The logsum as an evaluation measure: review of the literature and new results

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Abstract:

The logsum is a measure of consumer surplus in the context of logit choice models. In spite of the abundant use of logit models in transport, project assessment is only rarely done using logsums. Instead in project evaluation or appraisal, changes in transport costs and time (borrowing values of time from some source) are commonly used to get the traveller benefits. The paper contains a review of the theoretical and applied literature on the use of logsums as a measure of consumer surplus change in project appraisal and evaluation. It then goes on to describe a case study with the Dutch National Model System (LMS) for transport in which the logsum method and the commonly used value of time method are compared for a specific project (high speed trains that would connect the four main cities in the Randstad: Amsterdam, The Hague, Rotterdam and Utrecht).

1. Introduction

Transport infrastructure projects in The Netherlands are normally appraised ex ante by using cost-benefit analysis (CBA) procedures following the so-called 'OEI-guidelines' (CPB and NEI, 2000). The project benefits for travellers are incorporated in the form of changes in demand (e.g. from the Dutch National Model System, LMS, or the regional models, NRM) and changes in the generalised travel costs (using values of time from Stated Preference studies to monetise travel time savings), and applying the rule of half.

While a number of short-term improvements to the current procedures have been proposed (see Ecorys and 4cast, 2004), it is also interesting to consider a more radical approach using explicit measures of consumer surplus, obtained by integrating the demand models directly.

The direct effects of a particular policy on the travellers can be measured as the change in consumer surplus that results from that policy (there can also be indirect and external effects that may not be covered in the consumer surplus change).

The consumer surplus associated with a set of alternatives is, under the logit assumptions, relatively easy to calculate. By definition, a person's consumer surplus is the utility, after conversion to money terms, that a person receives in the choice situation. If the unobserved component of utility is independently and identically distributed extreme value and utility is linear in income, then the expected utility becomes the log of the denominator of a logit choice probability, divided by the marginal utility of income, plus arbitrary constants. This is often called the '*logsum*'. Total consumer surplus in the population can be calculated as a weighted sum of logsums over a sample of decision-makers, with the weights reflecting the number of people in the population who face the same representative utilities as the sampled person. Assuming no change in the unobserved component of utility, the change in consumer surplus is calculated as the difference between the logsum under the conditions before the change and after the change (e.g. introduction of a policy). The arbitrary constants drop out.

The advantages that the logsums would give to the appraisal procedure would be that logsums can incorporate a degree of heterogeneity in the population, while also being theoretically more correct and in many cases easier to calculate. However, to calculate this change in consumer surplus, the researcher must know the marginal utility of income.

Usually a price or cost variable enters the representative (indirect) utility and, in case that happens in a consistent linear additive fashion, the negative of its coefficient is the marginal utility of income by definition. If the marginal utility of income is not constant with respect to income, as is the case in the Dutch National Model System LMS and the Dutch regional models NRM, a far more complex formula is needed, or an indirect approach has to be taken, while thought is also needed about the measure of surplus to be used.

In this context, the Transport Research Centre (AVV) of the Dutch Ministry of Transport, Public Works and Water Management has commissioned RAND Europe to undertake a study comparing the conventional approach to the use of the logsum change as a measure of the change in consumer surplus that would result from a transport infrastructure project. The paper is based on the work conducted in this study.

After having introduced the basic concepts in section 2, this paper reviews the theoretical literature on the use of the logsum as an evaluation measure, including both the original papers on this from the seventies and the work on the income effect in the nineties (section 3). Also recent application studies that used the logsum for evaluation purposes are reviewed (section 4). It then goes on in section 5 to describe a case study with the (LMS) for transport in which the following methods are compared for a specific project, 'Rondje Randstad' (a proposed high speed (probably MAGLEV) train project that would connect the four main cities in the Randstad: Amsterdam, The Hague, Rotterdam and Utrecht):

a. the 'classical' approach of measuring the change in generalised cost, with external values of time, invoking the rule-of-a-half; and

b. the logsum approach.

Different methods for monetising the logsum change are compared as well. A summary and recommendations are provided in section 6.

2. Logsums: the basic concepts

In this section we provide an introduction to the concept of logsums, largely following the most recent textbook on discrete choice models (Train, 2003). A separate section of this book is devoted to describing the calculation of the consumer surplus for policy analysis.

In the field of policy analysis, the researcher is mostly interested in measuring a change in consumer surplus that results from a particular policy. The consumer surplus associated with a set of alternatives is, under the logit assumptions, easy to calculate. By definition, a person's consumer surplus is the utility (also taking account of the disutility of travel time and costs), in money terms, that a person receives in the choice situation. The decision-maker n chooses the alternative that provides the greatest utility, so that the consumer surplus (CS_n) can be calculated in money terms as:

$$CS_n = (1/\alpha_n) U_n = (1/\alpha_n) \max_j (U_{nj} \ \forall \ j)$$

where U_{nj} is the utility that decision maker n obtains from alternative j ($n = 1,..N$; $j = 1,…,J$),

α_n is the marginal utility of income and equal to dU_{nj}/dY_n if j is chosen,

Y_n is the income of person n, and

U_n the overall utility for the person n.

