Accessibility appraisal of land-use/transport policy strategies: more than just adding up travel-time savings

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Abstract.
We examine the accessibility benefits associated with some land-use policy strategies for the Netherlands that that anticipate to a greater or lesser degree on expected climate changes. A disaggregate logsum accessibility measure using the Dutch national land-use/transport interaction model TIGRIS XL is used to compute changes in consumer surplus. The measure provides an elegant and convenient solution to measure the full accessibility benefits from land-use and/or transport policies, when discrete choice travel demand models are available that already produce logsums. It accounts for both changes in generalised transport costs and changes in destination utility, and is thus capable of providing the accessibility benefits from changes in the distribution of activities, due to transport or land-use policies. The case study shows that logsum accessibility benefits from land-use policy strategies can be quite large compared to investment programmes for road and public transport infrastructure, largely due to changes in trip production and destination utility, which are not measured in the standard rule-of-half benefit measure.

KEY WORDS: Logsum accessibility benefits, land-use policies, travel time-savings

1. Introduction

Several studies have examined integrated land-use and transport policy strategies as a way to mitigate the transportation sector's contribution to climate change (Hensher, 2008). Far less attention has been paid to the adaptations to climate changes that are already occurring and will continue to occur into the foreseeable future. Some studies have examined the land-use effects of climate-change adaptation strategies (Koomen et al., 2008), but the transport consequences have so far received little attention. We examine the transport and accessibility impacts of some land-use policy strategies for

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the Netherlands that anticipate to a greater or lesser degree on expected climate changes, for example, limiting urbanization to the existing built-up areas, areas with low chances of flooding, or shifting investment to areas above sea level.

Conventional approaches to accessibility measurement are not ideal for land-use policy appraisal. Conventional approaches to accessibility measurement are often based on ‘stand-alone’ transport models, and their outputs, such as travel times or costs, are used as input in the rule-of-half (RoH) measure of consumer surplus typically applied in transport project appraisals. This approach is problematic for our study purpose for two reasons. First, using a pure transport model instead of an integrated land-use/transport model implies that important interactions between land-use and transport developments are ignored. This is not only important for land-use policies; transport policies may have an impact on land use, which in turn will lead to additional costs or benefits from the transport policy. Secondly, several studies argue that the RoH measure of consumer surplus does not correctly measure welfare effects when land uses change as the result of a land-use and/or transport policy strategy. This is because the measure assumes that all benefits accruing to economic agents can be attributed to generalised cost changes. This implies that disbenefits from changes in the attractiveness of locations resulting from land-use policies, will be missing.

This paper has two objectives. The first, and primary objective, is to provide an in-depth analysis of accessibility benefit measurements using the logsum. In this paper we argue that the logsum is capable of computing the full accessibility benefits consisting of both changes in (generalised) transport costs and land-use changes resulting from transport or land-use policies. In this paper, the logsum is computed using an integrated national land-use/transport model for the Netherlands, which also allows us to examine the effect of land-use changes resulting from transport investments on the logsum accessibility benefit computations. The second objective is to show the added value of the logsum benefit calculations over conventional RoH benefit calculations. For this purpose, we give a theoretical comparison between the RoH and logsum benefit measures, and compare detailed RoH benefit calculations with the logsum benefit calculations in a case study, using the same land-use/transport transport model.

The remainder of the paper is structured as follows. In Section 2, the paper first discusses accessibility measures, describing the theoretical basis and applications in practice for the logsum accessibility measure. Furthermore, in this section, a theoretical comparison is made between the RoH measure and logsum measures. The TIGRIS XL land-use/transport modelling framework, that has been applied to calculate the accessibility effects of integrated land-use and transport strategies, is presented in Section 3. In Section 4, the paper describes the application of the logsum accessibility measure within a large-scale land-use/transport policy evaluation study for the Netherlands. Finally, Section 5 contains the conclusions and discussion.

2. Accessibility measures in economic appraisal

In the Dutch CBA appraisal guidelines (OEI) and guidelines in other countries, such as the New Approach To Appraisal (NATA) in the UK, economic benefits from transport investments are classified in direct and wider, or indirect, benefits. With the assumption of perfect competition in all sectors of the economy using transport, the transportation consumers' surplus summarises the welfare effects of transport changes for consumers and producers; all effects are captured by the direct benefits; additional wider or indirect benefits do not exist. In reality, many market imperfections exist and, for a few of these market imperfections, calculation methods are available to calculate the wider benefits[1].

