of users' surplus estimation, investment cost and running costs on results.

5.2 The scenarios

Previously to the assessment phase, the planners selected a number of actions to be considered among the entire set of projects at stake (for example present in previous planning documents, or indicated by stakeholders). This pre-selection was based on a preliminary technical evaluation (for example, among comparable alternative solutions for a single problem, the less effective were discarded before

the cost benefit analysis) and on the goals set by the political actors (for example, the extension of cycling paths).

The pre-selection generated 51 *explorative scenarios*, each one made of one single action. The nature of these actions is very heterogeneous, ranging from large infrastructural investments to existing lines extension, to the reorganisation of services. In some cases, different variants have been considered. The Table 5 lists the scenarios considered.

Explorative scenario	Number of sub scenarios (alternative options)
Previous land use plan (PGT) infrastructure	3
Metro line 1 extension	3
Metro line 2 extension	5
Metro line 3 extension	3
Metro line 4 extension	4
Metro line 5 extension	3
New Metro line 6	3 (explorative paths)
Tram 7 extension	4
Tram 24, 27, 178 extensions	2 + 2 + 1
Reorganisation of tram lines in the city centre	1
New urban stations to support rail "circle line" services	7
Change in a suburban rail line path	1
Extension of bike lanes	2
30 km/h city	1
Road pricing (AreaC) extension	4
Actions to increase commercial speed of surface public transport	2

Table 5. Pre-scenarios considered

All these *explorative scenarios* have been assessed using the same procedure and inputs, to keep a perfect comparability. The purpose of this preliminary assessment was to show which actions pass the CBA tests or, in case of negative results, which were the conditions to make them socio-economically feasible. In some cases, one can argue that the action alone generates a surplus loss, but together with other actions, the result may change. This is the case of the 30km/h city policies: the effect on traffic is negative because of a reduction in road capacity, but when the policy is assessed together with other actions capable of shifting road users to public transport, the negative result improves.

All positively assessed actions have been included in the final Plan Scenarios and evaluated together.[9]

5.3 Outputs: the Appraisal Summary Table and the Book of Maps

The CBA here shortly described is, for the first time in Italy, part of the planning process, as suggested in SUMP guidelines (Eltis, 2013), and does not come at the end to justify the decisions taken.[10] In order to make the decision of the Mayor and of the City Council, but also citizens' opinion, more transparent and informed, the outputs of the assessment have been presented in a homogeneous and

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[9] In this stage, no budget constraint is foreseen and all actions are included. Budget constraints can be managed consistently using appropriate algorithms (Bonnafous and Jensen, 2005).

[10] The process is still ongoing at the moment of writing and no final decisions have been taken yet.

detailed way. Documents and analysed clarify all the relevant facts which should back the decisions, not limitedly to the sole aggregate CBA indicators (NPV, NBIR, B/C).

To do that, the results of both the explorative scenarios and the final scenarios are presented through the following outputs.

i. The Appraisal Summary Table ("*Tabella di valutazione sintetica*"), directly inspired by the ones used in the UK (DfT, 2014);

ii. the Book of Maps ("*Quaderno delle mappe*") representing spatially the main effects of the actions.

The Appraisal Summary Table is organised in four parts (Figure 4): the socio-economic assessment (including the sensitivity analysis), the financial assessment, the distributive analysis and a summary of results, which includes a general comment.

The socio-economic assessment box includes a summary of the aspects considered in the appraisal. In the majority of cases, we provided both a description of the effect, a quantification (for example the reduction of km driven) and the translation in monetary terms. The sum of all monetised impacts gives the Net Present Value (NPV). As already said, we provided two versions of the NPV, one including the effects with a reliable quantification and another which adds up also some extra effects. In addition to NPV, the Net Benefit over Investment Ratio (NBIR) and the Benefit Cost Ratio indicators have been computed, too.