Note that the division by α_n in the consumer surplus formula, translates utility into money units (e.g. dollars, euros) since $1/\alpha_n = dY_n/dU_{nj}$.

In this framework, the utility is known to the decision-maker, but not to the researcher. The researcher observes some attributes of the alternatives as faced by the decision-maker, labelled $x_{nj} \ \forall j$ and some attributes of the decision-maker, labelled s_n and can specify a function that relates these observed factors to the decision-maker's (indirect) utility:

$$V_{nj} = V(x_{nj} \ , \ s_n) \forall j = \text{"representative utility"};$$

Furthermore, utility is decomposed into an observed and an unobserved (random) component:

$$U_{nj} = V_{nj} + \varepsilon_{nj}$$

where ε_{nj} captures the factors that affect utility, but are not observable by the researcher. Taking this into account, the researcher is able to calculate the expected consumer surplus by:

$$E(CS_n) = (1/\alpha_n) E \left[max (V_{nj} + \varepsilon_{nj} \ \forall j) \right]$$

where the expectation is over all possible values of the ε_{nj}'s.

If each ε_{nj} is iid extreme value with standard variance ($\pi^2/6$) and utility is linear in income (that is α_n is constant with respect to income), then the expectation becomes:

$$E(CS_n) = (1/\alpha_n) \ln \left(\sum_{j=1}^{J} e^{V_{nj}} \right) + C$$

where C is an unknown constant that represents the fact that the absolute value of utility can never be measured.

The term in parentheses in this expression is the denominator of a logit choice probability

$(P_{ni} = \dfrac{e^{V_{nj}}}{\sum_j e^{V_{nj}}})$. Aside from the division and addition of constants, expected consumer

surplus in a standard logit model is simply the log of the denominator choice probability. This is often called the "logsum term".

Under the usual interpretation of distribution of errors, $E(CS_n)$ is the average consumer surplus in the subpopulation of people who have the same representative utilities as person n. Total consumer surplus in the population can be calculated as the weighted sum of $E(CS_n)$ over a sample of decision-makers, with the weights reflecting the number of people in the population who face the same representative utilities as the sampled person.

The change in consumer surplus is calculated as the difference between the calculation of $E(CS_n)$ under the conditions before the change and the calculation of $E(CS_n)$ after the change (e.g. introduction of policy):

$$\Delta E(CS_n) = (1/\alpha_n) [\ln(\sum_{j=1}^{J^1} e^{V^1{}_{nj}}) - \ln(\sum_{j=1}^{J^0} e^{V^0{}_{nj}})]$$

where superscript 0 and 1 refer to before and after the change.

Since the unknown constant C appears in the expected consumer surplus both before and after change, it drops out in calculating the changes in the consumer surplus. However, to calculate this change in consumer surplus, the researcher must know (or have estimated) the marginal utility in income α_n. Usually a price or cost variable enters the representative utility and, in case that happens in a linear additive fashion, the negative of its coefficient is α_n by definition. The formula given by Train for calculating the expected consumer surplus depends critically on the assumption that the marginal utility of income is constant with respect to income. If this is not the case, a far more complex formula is needed, in which α_n becomes a function of the change in attributes. However, for policy analysis absolute levels are not required, rather only changes in consumer surplus are relevant, and the formula for calculating the expected consumer surplus can be used if the marginal utility of income is constant over the range of implicit changes that are considered by the policy. So, for policy changes that change the consumer surplus by small amounts per person relative to their

income, the formula can be used even though in reality the marginal utility of income varies with income.

A slightly different interpretation, namely the logsum as a measure of accessibility, is given in the textbook by Ben-Akiva and Lerman (1985). The authors only briefly describe the mathematical expression to calculate consumer surplus as part of describing a measure of accessibility:

If C_n is a choice set, for multinomial logit:

$$V_n^{'} = \frac{1}{\mu} \ln \sum_{i \in C_n} e^{\mu V_{in}}$$

where $V_n^{'}$ is the systematic component of the maximum utility, i.e. the measure of accessibility,

μ is the scale parameter of the disturbance term ε (ε is by assumption iid Gumbel) and $E\left[\max_{i \in C_n} U_{in}\right]$ is defined as the measure of accessibility, assuming that the utility scale is established such that $E(\varepsilon) = 0$.

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where $V_n^{'}$ = the systematic component of the maximum utility = measure of accessibility,

μ = scale parameter of the disturbance term ε (ε is by assumption iid Gumbel distributed) and $E\left[\max_{i \in C_n} U_{in}\right]$ is defined as the measure of accessibility, assuming that the utility scale is established such that $E(\varepsilon) = 0$.