The rule-of-half as a welfare measure

The conventional approach to measure accessibility benefits of transport strategies is to use the rule-of-half measure. This computes the change in user benefits as the sum of the full benefit obtained by original travellers and half the benefit obtained by new travellers. This can be calculated by multiplying the average number of trips between a base scenario (zero) and a scenario with a project (unity) by the difference in generalized travel costs:

$$\Delta\, E(\mathrm{CS}_n^{\mathrm{ROH}}) = -0.5 \sum_{z=1}^{Z} \sum_{j=1}^{J} (\mathrm{GC}_{zj}^{1}-\mathrm{GC}_{zj}^{0})\,(\mathrm{A}_{zj}^{1}+\mathrm{A}_{zj}^{0}) \qquad (1)$$

where: GC is generalised cost; z is origin (z=1, …, Z); j is transport mode/destination alternative (j=1,…,J) and A is number of trips.

The main advantage of the measure is that it is transparent, fairly intuitive and relatively easy to explain to non-experts. Rule-of-a-half calculations can, however, get complicated when taking into account all the changes in travel behaviour resulting from a transport project, for instance, changes in route choice, time of day, destination and/or modes of transport.

To use it as a practical approximation of consumer surplus, a number of assumptions are made that do not generally hold. First, the rule-of-half effectively assumes a linear demand function. This is satisfactory for the levels of change normally brought about by new infrastructure projects. The RoH can be shown to give a good approximation of consumer surplus when the change in generalised cost can be regarded as marginal (Bates, 2006). However, for measures which can result in large changes in demand, such as some traffic reduction measures, the rule-of-half can lead to significant errors (SACTRA, 1999).

Secondly, the rule-of-half assumes that all accessibility benefits accruing to economic agents are attributable to generalised cost changes within the transport system. This is a convenient argument with a practical outcome, since it is easier to identify and estimate the benefits/disbenefits accruing directly to travellers rather than search for their more

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[1] For a discussion on how to estimate the wider or indirect benefits in practice, reference can be made to the guidelines of the UK Department for Transport (2005) and in Zondag and De Jong (2005). Our discussion is limited to the methods for calculating the direct benefits from changes in accessibility, within the transport market; in the Netherlands and the UK, the rule-of-half measure is used to measure the direct benefits from transport measures.

elusive manifestations further along the chains of reaction in other markets. This assumption becomes problematic when land-use changes are to be taken into account.

The logsum as welfare measure

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

$$U_{nj} = V_{nj} + \varepsilon_{nj} \qquad (2)$$

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

In a standard multinomial logit (MNL) model, the choice probabilities are given by:

$$P_{nj} = \frac{e^{V_{nj}}}{\sum_j e^{V_{nj}}}\,. \qquad (3)$$

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. It is defined as the integral with respect to the utility of an alternative, and provides an exact measure of transport user benefits, assuming the marginal value of money is constant.

In the field of policy analysis, the main interest is in measuring a change in consumer surplus that results from a particular action. By definition, a person's consumer surplus is the utility in money terms that a person receives in the choice situation taking account of the disutility of travel time and costs. 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:

$$CS_n = (1/\alpha_n)\, U_n = (1/\alpha_n)\, \max_j (U_{nj}\ \forall\ j) \qquad (4)$$

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 and U_n the overall utility for the person n. The division by α_n in the consumer surplus formula, translates utility into money units beacuse $1/\alpha_n = dY_n\ /dU_{nj}$.

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

$$E(CS_n)= (1/\alpha_n) \ln \left(\sum_{j=1}^{J} e^{V_{nj}}\right) + C \qquad (5)$$

where C is an unknown constant that represents the fact that the absolute value of utility cannot 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 sub-population of people who have the same representative utility 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 utility as the sampled person.

The change in consumer surplus for decision maker n is calculated as the difference between $E(\mathrm{CS}_n)$ under the conditions before the change and after the change (e.g. introduction of policy):

$$\Delta\, E(\mathrm{CS}_n) = (1/\alpha_n)\ [\ \ln\left(\sum_{j=1}^{J^1} e^{V^1{}_{nj}}\right) - \ln\left(\sum_{j=1}^{J0} e^{V0_{nj}}\right)] \tag{6}$$

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

Since the unknown constant C appears in the expected consumer surplus, before and after change, it drops out in calculating changes in the surplus. However, to calculate this change, we must estimated the marginal utility of 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 (McFadden, 1981). The 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 policies that change the consumer surplus by small amounts per person, relative to their income, the formula can be used even though the marginal utility of income varies with income.