The assessed policies include also soft mobility policies, entailing effects of difficult monetisation, such as the quality of urban environment, etc. We decided not to stress the quantification of these aspects and kept them explicitly separate from the "core" of direct impacts, providing just a simple qualitative judgement. In the majority of cases, typically new infrastructure, these non-quantified effects are likely not such to change the overall results. To the contrary, in some cases these are the most relevant aspects and the CBA results incomplete, providing just a quantification of the transport impacts. The decision on these policies will then just take into account the quantified effects and the trade off with the non-quantified ones is left to the decision maker; however, as the main direct transport effects are clarified, the decision results more transparent than without any quantification.
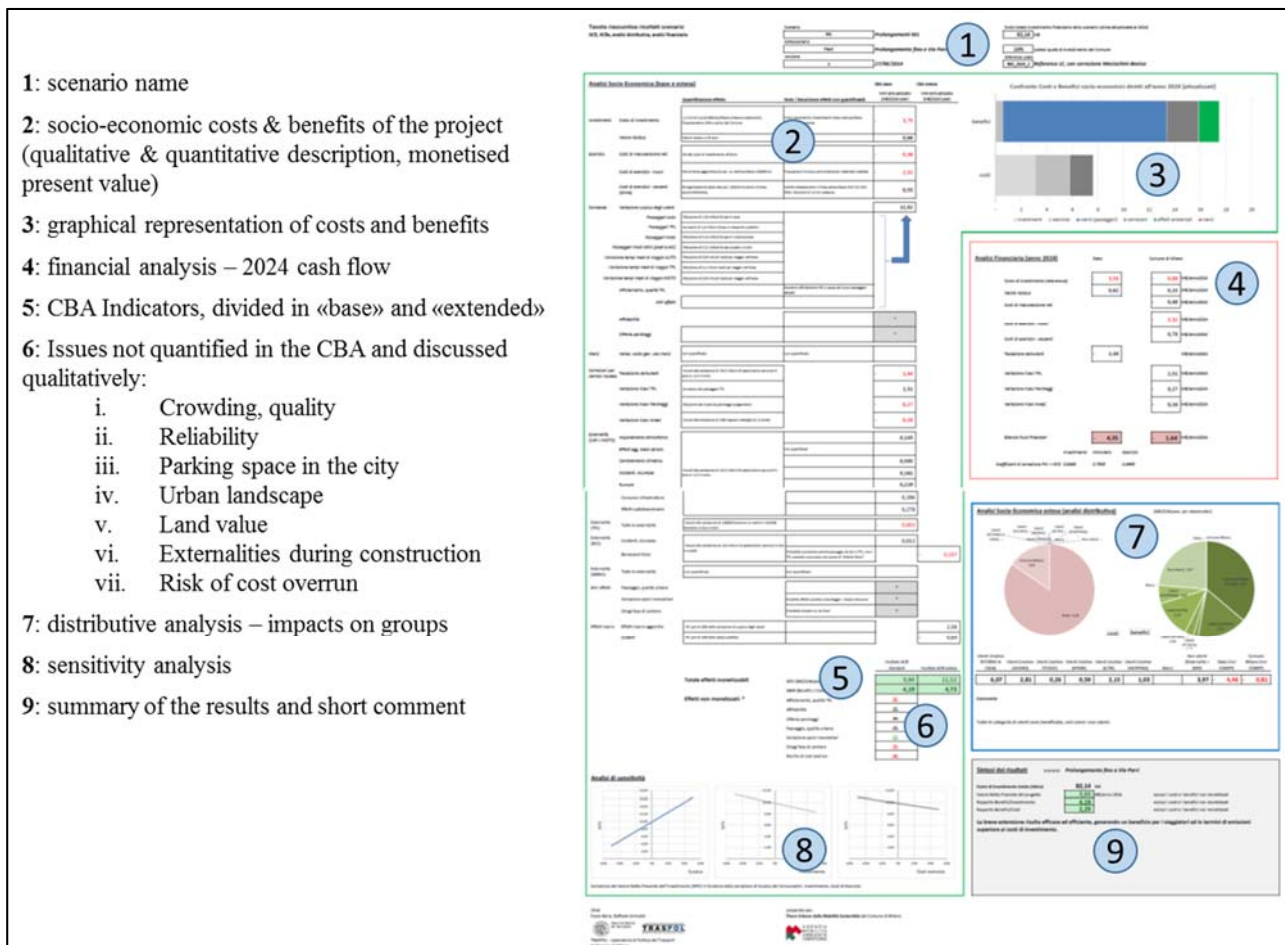
Figure 4. An example of Appraisal Summary Table organisation

1: scenario name

2: socio-economic costs & benefits of the project (qualitative & quantitative description, monetised present value)

3: graphical representation of costs and benefits

4: financial analysis – 2024 cash flow

5: CBA Indicators, divided in «base» and «extended»

6: Issues not quantified in the CBA and discussed qualitatively:
  i.   Crowding, quality
  ii.   Reliability
  iii. Parking space in the city
  iv.   Urban landscape
  v.   Land value
  vi.   Externalities during construction
  vii. Risk of cost overrun

7: distributive analysis – impacts on groups

8: sensitivity analysis

9: summary of the results and short comment

In addition to the AST, and to enrich the distributive analysis, a Book of Maps has been produced. Based on the detailed zoning of the city, it represents spatially numerous indicators included in the analysis, aggregated by origin or by destination zone (surplus gains and losses per zone, modal shift, travel time and distance variations). In particular, it precisely depicts the distribution of the Consumers' Surplus, showing which zones benefit from the investment and which zones present a welfare loss.