Thus, we can calculate a measure of consumer surplus. The choice model is viewed as an individual's demand curve for an alternative. The difference in an individual's consumer surplus between two situations corresponding to attribute vectors x_n^1 and x_n^2 or vectors of systematic utilities V_n^1 and V_n^2 is

$$\sum_{i \in C_n} \int_{V_n^1}^{V_n^2} P(i \mid V) dV$$

where the choice probability is denoted as conditional on the vector of systematic utilities in order to make the dependency explicit. For the logit model it can be shown that the result of this formula is

$$\frac{1}{\mu} \ln \sum_{i \in C_n^2} e^{\mu V_{in}^2} - \frac{1}{\mu} \ln \sum_{i \in C_n^1} e^{\mu V_{in}^1}$$

which is the difference among expected maximum utilities in the two situations. This measure is expressed in utility terms, but could be transferred to monetary terms in various ways, such as by dividing this measure by a coefficient of travel cost.

More complex discrete choice models (notably Generalised Extreme Value or GEV models) are discussed in the next chapter.

3.   Review of the theoretical literature

This section provides an overview of the theoretical literature discussing the issue of calculating overall utility derived by diverse consumers facing a discrete choice and the role of the 'logsum' formula in that calculation. First a general description of the early literature (until the early nineties) is given. Then the issues addressed in the more recent literature (income effects and taste variation) are introduced.

It is supposed that consumers face a situation in which they must choose one of a finite number of mutually exclusive alternatives[1]. Each alternative has a utility and each consumer chooses the alternative that gives him or her the maximum utility. However, because the consumers are diverse, i.e. have different preferences, the alternative that gives maximum utility may be different for different consumers. Moreover, it is acknowledged that neither the analyst nor the consumer can measure the utilities with perfect precision; any predictions of choice can therefore be made only as probabilities.

This analysis gives the Random Utility Model (RUM) framework, in which consumers (i.e. travellers or freight shippers, in the transport context) are represented as maximising utility, but that this utility is considered random, either because the analyst cannot measure the utilities perfectly or that the consumer does not act consistently, e.g. by making mistakes. This framework has been questioned persistently by psychologists and other social scientists,

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[1]   For the purposes of discussion, it is presumed that a market segmentation has been carried out such that consumers within one segment can be considered to choose from the same set of alternatives. This segmentation has the practical consequence that overall utilities must be calculated separately for each segment.

but remains the only complete paradigm for modelling and evaluating choice behaviour. For the present work we shall remain within the RUM framework.

The theoretical literature reviewed falls into two phases. First, covering the period up from the early 1970's to the early 1990's, appraisal analysts working within the RUM paradigm constrained themselves to models which did not allow for any effect of income on choice, nor for any variation in tastes which was related to variables in the model. Later, from the mid-90's to the present day, attempts have been made to incorporate these two effects into appraisal models, following successful incorporation of such effect in choice models. It is fair to say that not all of the problems of extending the appraisal models have yet been solved. In any case, practical appraisal procedures up to the present day have almost exclusively been based on the simpler, earlier, models. A summary of the theoretical literature review is presented below, split into the two phases. The detailed reviews are in RAND Europe (2005). Two recent papers offer an overview of the field from different points of view: Bates (2003) and Daly (2004). Bates gives a complete overview of current practice[2] of transport policy appraisal, relating this to the relevant theory. In particular this paper gives an excellent discussion of the strengths and weaknesses of the 'rule-of-a-half' approximation to consumer surplus calculation. Daly reviews the early theory of RUM modelling, showing that all the important researchers were working on basically equivalent hypotheses, which include a constant marginal utility of money and the exclusion of taste variation in policy variables. He then goes on to discuss more recent work that abandons these restrictions and to discuss the consequences that the various approaches have for appraisal.

3.1   The early RUM literature

The key early papers in the RUM literature are McFadden's 1978 and 1981 publications, which form his most important contribution to the discrete choice literature and a major component of his Nobel work. In those papers he first set out the GEV theorem (1978) and then gave full mathematical detail of the links between RUM, choice models and welfare functions (1981), which form the basis for discussing this issue. Essentially, the GEV theorem gives the basis for deriving choice probabilities and overall utilities from a class of

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[2]   Perhaps, current British practice.

functions, which satisfy a list of conditions. The specific form of the expression giving the overall utility (the welfare function) is, in simple cases, the log of the sum of the exponentiated utilities of the alternatives, hence acquiring the name 'logsum'.

In many papers, the first publication advocating the use of the logsum as a measure of consumer surplus is stated to be Williams (1977). However, Cochrane (1975) gives the logsum formula for total utility and refers to 1971 work by Neuberger and work parallel to his own by Koenig. Williams himself refers to Neuberger and to work by Wilson and Kirwan of 1969, in both cases as having used the logsum formula for evaluation. The logsum measure was also in practical use for appraisal before 1977 (by Daly and probably by others, as it is quite simple to derive as the integral of a logit demand function). Both Cochrane and Williams gave a complete theory of utility on which the logsum could be based, but Williams and Daly and Zachary (1978) took this further to establish that the logsum was the key 'composite cost' measure which could be used in further modelling to obtain tree (nested) logit models and derived extended logsum measures from tree logit models. McFadden's contribution in this context was to generalise further the models from which logsum-type measures could be derived and to extend and make more rigorous the theory on which their derivation was based.

