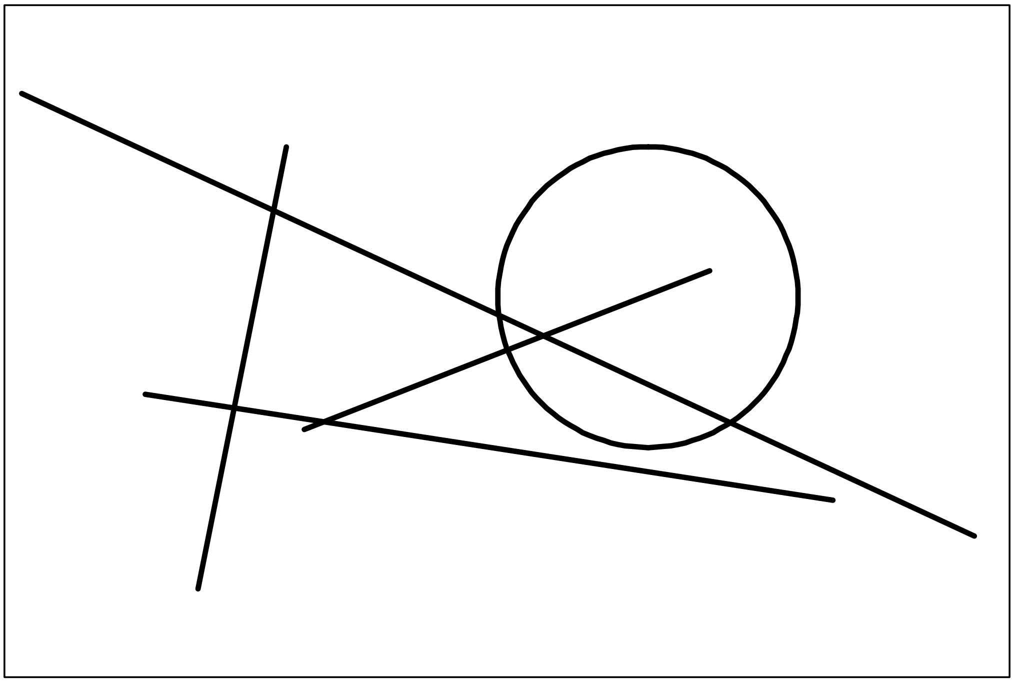

Using the logsum in project appraisal

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Abstract

In the appraisal of transport projects many countries use cost-benefit analysis in which the benefits to the travellers are calculated by combining the estimated time and cost gains from a transport model with values of time from some other source. For 'new' travellers (those who change mode or some other transport choice, as a result of the project), the rule-of-a-half is invoked. For situations where a Generalised Extreme Value (GEV) model (such as multinomial and nested logit) is used to produce the forecasts, an alternative approach to evaluation would be to use the change in the logsum, directly from the choice model. This approach was already published in the seventies and is more exact and more consistent and in some situations easier to apply. Nevertheless, little use has been made of logsums in the evaluation of transport projects. This may have to do with the fact that in many countries there is no national model system, or a consistent set of regional models, based on disaggregate random utility models. But is true that when trying to apply logsums in evaluation, a number of theoretical and practical issues emerge, especially with regards to monetisation, which have to be dealt with. This paper sets out to discuss these issues, focusing on a number of recent real-world applications of the logsum approach.

Keywords

Logsum, consumer surplus, logit model, project appraisal

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1. Introduction

1.1 Background

In the appraisal of transport projects many countries use cost-benefit analysis (CBA) in which the benefits to the travellers are calculated by combining the estimated time and cost gains from a transport model with values of time from some other source. For 'new' travellers (those who change mode or some other transport choice, as a result of the project), the rule-of-a-half is invoked, which equates the benefits for such a traveller to half of the benefits for an existing traveller. This provides an approximation of the change in consumer surplus that is caused by the project.

For situations where a Generalised Extreme Value (GEV) model (such as multinomial and nested logit) is used to produce the forecasts, an alternative approach to evaluation would be to use the change in the logsum. A person's consumer surplus is the utility, after conversion to money terms, that he or she 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 natural logarithm 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 sampling rates from the population. 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 with and without the project.