The logsum benefit measure (Equation 6) provides a more accurate benefit estimates of transport projects than the rule-of-half benefit measure (Equation 1). When land use is fixed, an approximation based on the rule-of-half will in practice only slightly differ from the exact logsum measure computed at the same level of aggregation. This is, however, not the case when land use is forecasted to change.

De Jong et al. (2007) conclude that although the theory on the use of the logsum change as a measure of consumer surplus change was published in the late seventies and early eighties, the application in practical transport projects appraisal has been fairly limited. Applications in evaluation can be found in the US (Gupta et al., 2006), Scandinavia and the Netherlands. Most applications use one or more cost coefficients (e.g. by household income category) to obtain outcomes in monetary terms. However, some convert the utility change to time in minutes.

There are few applications of the logsum method in transport appraisal, but even less in the measurement of accessibility and welfare changes in land-use policy appraisal. In many operational integrated land-use/transport interaction models (e.g., TIGRIS XL) or land-use models ‘connected’ to stand-alone transport models (Urbansim - Waddell et al., 2007), logsum values are taken from the logit models used in the travel-demand model, as input to the land-use model, for example, as variables in residential and/or business location choice models. Surprisingly, however, these logsum values are seldom converted to monetary terms and used as an evaluation measure in land-use policy appraisal. Niemeier (1997) presented one of the very few applications in the academic literature, so far. She examined consumer welfare changes of land use and transport by constructing a series of hypothetical policy scenarios (elimination of travel destinations or transport modes). Logsum accessibility changes were taken from a transport mode/destination logit model for home-to-work trips in Washington State. Another example is Srour and Kockelman (2001) who used logsum measures of accessibility as explanatory variables in hedonic models to assess the importance of accessibility on land and property values and location choices. They concluded that location accessibility is as a major explanatory variable for property-valuation and residential location modeling.

Accessibility benefit measurement and land use changes

In general, accessibility may change as a result of either a transport (generalised cost) change or a land-use change. The rule-of-half measure, however, only estimates benefits for the origin-destination combinations where (generalised) costs change (Geurs et al., 2006). The rule-of-half is commensurate with the assumption that the benefit of switching between alternatives is related only to the (generalised) cost changes associated with the alternatives, and can ignore the underlying attractiveness of the alternatives, since this does not change (Bates, 2006). Hence, the measure does not account for changes in the relative attractiveness of locations due to land-use changes and related changes in trip distribution taking place for reasons other than transport cost changes. Neuburger (1971) illustrates this as follows. It is quite possible for the introduction of a new facility to attract trips to a further destination, so that average trip time and cost will increase and more trips will take place. A RoH measure would in this example show that the user benefit was negative, which is clearly absurd. In this case, the rule-of-half method would give misleading results. The RoH fails to take account of benefits from changes in the attractiveness of destinations while allowing these changes to affect demand. In other words: there is no direct association between benefits and trips.

Some efforts have been made to measure user benefits accounting for land-use changes. These have been examined within the framework of the doubly-constrained entropy models and logit choice models. Martínez and Araya (2000) derive user benefit measures for the doubly-constrained entropy model that provide a direct association between benefits and trips. Martínez and Araya derive ‘short-run’ and ‘long-run’ user benefit measures. The long-run user benefit measure contains terms to measure benefits accruing from a change in generalised transport costs between all transport zones, zone attractiveness and trip generation. The short-run measure assumes that trip origins and destinations are constant and is valid only in the short term when land uses do not change. Geurs et al. applied this evaluation framework in a case study for the Netherlands to estimate accessibility benefits of integrated land-use/transport scenarios. Martínez and Araya’s evaluation framework shows equivalence with our approach. The major differences between both approaches are the transport demand modelling framework and level of detail of estimation. Martinez and Araya’s benefit measures are derived for the aggregate doubly-constrained spatial interaction model, we examine detailed logsum benefit measures for disaggregate logit choice models. Although Anas (1983) showed that doubly-constrained entropy models and logit choice models produce identical results when estimated at the same level of aggregation, a rigorous relationship between the transport user benefit measure within the entropy framework and the logsum benefit measure within random utility theory has, according to Martínez and Araya, not been established so far. This is also beyond the scope of this paper.