McFadden's GEV theorem also gives the choice probabilities for the model. These are equal to the derivatives of the logsum with respect to the utilities of the alternatives. That is, the logsum is equal to the integral of any of the choice probabilities with respect to the utility of the corresponding alternative. Given that the choice probability is the expected demand for the alternative from each consumer, it can be seen that the logsum is thus – in some sense – the integral of the ordinary demand curve.

It would thus be convenient to identify the logsum with the Marshallian consumer surplus arising from the choice situation, which is conventionally presented as the integral of the demand curve. However, Marshallian surplus is defined in terms of the integral of demand with respect to the *price* of an alternative, while the logsum is defined as the integral with respect to the *utility* of an alternative. In a context where the marginal value of money is considered to be constant, this presents no problem. The literature up to the early 1990's, including McFadden, is based on this assumption, which is tantamount to ignoring any

influence of income on choice. Most models simply do not deal with the impact of budget constraints on behaviour.

In McFadden's early theory, the key assumptions identifying the models are:

1. the AIRUM assumption (Additive Income RUM), which requires income to enter indirect utility in a specific linear additive form, precluding any income effect on choice behaviour; and

2. the invariant RUM assumption that the distribution of the random component of utility[3] is not affected by the values of the observable components – essentially, there is no unobserved taste variation.

A recent paper by Daly (2004) shows that all the key early researchers made these key assumptions (in so far as they discussed the role of income) and also made the same more technical assumptions that are necessary to make the models operational. The most general form of these technical assumptions allows for the possibility that the logsum should be scaled by a constant positive factor to express it on a monetary scale.

3.2 Income effect and taste variation

The impact of income on discrete choice has of course been considered in models of car ownership and other issues for many years, but it seems that McFadden (1996) was the first to propose acceptable procedures for calculating consumer surplus measures for models with income effects. This paper gives three methods for assessing consumer surplus with models that are nonlinear in income: a simulation procedure; an approximation based on a representative consumer approach, which he rejects as inaccurate; and some bounds on the true value of the surplus. Herriges and Kling (1999) test these approaches on real data, concluding that the calculation of bounds is inconvenient and may be inaccurate but are unable to choose decisively among the other McFadden approaches and more approximate methods.

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[3]   More strictly, the distribution of the *differences* of the random components.

However Cherchi *et al*. (2004) conclude that approximations obtained by linearising the demand model may give substantial error. Karlström (2000) offers an alternative calculation procedure to replace the McFadden simulation.

Taste variation presents a different type of difficulty, in that the valuation attached to attributes of the alternatives are not constant. In particular, the money coefficient may vary randomly, which presents complications of a more fundamental kind. Here we may be concerned with the issue of whether variation is viewed as being between individuals only, or possibly also 'within' a given individual. Von Haefen (2003) makes his evaluations without apparent concern for this issue and it is possible that this may be a valid approach. It seems the best conclusion at present is to view the issue as being unresolved.

4.   Review of the applied literature

Although the theory on the use of the logsum change as a measure of the change in the consumer surplus was published in the late seventies and early eighties, the application of this theory in practical appraisals of transport projects has been very limited. Most applications in transport evaluation that the authors are aware of have been undertaken only recently (after 2000). The applications that were reviewed are summarised in Table 1. All applications use models that include mode choice. Some logsum applications in project evaluation also use models for destination choice and/or departure time choice. Logsums are first calculated for each individual decision-maker in the sample, and then aggregated over groups of decision-makers. Various segmentations are used, also depending on the segmentation used for the time or cost coefficients used later on to convert from the utility scale (measured in, say, 'utils') to money or time. A common segmentation for the logsum calculations and outputs is by travel purpose. The applications of the logsum concept in transport project appraisal all use the relatively simple formulation with constant marginal utility of money. It could be dangerous to assume that the marginal utility of income would be constant over a wide income range (it is more likely that it will decline with increasing income). Theory has moved beyond that in the nineties, but the later formulations are not in practical use. Also note that the Sacramento application uses the assumption of a constant marginal utility of money only within a number of distinct income/worker categories. This