We think that replacing the current approach in project appraisal by the logsum approach would provide a number of advantages. The logsum change gives the change in the consumer surplus in a more exact way than the rule-of-a-half does (which is based on a linearisation). The logsum approach also removes an inconsistency in the evaluation procedure. The transport models have their own set of implied values of time. These are usually not consistent with the "standard" set of values of time used in the appraisal method (e.g. from stated preference studies). But when using logsums, we can avoid the use of external values of time. 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 choice alternatives are changing, e.g. in a destination and time period choice when traffic is redistributed 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 estimate travel demand. The logsum method can also easily give results broken down by population group (the conventional approach can do this as well, but this requires often a lot of extra work).

On the other hand, it is true that when trying to apply logsums in evaluation, a number of theoretical and practical issues emerge, especially with regards to monetisation, which have to be dealt with. This paper sets out to discuss these issues.

1.2 Contents of this paper

In this paper, we shall briefly review the theory on the use of the logsum in project appraisal (section 2). The focus will be on applications of the logsum approach, with examples from The Netherlands, the UK and an application at the European scale (sections 3-9). In section 10 a number of practical issues that emerge when applying the logsum in evaluation are discussed. Finally section 11 gives a summary and recommendations.

2. Short summary of the theoretical literature

2.1 An introduction to the logsum concept

In this section we provide an introduction to the concept of logsums. A more extensive introduction can be found in the textbooks on discrete choice models (e.g. Train, 2003).

The utility that decision maker *n* obtains from alternative *j* is decomposed into an observed and an unobserved (random) component:

$$U_{nj} = V_{nj} + \varepsilon_{nj} \qquad (1)$$

Where:

U_{nj} is the utility that decision maker *n* obtains from alternative *j* ($n = 1,..N$; $j = 1,\ldots,J$),
V_{nj} = "representative utility";
ε_{nj} captures the factors that affect utility, but are not observable by the researcher.

In a standard multinomial logit (MNL) model, with ε_{nj} i.i.d. extreme value with standard variance ($\pi^2/6$), the choice probabilities are given by:

$$P_{ni} = \frac{e^{V_{nj}}}{\sum_j e^{V_{nj}}} . \qquad (2)$$

The "logsum" now is the log of the denominator of this logit choice probability. It gives the expected utility from a choice (from a set of alternatives), and is also used to link different choices (as in nested logit models, e.g. of mode and destination choice). The logsum can also be used in project evaluation in an expression for the consumer benefits. This is explained below.

In the field of policy analysis, the researcher is mostly interested in measuring a change in consumer surplus that results from a particular policy. 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, provided that utility is linear in income, the consumer surplus (CS_n) can be calculated in money terms as:

$$CS_n = (1/\alpha_n)\, U_n = (1/\alpha_n)\, \max_j (U_{nj}\ \forall\ j) \qquad (3)$$

where
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 $1/\alpha_n = dY_n /dU_{nj}$.

If the model is MNL and utility is linear in income (that is α_n is constant with respect to income), then expected consumer surplus becomes:

$$E(CS_n)= (1/\alpha_n) \ln \left(\sum_{j=1}^{J} e^{V_{nj}} \right) + C \qquad (4)$$

where C is an unknown constant that represents the fact that the absolute value of utility can never be measured. Aside from the division and addition of constants, expected consumer surplus in a standard logit model is simply the logsum.

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):

$$\Delta E(CS_n) = (1/\alpha_n) \left[\ln \left(\sum_{j=1}^{J^1} e^{V^1_{nj}} \right) - \ln \left(\sum_{j=1}^{J^0} e^{V^0_{nj}} \right) \right] \qquad (5)$$

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 above equations for calculating the expected consumer surplus depend 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. 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.

2.2 The theoretical literature on the logsum an an evaluation measure

In the period up from the early 1970's to the early 1990's, appraisal analysts working within the Random Utility Model paradigm constrained themselves to models which did not allow for any effect of income on choice (except for car ownership models), 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. More detailed reviews of the theoretical literature on using the the logsum in project appraisal can be found in Bates (2003), Daly (2004) and RAND Europe (2005).

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 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). This was indeed the paper that made the breakthrough in understanding the linkage between choice models and user benefit measures. 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.

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.

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.

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, as discussed below, have almost exclusively been based on the simpler, earlier, models.

3. The applied literature on the logsum in evaluation

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). In the next sections a number of applications of the logsum in evaluation in The Netherlands, The UK and at the European scale will be discussed. Other recent applications are in the US (e.g. Castiglione *et al*., 2003 and Gupta *et al*., 2004) and in Scandinavia (e.g. Odeck *et al*., 2003 or the application of the Swedish SAMPERS model in the European POET project: POET, 2005).