The majority of actions, like new infrastructure, give extra benefits to the users of the zones directly involved and is nearly irrelevant for those not involved (see for example Figure 5, left side). The spatial extension of the benefits depends on the nature of the action: for example, new metro lines spread their benefits on larger parts of the study area, while short tram extensions give only local benefits. However, some actions may give different impacts, such as a benefit for part of the city and costs to other zones, as exemplified in Figure 5, right side. These cases must be addressed carefully by the policy maker. Typically, if the action overall is socio-economically efficient, it might be necessary to implement other actions to offset the costs generated to part of the users. In the case of Milan's SUMP, the final scenarios, including all actions chosen, present positive impact on the entire urban area, but this has been made possible by the analysis of single action scenarios.
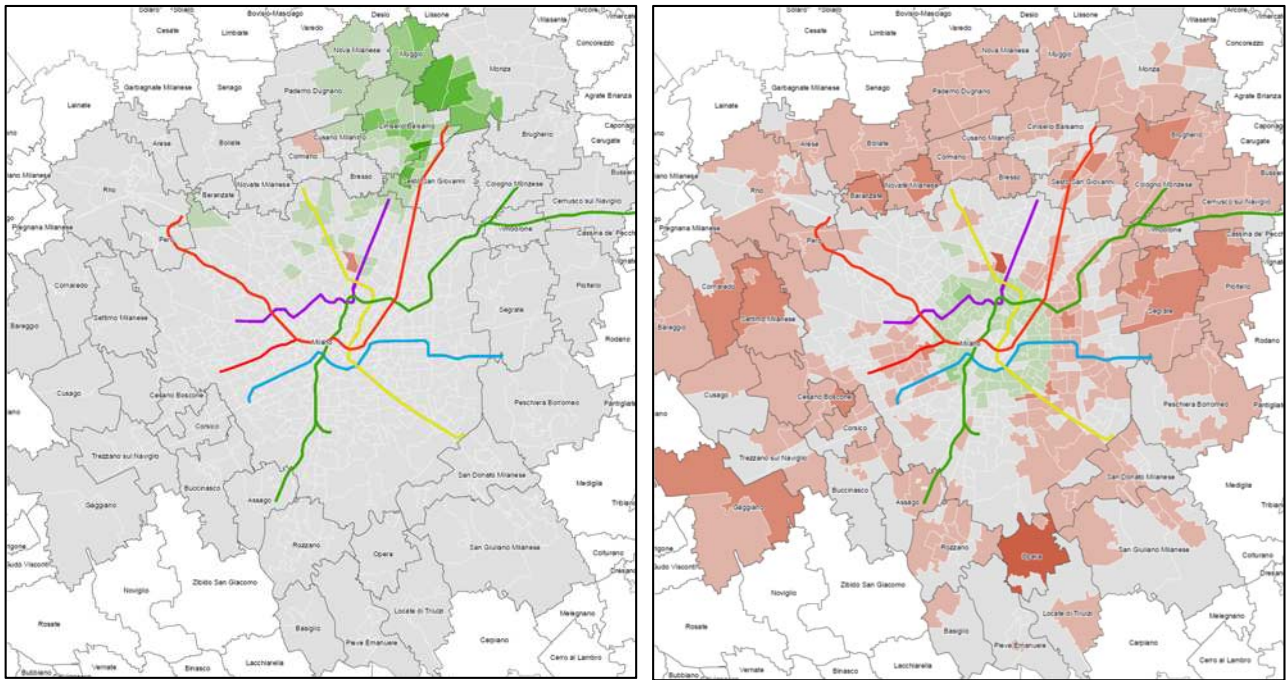
Figure 5. Examples of consumers' surplus variation maps

5.4 General findings

It is out of this paper's goals to present the results of the plan assessment. However, some policy and methodological indications of general interest can be derived from the work done.