Table 1. Summary of applications of the logsum in transport project appraisal

Model application	Choices included	Segmentation	Marginal utility of income	Conversion method of utlity into money
San Francisco (Castiglione et al, 2003)	Mode choice	By zone pair and 9 segments based on household size and car availability	constant	Using a common in-vehicle time coefficient to get outcomes in minutes
Europe (EXPEDITE, 2002)	Mode-destination choice	By almost 1,000 person segments and 5 travel purposes	constant	Using an implied cost coefficient per purpose to get outcomes in euros
Austin (Gupta et al., 2004; Kalmanje and Kockelman, 2004)	Mode, destination and departure time choice	4 trip purposes, calculated for an individual resident	constant	Using a cost coefficient per purpose to get outcomes in dollars
The Netherlands LMS (Koopmans and Kroes, 2004; De Raad, 2004)	Mode, destination and departure time choice	8 travel purposes	constant	Using time coefficients per purpose to get minutes, then using value of time to get euros
Oslo (Odeck et al, 2003)	Mode-departure time choice	By trip purpose	constant	Using a cost coefficient per purpose to get outcomes in Kroner
The Netherlands TIGRIS (RAND Europe, 2004)	Mode, destination and departure time choice	8 travel purposes	constant	No conversion to money used
Sacramento (USDoT, 2004)	Mode choice	Household segments base on income/worker categories	constant	Using a cost coefficient per segment to get outcomes in dollars

provides a solution, which we also used for the LMS applications where cost coefficients also differ between five income groups. Two applications (Castiglione et al, 2003 and Koopmans and Kroes, 2004) do not convert the (dimensionless) logsum change directly into money units, but convert to time in minutes. The other applications use one or more cost coefficients to get outcomes in money units.

5.   Case study for The Netherlands

In this case study, we are using results from two different runs that were carried out with the Dutch National Model System LMS:

- the reference situation 2020; and

- the project situation 2020 (the same as the reference situation, except for the implementation of 'Rondje Randstad', with particular speed and frequency increases for a number of train links between the big cities in the Randstad, and reductions on some of the minor train links).

Below are the results for the number of tours by train travellers from the two LMS runs. Note that for home-based business and 'other' travel, the number of train tours is predicted to decrease. This is due to the fact that the project variant does not provide train times that are better than the reference situation 2020 in all cases; for some origin-destination relations, the train times in the reference situation are shorter. The travel times by train in the project variant always at least as good as in the base year, but the reference situation also includes some improvements in train travel times compared to the base year, some of which (especially stop trains) are not in the 'Rondje Randstad' variant.

Table 2. Number of tours by train on an average working day in 2020

	Reference 2020	Project 2020	Project 2020 (Reference=100)
Commuting	505571	513088	101.5
home-based business	16659	16509	99.1
non-home-based business	18959	18978	100.1
education	170121	171955	101.1
shopping	37499	37584	100.2
other	112678	112455	99.8
total	861487	870569	101.1

5.1 The 'classic' method

In the 'classic' method, the benefits from the project are calculated as follows. For instance for commuters the number of travellers that stay in the train is taken to be 505571. The number of 'new' travellers is taken to be 513088 – 505571 = 7571 (in fact this is substitution from other modes). The average travel time (train in-vehicle-time) in the reference situation is 62.26 minutes for commuting. With the project this is 61.62 minutes. This time gain is used as the benefit for all stayers: 505571* (62.26-61.62) * (value of time for train commuters). This value of time comes from the 1997/1998 stated preference (SP) surveys that Hague Consulting Group carried out for AVV. For the new travellers the gain is (rule-of-a-half): 7571* (62.26-61.62) * (value of time for train commuters) * 0.5. Repeating this for all purposes gives the traveller benefits as in Table 3 (first row).

As can be seen from the above example and the numbers of train travellers in Table 2, the benefits to travellers are completely dominated by the benefits of those that stayed in the train. The new train passengers make up only about 1% of the total number of train passengers in the project situation. Furthermore the benefit for a new train passenger is calculated as only half that of a remaining train passenger.

In the second row of Table 3 are outcomes when including not only the train in-vehicle-time benefits, but also the gains in terms of in-vehicle-time (bus) during the access to the train station and during the egress from the train station (this is exogenous project input). This more than doubles the time benefits of the project. The increase is caused by the fact that the (large) railway stations that will be used more in the 'Rondje Randstad' variant have better bus/tram/metro connections, so the access and egress times will be shortened. The benefits in Table 3 are between 0.10 and 0.23 Euro per train tour.

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Table 3. Traveller benefits (project minus reference) for the full year 2020 in millions of 2003 Euros[4]

Method:	Traveller benefits
Classic method, train in-vehicle time only	24
Classic method, including access/egress time	58
Logsum using SP values of time	44-51
Logsum using average costs	56

We did not calculate additional benefits for the car users due to the reduction of congestion on the roads (that would be caused by substitution from road to rail), because the substitution from car driver to rail was so small (about a third of the 'new' train travel) that the average travel time by road did not change.

5.2 The logsum method

Logsums (dimensionless) were first calculated for the reference situation 2020 and for the project situation with shorter train times because of the 'Rondje Randstad' project. Then, logsum differences for the difference between the reference and the project situation were produced. The logsums and logsum differences were originally calculated per tour. These outcomes were aggregated/expanded to logsums and logsum differences for combinations of travel purpose and income class (with five income classes, as used in the LMS).