4. The EXPEDITE model for Europe

The EXPEDITE project (EXPEDITE, 2002) was carried out for the European Commission. The starting point was the question how in forecasting and policy simulation at the European scale one can benefit from the detailed knowledge on transport behaviour and reactions to policy measures embodied in a number of existing national models. In other words: how can one extend this knowledge to a study area comprising the member states of the EU, Switzerland and Norway?

Within EXPEDITE, five national models were available for passenger transport (in the order in which they were originally developed):

- The Dutch National Model System (NMS or LMS);
- The Norwegian National Model (NTM-4);
- The Italian National Model (SISD);
- The Danish National Model;
- The Swedish National Model (SAMPERS).

In the first part of the EXPEDITE project, a large number of runs have been carried out (up to 80 runs per model) with each of the above-mentioned national models. To the maximum possible extent, the same runs were done with each of the models. For the base-year (1995), outcomes were generated in the form of ‘levels matrices’, giving the number of tours and kilometres per person per year by mode and distance band. Please note that these are not origin-destination matrices, but matrices with modes in the columns and distance bands in the rows. There are different levels matrices for five travel purposes and for hundreds of population segments. Besides levels matrices for 1995, the outcomes of the national model runs also consist of switching matrices: changes in the number of tours or in passenger kilometres (same units as the levels matrices), as a result of a change in a policy-related model input variable. There are switching matrices for changes in the running cost of the car, travel times by car, and for cost, in-vehicle time, wait and transfer time and access/egress time of train and bus/tram/metro. For each segment, the levels and switching matrices in tours and kilometres from all five national models were averaged (unweighted) to get the 'prototypical' matrices that are used in the meta-model to forecast for Europe. The model now calculates the impact of a policy by adding the relevant levels matrix T and switching matrix D^1 for policy 1: $T_{mdp} + D^1{}_{mdp}$. A method to calculate the impact of policy bundles (e.g. a combination of road pricing and investments in public transport), taking account of non-linear effects, was developed as well

The zoning system in the meta-model is the NUTS2 level. At this level there are around 250 zones. For each zone, expansion factors were calculated depending on the importance of the population segments in the zone (many of these weights could be zero for a specific zone) in 1995 and in future years. By multiplying the tours and passenger kilometres from the prototypical matrices with the 1995 expansion factors, initial predictions for each of the zones were derived, which were later adjusted to reflect aggregate local information .

This way, we can produce demand forecasts for Europe. These can be expressed as probabilities P_{mdp} with mode m, distance class d and segment p. The underlying utility functions are defined as follows:

$$U_{mdp} = \ln(P_{mdp}) + \ln(\sum e^{U_{mdp}}) \qquad (6)$$

The same can be done for the average utility of the shortest distance band for the non-motorised mode. The standardised utility for mode m, distance class d and segment p then becomes:

$$\text{Standardised } U_{mdp} = \ln(P_{mdp}) - \ln(P_{m=non\text{-}motorised,d=shortest,p}) \qquad (7)$$

Equation (7) is used to calculate the underlying utilities. Given that the starting point are the 'p's, i.e $e^U/\Sigma e^U$, a scale standardisation is needed to recover comparable logsums $\ln(\Sigma e^U)$ as between base and forecast/scenario. Since the forecasts/scenarios studied in EXPEDITE did not have pedestrian schemes or bike lanes, short distance non-motorised was chosen as base. What is effectively done here is that the underlying utility functions are calculated: the utility functions that are not specific to any one of the national models, but apply to EXPEDITE as a whole.

These underlying utility functions are used to calculate the change in the logsum, that is caused by a policy measure or bundle. This gives the change in consumer surplus, and can be segmented by population segment to analyse how different population segments are affected by a policy. Twenty-one different policies (and a reference 2020 situation) have been tested using the EXPEDITE meta-model. The logsum difference between the policy run and the reference run for 2020 was calculated. This difference needs to be attributed a monetary value. In a simple linear additive discrete choice model without income effects, this could be done by using the cost coefficient (by travel purpose). However, the EXPEDITE model does not contain cost coefficients (by travel purpose), but uses results from underlying national model runs (as described above), which contain different cost coefficients (sometimes in logarithmic form). As an approximation a car cost increase by 10% for the year 1995 (which is an amount of money that is known) has been used to establish conversion factors (implied average cost coefficients) for the logsum, with a distinction per travel purpose. Outcomes for the different policies can be found in EXPEDITE (2002) and de Jong et al. (2004).