Bates (2006) states that the RoH benefit calculation based only on generalised cost is only valid when land-use is constant. For the case where land-use changes, he proposes to transform the destination utility into units of generalised transport costs and include these in a RoH calculation, which can be added to the RoH calculation on the generalised transport costs themselves. This approach requires a utility model as well and has much in common with the logsum approach. Compared to our approach disadvantages are that the production effects are not included and that a linear demand curve as assumed for the RoH method is used instead of the estimated demand curve in the transport model as used in the logsum method.

3. Using TIGRIS XL to evaluate land-use and transport policies

Overview of TIGRIS XL

Land-use and transport policies both affect the accessibility for firms and residents. A land-use and transport interaction model is capable of calculating accessibility changes, resulting from land-use and transport strategies. This includes the mutual interactions between land use and transport, over time, and the outcome is different from the sum of the two measures evaluated individually. Here, the changes in accessibility are calculated by the TIGRIS XL model; an integrated land-use and transport model that has been developed for the Transport Research Centre in the Netherlands (RAND Europe, 2006; Zondag, 2007).

The TIGRIS XL model is a system of sub-models that includes dynamic interactions between them. Its land-use model uses time steps of one year, which enables the user to analyse how the land use evolves over time. The land-use model is fully integrated with the National Transport Model (LMS) of the Netherlands, and both the land-use and the transport model interact every five years.

TIGRIS XL is a linkage module model and it consists of five modules addressing specific markets. Figure 1 presents an overview of the model and the main relationships between the modules. TIGRIS XL operates at the spatial resolution of local-transport zones (1308 zones, covering the Netherlands).

Core modules in TIGRIS XL are the housing-market and labour-market module; these modules include the effect of changes in the transport system on residential or firm-location behaviour and in this way, link changes in the transport system to changes in land use. The parameters for both modules have been statistically estimated. The residential location choice module has been estimated by household type on a large four-annual housing market survey in the Netherlands with over 100,000 households[2]. The parameters of the firm (simulated as jobs) location choice module have been estimated on a historical data set (1986 – 2000), including employment figures by seven economic sector at a local level.

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[2] The different disaggregate data sets used (e.g. the national travel survey OVG for the LMS and the housing-market survey for the residential location model) are not linked at the disaggregate level, nor are the models. Consequently, there may be unobserved correlation across the different sub-models, which may affect the results.

A land and real-estate module simulates supply constraints arising from the amount of available land, land-use policies and construction. The module can be used for different levels of government influence, ranging from completely regulated to a free market, and various feedback loops between demand and supply are available. A demographic module is included to simulate demographic developments at the local level. At the regional or national level, the model output is consistent with existing socio-economic forecasts.

The *transport* module calculates the changes in transport demand and accessibility. The TIGRIS XL model is integrated with the National Transport Model (LMS). The LMS consists of a set of discrete choice models for various choices in transport (including tour frequency, transport mode, destination and departure time). These choice models can be based on the micro-economic utility theory, enabling the derivation of utility-based accessibility measures. TIGRIS XL calculates a wide range of accessibility indicators, ranging from 'infrastructure-based' accessibility measures (e.g., travel times, vehicle hours lost in congestion), 'location-based' accessibility measures (e.g., number of jobs or other opportunities which can be reached within 45 minutes by car or public transport), to 'utility-based' accessibility measures (logsum accessibility measure). This paper focuses on the logsum measure of accessibility.

The logsum measure using TIGRIS XL

The logsums in the TIGRIS XL model are derived from the National Transport Model (LMS). These logsums are computed for tours (round trips) at the individual level, and express a traveller's utility from a choice set of travel alternatives. This choice set contains five different transport modes (car driver, car passenger, train, bus/tram/metro, walking/cycling) to all 1,308 possible destinations. The model application does not use a sampling of alternatives from this choice set, but includes all available alternatives. For each origin zone *z* in the TIGRIS XL model, the logsum is computed from the travel alternatives to all destinations and transport-mode combinations *j* for each person type *i* (490 person types segmented to 5 household income classes), 2 gender classes, and 49 age classes, and travel purpose *p*:

$$L_{piz} = \log\left(\sum_{j} \exp\left(\mu_p V_{pijz}\right)\right) \qquad (7) \text{ where:}$$

μ_p: is the logsum coefficient for travel purpose p (this coefficient appears here, because we are using a nested logit model for each travel purpose)