For each of these two logsum types of differences (NL, MNL), we applied two different methods for the conversion to money:

- Method 1: Translate the logsum differences to minutes, using the LMS travel time coefficients (by purpose) and then translate from minutes to 1995 money values by using the recommended values of time (from the 1997/1998 stated preference (SP) surveys that Hague Consulting Group carried out for AVV) by purpose and income group. Because the project studied (Rondje Randstad) is a rail project, and rail users are affected most, we used the time coefficients (for in vehicle time and other time

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[4] The calculations were originally made in 1995 prices (as used in the current LMS version). For business travel a factor 1.28 was used to go from 1995 to 2003 (average contractual wage rate increase) and 1.30 for the increase in the values of time between 2003 and the forecast year 2010 (Ecorys and 4Cast, 2004). For commuting these values were 1.23 (consumer prices) and 1.15, and for other travel the values were 1.23 and 1.11. For the conversion from an average working day to a full year we used the factor 285 (Ecorys and 4Cast, 2004).

components) of rail here. The values of time used are those by income class and travel purpose (not by mode, but over all modes). This method has a consistency problem: it uses one set of implied values of time from the LMS to get the transport demand impacts in minutes and another set of information on values of time from SP surveys to get the transport demand impacts in money.

- Method 2: Divide the logsums by the product of the LMS cost coefficients and the expected value of (1/cost) per tour (all by income class and purpose). In a linear cost model, division by the cost coefficients would have been sufficient for conversion to money units. But here the costs enter the calculation because of the use of logarithmic costs in the LMS mode-destination choice models. Moreover, the use of the expectation of (1/cost) is only approximately correct. On the other hand, this method does not use the information on values of time from the SP survey and therefore does not have the inconsistency problem that Method 1 has.

The cost coefficients in the LMS are the same for all modes (but differ between purposes and income groups), but a problem is the treatment of modes and population groups with zero costs (slow modes, car passengers, students). The LMS itself uses zero if there are no cost and ln(cost) for positive cost. For our conversion to money in method 2, we need to divide by costs, and have to avoid division by zero. To calculate this, we used the lowest observed cost (we found that this is just below 1 guilder, approximately € 0.45, and used 1 guilder here) per tour for modes and groups with zero costs, so that these have will have a small impact on the final results.[5]

Below the monetisation methods are described formally (for a given purpose and person type):

We have utility functions of the form:

$$U = \alpha_c \ln[C] + \alpha_t T + \dots$$

in which:

C is cost in 1995 guilders

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[5] A cost formulation of the form ln(cost+1) in the LMS would have been more convenient. This also gives zero when cost is zero and a proper derivative for zero costs (1 guilder).

T is time in minutes

α_c: 1 guilder is α_c utils, or 1 util is $1/\alpha_c$ guilders

α_t: 1 minute is α_t utils, or 1 util is $1/\alpha_t$ minutes

We also define:

LS = logsum value in utils

Now method 1 and 2 work as follows:

Method 1 (Value of time):

LS/α_t = logsum in minutes

Logsum in guilders[6] = $(LS/\alpha_t).VoT$

VoT comes from an external model, estimated on stated preference data.

Method 2 (expectation of 1/ cost):

Conversion from utils to money:

$E(\partial U/\partial C) = E(\alpha_c/C) = \alpha_c.E(1/C)$

Therefore we get:

Logsum in guilders = $LS/(\alpha_c.E(1/C))$

The outcomes for the logsum approach are shown in Table 3 above. The outcomes are in the same range for both ways of monetising the logsum. Method 1 with the current LMS we have different results depending on whether we do the calculations by income group (first value given) or for all incomes at the same time (second value given). Differences between the first and second method are due to the fact that the first method uses external values of time (not from the LMS), whereas the second only uses information from the LMS. If values of time as implied by the LMS coefficients would have been used, both methods would have produced approximately the same total monetary change. Generally speaking the SP values of time are larger than the implied average LMS values of time for commuting for the lowest income classes. Also the SP values of time exceed the LMS values for business travel, shopping and other purposes. For commuting for the higher income classes (these are

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[6] When the model is a two-level nested logit (such as the LMS mode-destination choice models for most purposes), the time coefficient needs to be multiplied by the logsum coefficient (the differential of the logsum with respect to time is $\alpha_t.\gamma$, where γ is the logsum or tree coefficient that needs to be between 0 and 1 for global consistency with utility maximisation).

important categories for train travel), the SP values of time are lower than those implied by the LMS.

The project benefits for travellers (according to method 2) by travel purpose are illustrated in Figure 1.