5. Costs of queues in The Netherlands

In Koopmans and Kroes (2004) the costs of queues in the whole of the Netherlands are calculated using logsums as provided by the Dutch National Transport Model (LMS) for the year 2000. This is a disaggregate transport model that includes tour frequency, mode, destination and time of day choice, as well as equilibrium assignment for road transport.
The costs of queues are determined as follows:

1. Perform an LMS run for the year 2000 using free-flow travel times for cars, and determine the consumer surplus using the standard logsums output, expressed in travel time equivalent
2. Do the same thing but then using congested travel times at equilibrium
3. Determine the difference between the logsums obtained in 1. and 2.
4. Multiply the results of 3. by a value-of-time measure; in this case an average value-of-time of 9 Euro per hour has been used. The marginal utility of money was not used here to convert the outcomes into money units, because in the LMS costs appear in a logarithmic form. This formulation is used, because in estimation it outperformed other specifications and also led to plausible elasticities (see Gunn, 2001). It is also used in other transport models. A different method to deal with this issue is discussed in section 7.
5. Gross-up the average weekday results obtained in 4. by the number of working days per year to obtain a yearly total

6. Apply some corrections, e.g. to account for international traffic and freight traffic.

The results indicate that for the year 2000 the total congestion cost on the highway network amounts to 1.5 Billion Euro. This is substantially higher than the estimated costs using the more traditional method based upon “vehicle-hours lost” (VHL) as obtained from the assignment in the LMS: that method gave an estimate of 0.8 Billion Euro for 2000. This happens to be the same number that was estimated for the year 1997 using measurements of queues and queue-lengths by the Transport Research Centre (AVV). The VHL method only calculates the costs of delays of persons that are in the queues, using standard values of times. The additional costs will be the cost to travellers who are no longer in the queue but have adapted their mode, destination and departure choice behaviour to avoid the congestion in the peak periods. The authors hypothesise, based upon a simple linear demand model, that for increasing levels of congestion the ratio of the estimated costs by the logsum method relative to the VHL method will further increase.

The authors conclude that the order of magnitude of the results is plausible, and that the costs of queues according to the logsum approach are, conform their expectations, higher than those obtained using the more traditional VHL method using the same model.

6. A land-use/transport model for the Netherlands

A pre-study (RAND Europe, 2004) was carried out for the Transport Research Centre (AVV) to analyse the influence of accessibility on settlement behaviour of residents and firms (jobs). In the TIGRIS XL land-use model, location choice of firms and households is dependent, among other things, on accessibility (represented by means of logsums and travel times from the LMS, the Dutch National Transport Model). TIGRIS XL includes a choice whether or not to move and a choice of zone for the new location conditional on the decision to move.

In this study, the impact of four different factors on accessibility (measured using logsums and travel times) has been assessed:

1. The expected changes in accessibility as caused by autonomous developments and existing policies;
2. The influence of infrastructure developments;
3. The influence of congestion charging and transfer from fixed cost to variable cost;
4. The influence of alternative spatial developments (including labour following residential locations).

The logsum accessibility measures appear to be most sensitive to pricing policies and infrastructural changes. Spatial developments have little impact at the national level, but the impact can be important at local level. Travel time, which lacks the theoretical justification that the logsum measure has, is a more sensitive measure for accessibility than the logsum: the changes in travel time obtained from the model are significantly larger than those in the logsum. The logsum measure is sensitive to changes in travel time, but also to changes in cost, employment and population, which may have an effect that works against travel time. The direction of changes in logsums may be the same as those in travel times (e.g. due to infrastructure projects) but also the opposite (e.g. road pricing: here the impact is negative for the logsum measure, but positive for the travel time). In this project, the logsums were not converted to money units.

7. A high speed rail (or MAGLEV) project in The Netherlands

In this case study for AVV, results are compared from two different runs that were carried out with the Dutch National Model System LMS (RAND Europe, 2005):

- The reference situation 2020;
- 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), reflecting a high speed rail or MAGLEV network between Amsterdam, Roterdam The Hague and Utrecht.

The logsums and logsum differences between project and reference situation 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).