V, the representative utility (the deterministic or observed utility component) in the transport-mode/destination choice models of the LMS in a simplified form can be specified as[3]

$$V_{zijp} = \beta_p T_{zj} + \chi_{ph} \ln(C_{zj}) + \delta_p D_{pj} + \ldots \qquad (8)$$

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[3] Transport-mode/destination choice models in the National Transport Model are nested logit models (for some purposes travel mode choice comes above destination choice in a decision tree, for other purposes it is the other way around) and these have many explanatory variables. Here, we present a somewhat simplified form for ease of understanding. In case of nested logit models, the logsum concept also applies (there are logsum-like measures of consumer surplus for all members of the Generalised Extreme Value family), but within the exponentiated utilities that are summed in the logsum, there are additional logsum coefficients (μ_p in equation 7).

where T is travel time (comprising various components with their own coefficients), C the travel cost, and D a variable representing the attractiveness of the destination zone (destination utility) for a specific activity (e.g. population, employment, shopping, number of students at schools and universities). The cost coefficients χ differ between travel purposes, but also between income groups h per travel purpose. The cost variable enters in logarithmic form, reflecting cost damping with increasing travel distances (Daly, 2008). Standard applications of the rule-of-half include changes in T and C (together forming generalised travel costs), but not in D from equation 8. It is, however, not inconceivable to also include changes in D in the rule-of-half, but this can be done more easily by using logsum changes.

Equation 7 has logsums expressed in utils, and these need to be translated into monetary terms. Because the costs are in logarithmic form, we cannot simply use the cost coefficients by income category as marginal utility of income (use the χs for the αs). In De Jong et al. (2007), a method is described to derive approximate marginal utility of income from the coefficients for logarithmic cost, which does not require external values of time[4]. In this application for a national policy document, however, it was important to use the officially recommended values of time (even though these are not fully consistent with the values of time implied by the LMS). First, the logsums are translated into travel times by the time coefficients β_p and next into costs by external values of time, *VoT*. The travel-time coefficients are purpose specific and are available from the LMS. The values of time VoT_{ph} per travel purpose *p* and household income category *h*, in equation (8) come from Stated Preference research, and are the officially recommend values for transport appraisal in the Netherlands. The monetary value of the accessibility of zone *z* for a person of type *i*, that belongs to household income group *h*, is, thus, computed as (with β_p being in time units):

$$CS^{L}_{piz} = VoT_{ph} \cdot \frac{1}{\beta_p} \cdot L_{piz} \qquad (9)$$

This term does not represent the absolute value of utility, for it does not include constant *C*, see equation 4. By definition, this constant is unknown and can not be measured.

The logsum is defined for a specific choice situation, often for a representative consumer. Here, the choice situation is a tour (a round trip). The monetary value of accessibility in equation 9 represents the accessibility value for a tour. For accessibility evaluation, the accessibility benefits are computed over all actors in the transport model, by multiplying the accessibility value by the number of people A_{piz} in that population segment i that make a tour for that purpose p from that zone z (or more exactly: the number of tours in this population segment for this purpose from this origin).

$$\Delta\, E(\mathrm{CS}_{\mathrm{piz}}) = (1/\alpha_{\mathrm{n}})\ [\ A^{1}_{piz} \ln\,(\textstyle\sum_{j=1}^{J^1} e^{V^1{}_{nj}}\ ) - \mathrm{A}^{\,0}_{piz} \ln\,(\textstyle\sum_{j=1}^{J\,0} e^{V\,0_{\,nj}}\ )] \qquad (10)$$

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[4] Because of the presence of logarithmic costs and cost coefficients by income group in the LMS, the model includes income effect. Logsums calculated by using different cost coefficients per income group (a spline function) can approximate income effect (Morey et al., 2003; Daly et al, 2008).

Where the superscript 1 refers to the situation with the policy to be evaluated and the superscript) to the situation without the policy.