Figure 1. Distribution of logsum change for Rondje Randstad over purposes (in millions of 2003 Euros for the full year 2020)
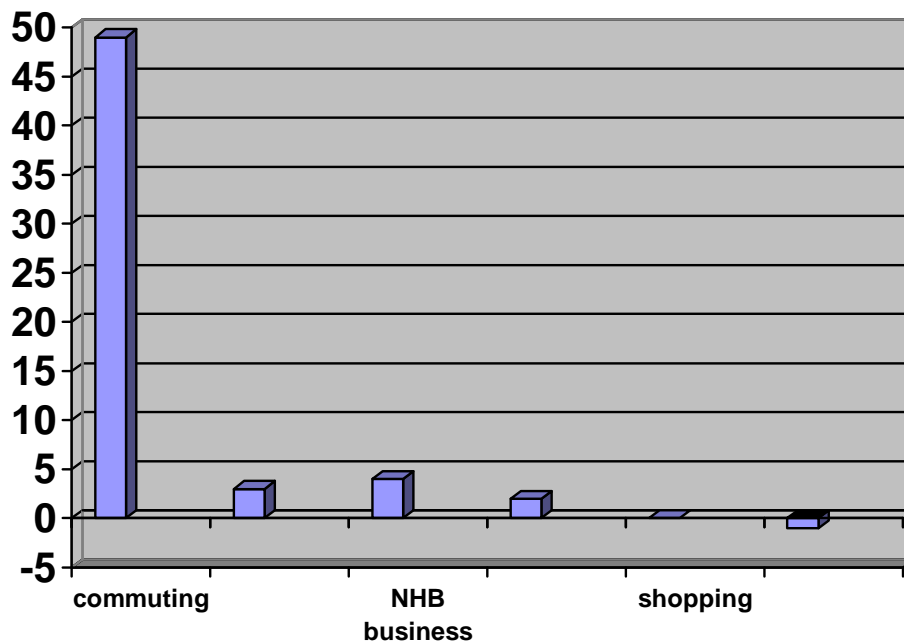
It is clear that most of the benefits of Rondje Randstad are accruing to commuters, with business travellers second and travellers to school/university third. The division over purposes is similar when using Method 1. One should keep in mind that about 58% of the train tours and 55% of the train kilometres (on an average working day) in the LMS are made by commuters.

Furthermore, the higher incomes groups are enjoying most of the benefits, as can be seen from Figure 2. Again the figure is for the second, but for both method 1 the distribution over income groups is very similar. Allowing for projected income growth, the share of the highest income group in total train tours in these LMS forecasts is 55% and it is also 55% in total train kilometres.

Figure 2. Distribution of logsum change for Rondje Randstad over income groups[7] (in thousands of 2003 Euros for the full year 2020)
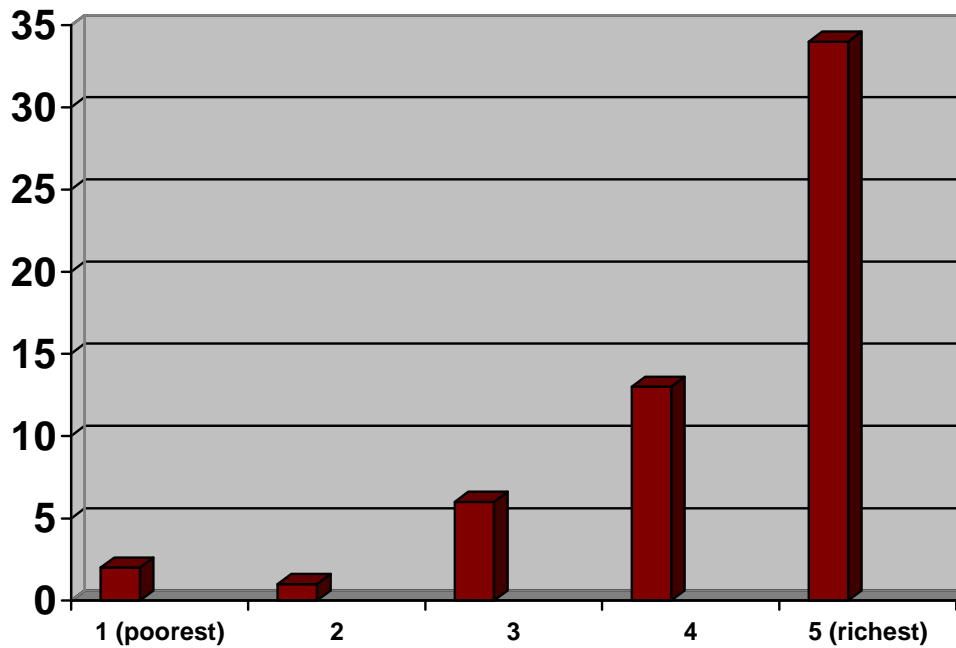
The logsum outcomes for the two monetisation methods are similar (see Table 3) to those using the in train in-vehicle time and access/egress time gains and SP values of time ('classic' method). This is just a coincidence. The logsums take into account the changes in all components of the utility functions: in-vehicle time, access/egress times, but also wait time. In the logsum approach, the LMS time coefficients are used to go from gains in utils to gains in minutes. These coefficients are not consistent with the SP results used in the 'classic' method. Most of the values of time from the SP are higher than those of the LMS (at the average costs). Substantial differences can be found especially for shopping, other purposes and for business (the LMS value of time does not include the employers' value of time for business travel, as the SP value of time does).

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[7] The income bands for net annual household income are: 0-€11300, €11300-18200; €18200-29500; €29500-38600; >€38600.