In a model with linear costs, division by the cost coefficients would have been sufficient for conversion to money units. But the LMS mode-destination choice models have logarithmic costs. Two different methods were applied for the conversion to money (this is discussed in more detail in section 10)

- 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. This method was also used in section 5.

- Divide the logsums by the product of the LMS cost coefficients and the expected value of (1/cost) per tour (separate for each income class and purpose, but averaged over all relevant origin-destination-mode combinations).

In Table 1 are the outcomes for traveller benefits both of the conventional approach of monetising time benefits using standard external values of time and applying the rule-of-a-half (RoH) for new train passengers, and of the logsum approach. The conventional results vary considerably between 24 mln euro in 2020 ands 58 mln, depending on whether one includes only the train in-vehicle-time benefits, or 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.

Table 1 Traveller benefits (project minus reference) for the full year 2020 in millions of 2003 Euros

Method	**Traveller benefits**
Conventional method (external VoTs, RoH)	24-58
Logsum approach	44-56

The outcomes for the logsum approach are also shown in Table 1 above. The outcomes are in the same range for both methods of monetising the logsum (44-51 mln for the first method and 56 mln for the second). Differences between these methods 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 important categories for train travel), the SP values of time are lower than those implied by the LMS.

The outcomes for the logsum approach are at least as high as those using the in conventional method. The conventional method does not include all traveller benefits. The logsums take into account the changes in all components of the utility functions: in-vehicle time, access/egress times, but also wait time.

8. Air travel demand analysis

This case study was carried out in 2005 and 2006 for the Dutch Ministry of Transport using the ACCM model (SEO and RAND Europe, 2005). ACCM stands for Airport Catchment Area and Competition Model. The ACCM is a passenger choice model of the logit family (see Figure 1), linked to a heuristic airline choice model (see Figure 2). Both models are applied in an iterative procedure, see Figure 3 below, to take account of capacity limits that may be exceeded (hourly runway capacity and total noise capacity). First (step 1) the passenger choice model is applied to provide an initial, unrestricted demand forecast. Then (step 2) the airline choice model is applied, to convert the passenger volumes into aircraft movements, and to compute the critical impacts: use of runway capacity and noise volume. The next step (step 3) is a check to see whether or not any of the capacity limits is exceeded. If yes, then a shadow or scarcity cost is added to the relevant choice alternatives and steps 1, 2 and 3 are repeated. If not, the iterative procedure is stopped and the model outputs the results.

Figure 1 Structure of the passenger choice model

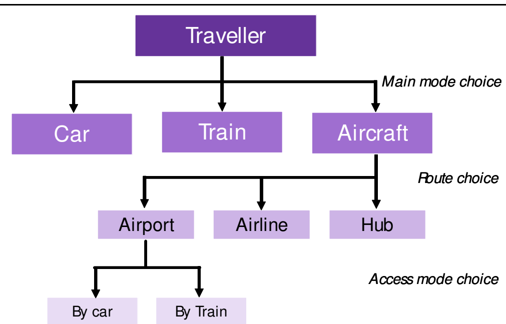


Figure 2 Structure of the airline choice model

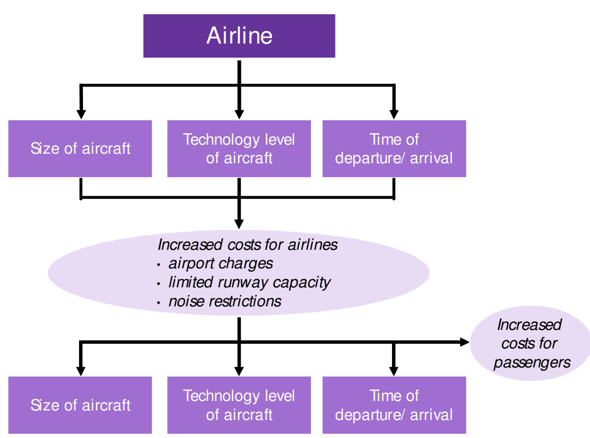
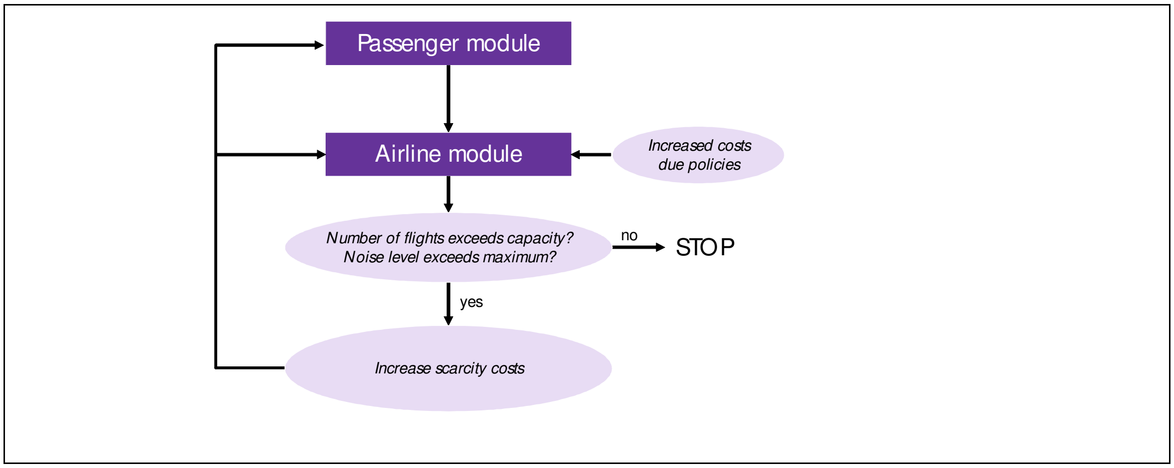