A first relevant fact is related to the decreasing B/C ratio with the dimension of the investment (Figure 6). The single-action scenarios analysed, despite not randomly chosen and despite different in nature, show quite clearly that the bigger is the investment, the smaller is the B/C ratio. This is true also limiting to infrastructural investments and extensions. A similar result has been found elsewhere in the literature (Eddington, 2006), but overall not sufficiently studied.
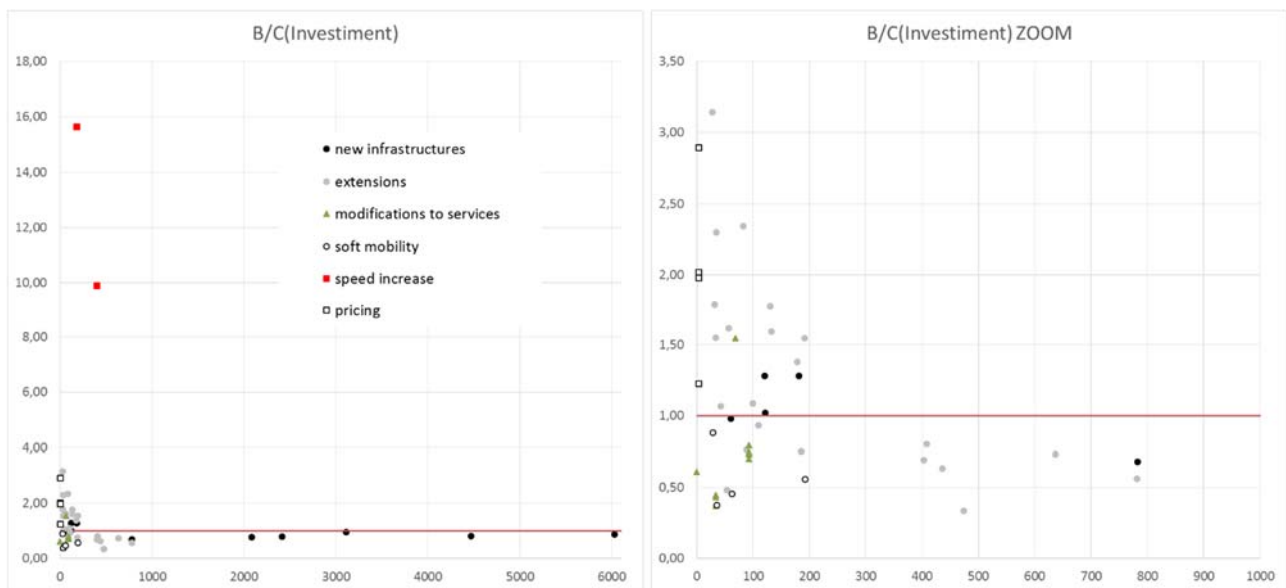

Figure 6. B/C ratio over investment for the 51 preliminary scenarios.

An interpretation is that, in a mature network like Milan's one, large additive investments result marginal with respect to smaller, but effective, bottleneck removal or missing links completion. Policies are even more efficient: involve very limited investments (or no investment at all) but, if

correctly designed, give large benefits. It is, for example, the case of road pricing extension, whose overall congestion benefits offset the drivers' welfare losses associated to the tolls.

A second relevant methodological result, to be further analysed in detail, deals with the difference between the surplus estimation calculated with the *Rule of Half* and with the *Logsum* method. As we have discussed before, the *Logsum* method is the only reliable method in case of non-additive policies (like pricing, capacity reductions, etc.), while the *Rule of Half* can be appropriately used if the scheme is the typical investment entailing an initial investment cost and successive users' benefits.