Logsum measure by transport mode

Logsums are computed in the transport mode/destination model of the LMS, in which destination and transport-mode choices are simultaneously simulated in a nested structure. Unlike results for different population segments, logsum results per transport mode cannot easily be calculated, since transport mode is not a segmentation variable, but an endogenous choice variable. An approximation method is applied to distinguish the contribution of changes in transport modes in the logsum. The approximation is based on the transport-mode choice probabilities and the sum of utilities over all alternatives within a transport mode. Changes in land use and the transport infrastructure influence the destination and transport-mode choices in the transport model, and the associated accessibility benefits can be split up in three effects (which together add up to the logsum change):

1. *Trip production effect*: accessibility changes or land-use policies lead to a different spatial distribution of population and thus different trip origins. In the model, this is represented by a different expansion of the logsums per tour (differences between A^1 and A^0 in equation 10). This effect could, therefore, also be called the ‘expansion’ effect. This is not included in the conventional application of the rule-of-half, based on the change in generalised costs from a transport model.
2. *Transport cost effect*: benefits from changes in transport costs and times lead to utility changes for specific transport modes and destinations (through the C and T terms in equation 8); it is included in the rule-of-half.
3. *Destination utility effect*: the redistribution of population and employment leads to differences in the attractiveness of the destinations in the choice model (through the D terms in equation 8); this is not included in the rule-of-half.

The production effect in a specific scenario influences the number of tours that are made from a location. This effect is calculated by using the change in the number of tours made, compared to the reference scenario, and the share of tours that are made with this mode of transport. First, the share of each transport mode is specified as the probability that a specific transport mode is chosen. This is calculated as the sum over all individual alternatives with that transport mode.

$$P_{pizm} = \sum_{j \in m} P_{pijz} = \frac{\sum\limits_{j \in m} \exp\left[V_{pijz}\right]}{\sum\limits_{j} \exp\left[V_{pijz}\right]} \tag{11}$$

Where m denotes a transport mode.

The logsum benefits from the production effect, ΔLR, is computed as:

$$\Delta LR^{1}_{pizm} = \left(A^{1}_{piz} - A^{0}_{piz}\right) \cdot P^{0}_{pizm} \cdot L^{0}_{pizm} \tag{12}$$

The second and third effect — the transport cost and destination utility effects — are calculated in one step because, in the LMS, the transport mode and destination choices are modelled simultaneously. The part of consumer surplus, calculated as the logsum, that can be attributed to a choice alternative is proportional to its choice probability. The share of the choice alternative in consumer surplus change, is then defined as the ratio of the utility change (after exponentiation) for that choice alternative to the utility change (after exponentiation) for all choice alternatives. Here, we also sum choice alternatives that belong to the same transport mode:

$$Frac^{1}_{pizm} = \frac{\sum_{j \in m} \exp\left[V^{1}_{pijz}\right] - \sum_{j \in m} \exp\left[V^{0}_{pijz}\right]}{\sum_{j} \exp\left[V^{1}_{pijz}\right] - \sum_{j} \exp\left[V^{0}_{pijz}\right]} \tag{13}$$

The transport cost and destination utility effect of accessibility changes, ΔLV is computed by using these fractions:

$$\Delta LV^{1}_{pizm} = T^{1}_{piz} \cdot frac^{1}_{pizm} \cdot \left(L^{1}_{piz} - L^{0}_{piz}\right) \tag{14}$$

4. Accessibility benefits from land-use and transport scenarios for the Netherlands

Case study description

The Netherlands Environmental Assessment Agency recently conducted a major land-use policy evaluation study entitled 'The Netherlands in the Future' (MNP, 2007). In this study, a land-use baseline scenario and several alternative land-use and transport policy scenarios were constructed — some of which were quite extreme — for the entire territory of the Netherlands, for the period from 2000 to 2040[5]. The scenarios were evaluated by using a wide range of sustainability indicators, including climate adaptation, flooding risks, biodiversity, traffic noise and urbanisation costs. Here, we focus on the transport and accessibility effects of the land-use/transport scenarios, estimated with the TIGRIS XL model.

The land-use baseline scenario shows the continuation of land-use trends and existing policies. Demographic trends and economic growth are based on one of four existing long-term socio-economic scenarios for the Netherlands (CPB/MNP/RPB, 2006). This scenario assumes modest economic growth (yearly GDP growth of 1.9%), modest population growth (up to 17 million inhabitants) and modest demand for housing (the housing stock increases by 0.5% per year) and employment locations (stabilisation in the number of workers)[6]. Existing investment plans for road and public transport and an additional road-investment package of about €14.5 billion are assumed to have been

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[5] Detailed land-use projections for the period from 2010 to 2040 were computed with the Land Use Scanner (Hilferink and Rietveld, 1999), a high-resolution GIS based land-use model. Future housing locations were used as input for the TIGRIS XL model.