Figure 3 Overall structure of ACCM



The ACCM model produces a very large number of detailed outputs such as annual passenger volumes and aircraft movements, but also changes in consumer surplus computed using the logsums within the passenger choice model. The model is capable of simulating a wide range of scenario's and policy measures. In the Schiphol capacity study four macro-economic and technological scenarios were simulated, for horizons 2020 and 2040, and fourteen policies were evaluated in addition to a "continuation of existing policy" alternative which was used as the reference case for each scenario.

Scenarios:

- Global economy: high growth and important hub function;
- Strong Europe: low growth and important hub function;
- Transatlantic markets: high growth and limited hub function;
- Regional communities: low growth and limited hub function.

Policy measures:

- System of slot trading replacing the existing slot allocation mechanism;
- Charge-per-aircraft scheme;
- Charge-per-aircraft scheme;
- Charge-per-passenger scheme;
- Charge-per-passenger scheme;
- Charge-per-passenger scheme;
- Charge-per-passenger scheme;
- General charges;
- General charges;
- Extra night flight restrictions;

- Outplacement of low-cost flights to other airport;
- Elimination of noise limit;
- Additional runway;
- Stricter noise limit.

The results of the simulations, in terms of changes in consumer surplus for each of the scenarios and all fourteen measures, are given in Table 2. The results are in millions of euros per year for travellers with a Dutch nationality, and all measures are evaluated relative to the reference case (reference = forecast for continuation of existing policy or "do nothing"). The following observations can be made:

- Replacing the existing slot allocation mechanism by a slot trading system with incentives for airlines to use modern low-noise aircraft technology, would have substantial positive consumer surplus effects in the high-growth scenarios;
- Measures applying a charge per aircraft would have similar effects, but to a smaller extent. Also there would be negative consumer surplus effects in the low growth scenarios;
- Measures applying a charge per passenger would, as expected, have a negative effect on consumer surplus, in all scenarios except a transfer passengers only charge which would generate benefits for the high-growth scenarios;
- General charges such as the application of VAT or fuel taxation would have strong negative effects for the Dutch consumers in all scenarios;
- The elimination of noise limits, additional night flight restrictions and outplacement of low-cost flights to another airport would have positive effects in the high growth scenarios, and little effect in the low growth scenarios;
- Building additional runway capacity would provide little benefit to the consumers; the application of stricter noise limits, however, would have strong negative effects for the high growth scenarios.

These results serve to illustrate how changes in consumer surplus, computed using the logsum approach, can be helpful in assessing the impacts of different transport policies on the passengers.