6. Summary and recommendations

6.1 Summary

At present, the method used in The Netherlands for quantifying the benefit for travellers of a transport project consists of calculating the change in consumer surplus (in terms of a reduction of generalised travel costs) for both the current users of the directly affected alternative and for new users. For the latter group the rule-of-a-half is used. This procedure has a basis in welfare analysis. For projects at a national scale, the LMS is often used to produce demand changes and the resulting benefits in travel time and costs. For regional projects, the NRM (new regional models) are regularly used, which use essentially identical demand functions as the LMS. In this study, an alternative approach is taken: instead of consumer surplus in terms generalized costs the "logsum" is used to calculate user benefits.

The theory on the use of the logsum change as a measure of the change in the consumer surplus, to be used in project appraisal, was published in the late seventies and early eighties. Nevertheless, the application of this theory in practical appraisals of transport projects has been very limited, and most applications in transport evaluation that the authors are aware of have been undertaken only recently (after 2000). It is not easy to find the reasons for the inertia to use the theory in applied work. To some extent it can be related to the complexity of some of the theoretical literature, but the basic logsum concept (with constant marginal utility of money) is fairly straightforward to apply. It may also have to do with the fact that in many countries there is no (national) model system based on disaggregate random utility models. For the computation of logsum changes, disaggregate Generalised Extreme Value (GEV) models, such as the multinomial logit and the nested logit, are required, although in the EXPEDITE project it proved possible to go back from a more aggregate model to the implied underlying utility models. National disaggregate transport models are in use in Scandinavia, the Netherlands and Italy and regional and urban models using these concepts can be found in the same countries, France, the United Kingdom, Australia, Israel and especially the United States. It is therefore not surprising that the logsums applications in evaluation took place in the USA, Scandinavia and The Netherlands. It is unlikely that the computer run times for the calculation have been a major obstacle for the use of logsums in evaluation, since all the required inputs are already computed in the standard procedures for

application of disaggregate models (calculation of individual probabilities in sample enumeration).

All applications reviewed use models that include mode choice. Some logsum applications in project evaluation also use models for destination choice and/or departure time choice. The applications of the logsum concept in transport project appraisal all use the relatively simple formulation with constant marginal utility of money. It could be dangerous to assume that the marginal utility of income would be constant over a wide income range (it is more likely that it will decline with increasing income). Theory has moved beyond that in the nineties, but the later formulations are not in practical use. Similarly, recent work on taste variation in policy variables has not become practical for application studies.

A case study in the logsums as an evaluation measure was carried out with the Dutch National Model System (LMS), for a rail project in the Randstad area ('Rondje Randstad'). We applied two different ways of monetisation of the logsum change in utils: method 1 that uses SP values of time and method 2 that uses the expectation of (1/cost).

For the rail project studied, we found that the application of the conventional rule-of-a-half approach leads to very different results depending on whether only the train in-vehicle time changes or also the access/egress time changes are taken into account. The logsum results for this project also vary between the two different monetisation methods which were tested, but the differences in outcomes are rather small. Most of the project benefits accrue to commuters and the highest income group, who each make more than half of the train tours and kilometres.

6.2   Recommendations

We think that replacing this approach by the logsum approach would provide a number of advantages:
- When using logit models as in the LMS, the logsum change also gives the change in the consumer surplus, and in a more exact way than the rule-of-a-half does, since it is based on a linearisation.

- At present there is an inconsistency in the evaluation procedure: for calculating the changes in travel demand. The LMS is used, which has its own set of implied values

of time. Then the resulting time changes are monetised using a different set of values of time (from Stated Preference surveys, SP). When using logsums we can avoid the use of external values of time (except in a method, which we called 'Method 1', of monetisation that expresses the logsum change in minutes first, and then through SP values of time in money). On the other hand, the SP studies might contain information that the LMS is lacking and it would be even better to estimate the transport demand models on a combination of the available Revealed Preference (RP) and SP data.

- The logsum method might seem to be much more complicated than the rule-of-a-half, but in fact a major advantage of logsums is the ease of calculation. Particularly when several alternatives are changing, e.g. in a destination and time period choice when traffic is reassigned in response to a project, the rule-of-a-half calculations can get very complicated while the logsum ones are easy and need to be done anyway to get demand. The logsum method can also easily give results per population group (the conventional approach can do this as well, but this is often a lot of extra work).

An advantage of the conventional approach is that it is more transparent (but only in simple situations) and more intuitive and therefore easier to explain to non-experts. On the other hand, the transport models that produce the logsums are already common practice.

We believe the advantages of the logsum approach can outweigh the disadvantages, but we also think that further testing of the logsum method is required. We recommend testing the logsum approach for other schemes, especially for highway schemes (or a combined road and public transport scheme) where the purpose and income mix is likely to be more representative of the travelling population as a whole and where the substitution effects might be more important. The monetisation of logsum changes through external values of time (as in Method 1) does not seem attractive, because that would reintroduce the consistency problem. Therefore at this stage we would prefer to use the monetisation of the logsum with the expectation of (1/cost) (Method 2).

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