[6] This scenario is called the Transatlantic Market Scenario. The baseline and alternative land-use scenarios were also computed for a scenario with a higher population and economic growth scenario, called Global Economy Scenario. These results are not presented here.

implemented, as described in the Dutch Mobility Policy Document (Ministry of Transport, Public Works and Water Management, 2006).

To give an idea of the possible spatial consequences of decisions that are to a greater or lesser degree prompted by expected climate changes, different land-use policy variants have been formulated:

- *Compact Urban Development* scenario. This scenario concentrates dwellings within the existing built-up area or, where possible, in newly-built designated clusters at close proximity. Half of the demand for new dwellings in the baseline scenario for the period from 2010 to 2040 (about 500,000 dwellings) is assumed to be realised in the built-up area that existed in 2000, compared to 13% in the baseline scenario. About 6 to 8% of the total housing stock and population will be relocated by 2040, compared to the baseline scenario. Compact urban development is often seen as a CO_2 abatement policy, as it reduces the need to travel and the travel distances. However, it can also be seen as a climate change adaptation policy; it retains flexibility in the spatial development of the Netherlands, which improves the ability to adapt to climate change, as it is easier to reserve land for flood protection.
- *Controlled flooding* scenario. In this scenario, a differentiation in safety levels is assumed, and the order in which low lying areas will flood is rearranged to cause the least possible damage. ‘Overflow dikes’ are built to make flooding as predictable and manageable as possible and, thus, reduce the risks, particularly to human life. No new large-scale urbanisation is assumed to take place in areas where there is a relatively high chance of flooding. A large proportion of new residential development in the western part of the Netherlands shifts away from the less safe areas to the safest areas in the central part of the country.
- *Uplands* scenario. This makes a radical break from the past trend in spatial development in the Netherlands. New housing and employment areas, in the period from 2010 to 2040, are relocated from the low-lying, most urbanised western part of the Netherlands (the Randstad Area) to peripheral areas lying above sea level. This is a quite extreme climate adaptation scenario. With current knowledge on the effects of climate changes, the Netherlands is expected to be climate-proof and protected against rising sea levels for some centuries to come. Structural spatial measures, such as a shift in investment to the upland areas of the Netherlands, are not urgently required.

The Compact Urban Development scenario is combined with four alternative transport policy variants to explore the impacts of combined land-use and transport policies:

- *Variant 1: Planned road investments.* Only planned road investments for the period up to 2010 and 2020 are assumed to be realised.
- *Variant 2: Road pricing.* A national road pricing scheme, based on a car kilometre charge differentiated by time, place and vehicle characteristics, and a congestion charge for all road traffic. The scheme is designed to be cost neutral for car owners; road taxes will be abolished and the car purchase tax will be reduced by 25% when the scheme is introduced.
- *Variant 3: Road pricing and better quality public transport.* This variant includes improvements in the quality of public transport, along with road pricing (as included in variant 2). It involves a doubling in the frequency of existing train services within and between the main urbanisation areas, the opening of some new railway stations and reduced waiting, interchanging and travelling times for buses, trams and metro.

– *Variant 4: Road pricing and additional road investments from the Mobility Policy Document.* This variant includes the additional road investment programme, which is also included in the Baseline Scenario along with road pricing (as included in variant 2).

Transport and congestion impacts

Table 1 shows the impacts of the land-use and transport scenarios on national passenger travel volumes and congestion estimated by the TIGRIS XL model.

Table 1: Passenger travel and congestion for the land-use/transport scenarios in the Netherlands in 2040

	Passenger travel			Congestion
	Car use (veh.kms)	Train use (pass.kms)	Slow modes (pass.kms)	(vehicle hours lost)
Baseline scenario	135	98.6	98.5	171
Compact Urban Development scenario	132	99.5	97.2	163
Variant 1: Planned road investments	130	99.8	97.3	230
Variant 2: Road pricing	115	103.2	100.9	110
Variant 3: PT and road pricing	115	117.0	100.5	111
Variant 4: Road investments and pricing	119	102.5	100.3	79
Controlled flooding scenario	135	98.0	98.7	168
Uplands scenario	136	96.6	99.1	93

*Note***:** 2000=100

Forecasted increase in car use is about 35% for the baseline scenario, in the period from 2000 to 2040. Passenger rail travel and slow transport modes stabilises, over the same period. Traffic growth is concentrated on the main motorway network resulting in an increase in congestion by about 70% in the baseline scenario. The impact of the land-use and transport policy strategies on national passenger travel is rather small, except for the scenarios including national road pricing. The impact of land-use and transport policy on congestion is much more substantial; this varies between a more than doubling when no additional road investments and road pricing are assumed (variant 1), and a reduction by about 20% when additional road investments and road pricing are assumed (variant 4).