Table 2 Consumer surplus for Dutch travellers for a range of policy measures (relative to do-nothing policy), in millions of Euros

	Global Economy	Strong Europe	Transatlantic Markets	Regional Communities
Slot distribution				
1 Slottrading	167	3	171	10
Charge-per-aircraft scheme				
2 depending on aircraft technology class	86	8	106	-26
3 depending on time-of-day departure	91	-23	132	-45
Charge-per-passenger scheme				
4 OD passengers	-66	-84	-45	-103
5 non-Skyteam passenger	-43	-69	-25	-85
6 low-cost passenger	-113	-219	-77	-223
7 transfer passenger	83	11	61	-8
General charges				
8 V.A.T.	-717	-748	-623	-565
9 fuel tax	-723	-731	-641	-699
Other				
10 extra night restrictions	143	-86	96	-52
11 new low-cost airport	190	22	184	-3
12 no noise limit	214	0	185	0
13 extra runway	-21	26	-10	0
14 stricter noise limit	-275	0	-250	0

9. Isles of Scilly travel demand study

The isles of Scilly are a group of islands located 45 kilometres off the coast of Cornwall (south west England). At present there are three commercial services operating between the isles and the main land: a sea ferry, a helicopter service and a fixed-wing aircraft. The ferry boat is nearing the end of its operational life and the sea ferry service might be discontinued after 2014. In the travel demand study (RAND Europe, Accent Marketing and Research and ITS Leeds, 2006; Kouwenhoven *et al*., 2006) for Cornwall County Council three options were compared:

- Do minimum: no ferry services after 2014;
- Do something ½: new modern ferry at 15 knots, minor harbour improvements;
- Do something ¾: new modern ferry at 20 knots, minor harbour improvements.

New revealed and stated preference information was obtained from residents and current visitors. This included several mode choice experiments and stated intentions questions on travel frequency. Discrete choice models for mode and frequency choice were estimated on the combined SP and RP material. The estimated models in turn were used to calculate exact consumer surplus changes in the form of logsum differences between runs for different scenarios for use in costs/benefit analysis.

The standard approach for cost/benefit analysis for infrastructure projects in the UK uses the rule-of-a-half (RoH). However the RoH breaks down if a new mode is introduced or an existing mode becomes redundant (as in the Do Minimum scenario here). The logsum approach can still be used. Moreover, whereas a RoH application would include the generalised costs components crossing time, fares and out of pocket costs (e.g. overnight accommodation), the user benefits from the logsum approach also include benefits associated with differences in timetables and quality benefits (of ferry and harbours).

For the conversion to money units, the model costs coefficients by demand segment (including a distinction by two income groups) were used. Costs were not in logarithms, so the approximations that had to be used in monetising the logsum in applications of the LMS for The Netherlands (see section 7) were not required here. Except for staying visitors, the logsum includes a not only a mode response, but also a frequency response (see Daly and Miller, 2006). Furthermore it also includes a shadow price (negative utility term) for situations where demand for ferry travel will exceed capacity

10. Practical issues

When trying to apply logsums in the evaluation of real-world projects and policies, a number of theoretical and practical issues emerge, which have to be dealt with. Most issues that emerge in these applications (also see Kohli and Daly, 2006) concern the treatment of a non-constant marginal utility of income:

- Transport models with logarithmic cost variables, including the treatment of trips with zero costs (e.g. walking, students with free public transport);
- Non-linear transformations in general;
- Use of mode-specific and origin-specific costs coefficients;
- Models with random cost coefficients;
- Incorporation of income effects.

Some transport models use linear costs. The logsum applications that we have seen in practice then take the logsum change (in utility terms) and divide by the cost coefficient, for conversion to money units. This is done by segment, usually by travel purpose (for which the costs coefficients tend to be different), sometimes also by income group. In the latter case (with different costs coefficients for different income classes), one does not have to assume constant marginal utility of income over the entire income range, but only within each income class.

Some other transport models have non-linear costs. In this case equation (4) has to be generalised because α_n is no longer constant and instead we must use the expected value of dU_{nj}/dY_n. A reasonable approximation of the expected marginal utility of income to traveller n can then be obtained by calculating dU_{nj}/dY_n at the average value of U and weighting across the alternatives j in proportion to their choice probabilities.

For example, in the LMS (Dutch national model system), the costs enter in logarithmic form in the mode-destination choice models. The cost coefficients in the LMS are the same for all modes (but differ between purposes and income groups), but apply to logarithmic cost.

Two methods were used in the LMS logsum applications for monetisation: a method that uses the external values of time and a method that uses the expectation of 1/costs. Below these methods are described formally (for a given purpose and person type):

We have utility functions of the form:

$$U = \beta \ln[C] + \chi T + \ldots \qquad (8)$$

in which:

C is cost in 1995 guilders (the model still uses Dutch guilders, 1 guilder is approximately € 0.45)
T is time in minutes

β: 1 guilder is β utils, or 1 util is $1/\beta$ guilders

χ: 1 minute is χ utils, or 1 util is $1/\chi$ minutes

We also define:
LS = logsum value in utils

The logsums and logsum differences between project and reference situation 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).