Thanks to the sample of 50 schemes analysed, we can test the difference between the two estimations. In particular, we calculate the ratio between the consumers' surplus obtained with the *Rule of Half* and the one obtained with the *Logsum* method: the nearest to one is this figure, the more similar are the two estimations. Figure 7 draw these ratios, distinguishing between *additive actions*, i.e. the actions (or groups of actions) that always generate net benefits to some users, and the *other actions*, i.e. the actions (or groups of actions) generating benefits to some users and costs to other, like pricing policies.
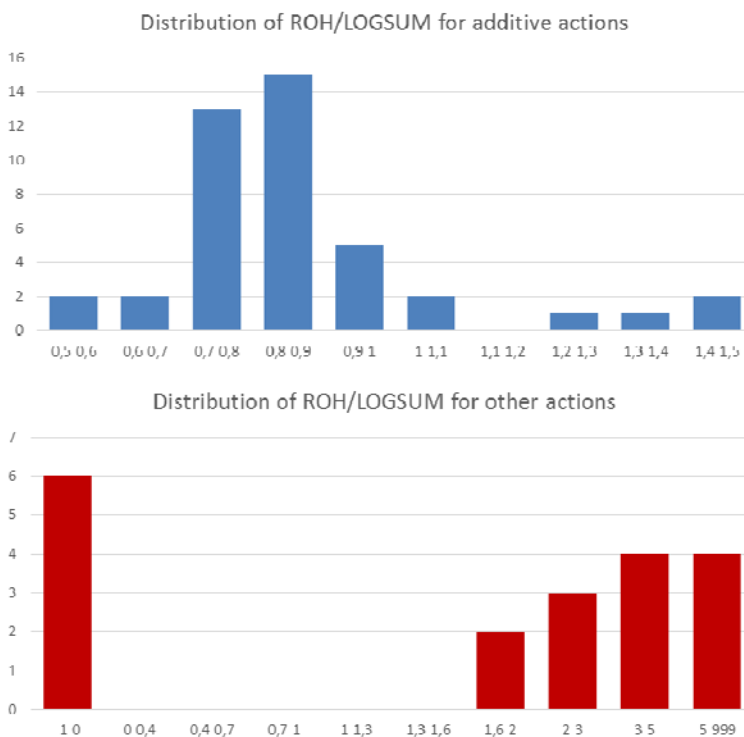

Figure 7. Distribution of RoH/logsum ratios

Results for the two groups are clearly different. The second group presents totally inconsistent ratios: assuming that the *logsum* method is correct – also because gives the expected signs – the Rule of Half method is totally misleading, generally calculating much more benefits than *logsum*. This suggests that double counts exist. For example, the final scenario plans present a net benefit for the users, as expected, if calculated with the *logsum*, but surprisingly a worsening in surplus if calculated with the RoH.

More interesting is the case of the additive actions, in which we classified all infrastructural investments and all modifications to existing services. In this case, the distribution is more revealing and the majority of measures is between 0.7 and 0.9 (with an average of 0.87): this evokes that the *Rule of Half* method underestimates the consumers' surplus, of 10% to 30%. Of course, this figure comes from our limited sample and is not generalizable as it is, but shows an interesting concentration. In general, this means that the *logsum* method is catching also some otherwise "hidden" benefits, i.e.

the benefits for the marginal users, ignored by the more deterministic *Rule of Half*. The cases at the extreme of our ranges may represent cases of limited double counts, or border effects, or general localised errors of the model.

6. Conclusions

Cost benefit analysis and public expenditure assessment techniques are broadly studied in literature. However, some relevant aspects of evaluation, especially related to the practical application in complex cases and to the effective inclusion of CBA in the policy design process, remain unsolved.

The primary objective of this paper is to give indications about how to correctly evaluate, using cost-benefit analysis, entire urban mobility plans. This need is more and more actual, given the increasing shift of mobility planning practices (Eltis, 2013) from single infrastructure, to complex and consistent urban plans. In fact, compared to simple infrastructure investments, plans entail the implementations of heterogenic actions, which might provide simultaneously benefit for some and costs for others. This can undermine the assumptions of the common methods to assess consumers' surplus: the *direct Generalised Costs comparison*, in general never recommended as we commented in detail, or even the usually more solid *Rule of Half*.

Since transport plans are – and should be, due to their complexity – supported by transport model analysis, we suggest here how to extract the needed data from the choice model and to adopt the *logsum* method for consumers' surplus calculation, which overcomes most of the limits of other methods. Thanks to the application of this method to the numerous scenarios of the new Milan's Sustainable Urban Mobility Plan, and comparing it with the Rule of Half, we find confirmation that the two methods give similar results when evaluating single infrastructure (the average ratio between the benefits calculated with the Rule of Half and the *logusum* is 0.87), but completely diverge when evaluating other policies or the plan overall.

A second outcome of the paper deals with the enrichment of the outputs of evaluation, again thanks to the integration with a transport model. The application developed for Milan include two possible ways to effectively represent and communicate the outputs of the evaluation: an Appraisal Summary Table (inspired by the British one) and a geographical and social Distibuive Analysis, depicting spatially the effects of the policies. These tools can help making the results more clear to politicians, policy makers, stakeholders and citizens, and in general improve the transparency and the awareness of the choices taken.

Finally, the results of the assessment of the actions considered in Milan's plan evidence decreasing socio-economic return on investment with the dimension of the project, as already found elsewhere. This fact has profound consequences on planning, suggesting that, on average, in mature networks smaller actions give systematically higher efficiency than large and expensive projects.

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