Now the two methods work as follows:

External values of time method:

LS/χ = logsum in minutes (9)

Logsum in guilders[1] $= (LS/\chi).VoT$ (10)

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

Expectation method:

The starting point is the consumer surplus equation (3). For a population which chooses j with probability p_j the average marginal utility then is:

$$A = \Sigma\, p_j\, dU_{nj}/ dY_n \quad (11)$$

in which:

A: average marginal utility

Now:

$$dU_{nj}/dY_n = -dU_{nj}/dC_n \quad (12)$$

in which:

C_n: the price of travel by alternative j

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[1] 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).

Therefore we obtain:

$$E(\partial U/\partial C) = [-A = -\Sigma\, p_j\, dU_{n\,j}/dY_n =]\ \Sigma\, p_j\, dU_{n\,j}/dC_n = \Sigma\, p_j\, \beta/C_j \qquad (13)$$

This calculation (13) needs to be made over all alternatives but the problems arise when the cost is zero (intrazonal) or non-existent (slow modes and car passenger).

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. An additional 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 the conversion to money in expectation method, 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, 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.[2]

In principle, instead of the cost of each alternative entering the utility function one would expect to have (income - cost) appearing. If (income - cost) appears linearly, then the income component represents a constant across all the alternatives and effectively 'falls out' of the choice problem: the model has no 'income effect'. However, the (income - cost) term, indicating the utility of budget available to spend on other things than the travel alternatives, ought in any case to appear in the same function in all the alternatives. That is if cost appears linearly, it ought to have the same coefficient in all the alternatives, and if (income - cost) appears in a non-linear function, that function should be the same in all the alternatives. In fact, the calculations of dU_{nj}/dY_n can be made anyway but the theoretical problems associated with such models should be noted.

The use of random coefficients in discrete choice models is becoming more widespread and often these apply to the cost term. The models are usually calculated by a Monte Carlo sampling procedure. In this case, the application of equation (4) should be done separately for each random draw, i.e. the same cost coefficient is used for the monetisation as is used in the calculation of the logsum.

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[2] 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).

Some transport models, especially some activity-based models, use Monte Carlo simulation to determine a discrete choice for each individual traveller instead of calculating the probabilities for each alternative that is available to a traveller and adding these up (sample enumeration). This can reduce the computational burden in a transport model, but it no choice probabilities are produced, then the model cannot produce (exact) logsums for evaluation either.

11. Summary and recommendations

11.1 Discussion of main findings

The method used in many countries 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. Time gains are converted to money units using standard values of time, which differ from the values of time incorporated in or implied by the transport models used in the demand analysis. This procedure has a basis in welfare analysis. In this paper, an alternative approach was investigated: instead of consumer surplus in terms of generalised 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.

11.2 Recommendations

We think that replacing this approach by the logsum approach would provide a number of advantages:

- When using logit models, as in applications of the Dutch national transport model LMS, the logsum change gives the change in the consumer surplus, and in a more exact way than the rule-of-a-half does, since this is based on a linearisation.
- At present there is an inconsistency in the evaluation procedure: for calculating the changes in travel demand, the transport model 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 (e.g. from Stated Preference surveys, SP). When using logsums we can avoid the use of external values of time. On the other hand, the SP studies might contain information that the transport model 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).
- The rule-of-a-half cannot deal with situations in which the number of choice alternatives

changes (e.g. when a new mode is introduced or removed), whereas the logsum approach can.

- The logsum change gives the changes in all variables that affect utility of travelers (depending on the choice model, but this could be based on SP data and include variables such as comfort and reliability), whereas the conventional approaches usually only include (in-vehicle) travel time and out-of-pocket travel cost.

The logsum approach also has some disadvantages. 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. Furthermore a number of practical difficulties arise when trying to use the logsum in evaluating projects, especially when the transport model has transport costs in logarithms. There are equally practical ways to solve these problems, but these do subtract from the theoretical rigour of the logsum
All in all, we believe the advantages of the logsum approach are likely to outweigh the disadvantages, but we also think that further testing of the logsum method is required, especially on the consequences of the practical solutions discussed in this paper to calculate and monetise logsum differences for actual transport projects using existing transport models

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