At the national scale, compact urban development makes only a small contribution to reducing car travel, but has more substantial impact on congestion. Compact urban development is, thus, not a very effective measure to mitigate greenhouse gas emissions from transport. Road pricing is a more effective measure, reducing car use and related CO_2 emissions by 10 to 15%. The Controlled Flooding Scenario has minor transport and congestion implications at the national level. In the Uplands variant, the shift in population and jobs away from the heavily urbanised low-lying Netherlands to the more rural, elevated areas leads to slightly increased mobility, but strongly reduces congestion on the main motorway network compared to the baseline scenario.

Logsum accessibility benefits by transport mode

Table 2 presents the logsum accessibility benefits by transport mode (car, train, bus/tram/metro, slow modes). First, the calculated benefits from the land-use policies are presented, with the baseline scenario as a reference. Next, the benefits from the transport policy variants are presented, which are calculated with the planned road-investment scenario (variant 1), with the Compact Urban Development Scenario as a reference.

Table 2 firstly shows that accessibility impacts from the land-use scenarios are largely due to changes in trip production and - to a lesser extent – changes in transport costs and destination utility. In the Compact Urban Development scenario, a high share of new housing is directed towards locations in the existing built-up areas near railway stations. This improves accessibility (production effect) for train users and for slow transport modes, but reduces accessibility by car. This shows that urban densification leads to significant accessibility benefits - arising from changes in trip origins - for slow transport modes, in particular. The opposite effect can be seen in the Uplands scenario. The shift to more rural areas leads to negative accessibility benefits in all transport modes, and in particular in slow transport modes. The utility of travellers is negatively affected by a reduction in travel opportunities at short distances. The planned flooding scenario has accessibility benefits for car users, resulting from the urbanisation pattern that is directed at the existing cities, but not rigidly within the existing built-up area.

The table shows that the road construction package of €14.5 billion (included in the Compact Urban Development base scenario and absent in variant 1) leads to accessibility benefits of €271 million by 2040. The logsum accessibility changes for public-transport users and slow transport modes, are the result of land-use responses to the road investments (relocation of people and jobs). All road-pricing variants have negative accessibility impacts, due to the increased costs. However, the road-pricing scheme yields substantially higher accessibility benefits than road and public-transport investments when taking into account that road taxes and 25% of the car purchase tax will be abolished when the kilometre charge is introduced (this is included in the results presented within brackets in Table 4). These changes in the road and car purchase taxes, forecasted at €3.9 billion by 2040, and will be a benefit to car owners.

The accessibility benefits from the Road Pricing and Road Investment scenario (variant 4) and Road pricing and public-transport investment scenario (variant 3) are higher than for the Road Pricing scenario (variant 2), due to additional accessibility benefits resulting from the investments in roads or public transport. In addition to the planned road investments and introduction of a national road-pricing scheme, the accessibility benefits from the public-transport investments are similar in size to those of the road-investment package. However, different population segments benefit from these investments. Public-transport users will mainly benefit from the public-transport investments, and car drivers will benefit from road investments; shifts in transport mode are marginal.

Table 2: Logsum accessibility changes by mode for the land-use scenarios, compared to the baseline scenario, and benefits from transport policy variants within the compact urban development scenario

	Accessibility benefits, in € million/year						
			By transport mode				
	Total		car		train	BTM	slow modes
Compact urban development scenario:							
Total effect	1535		-138		106	25	1542
Trip production effect	*1176*		*-319*		*90*	*17*	*1388*
Transport cost and destination effect	*360*		*182*		*16*	*9*	*153*
Controlled flooding scenario:							
Total effect	539		631		-7	-8	-77
Trip production effect	*189*		*450*		*-3*	*-10*	*-249*
Transport cost and destination effect	*350*		*181*		*-4*	*1*	*172*
Uplands scenario:							
Total effect	-1343		142		-188	-10	-1287
Trip production effect	*-2408*		*-516*		*-163*	*-16*	*-1714*
Transport cost and destination effect	*1066*		*658*		*-26*	*6*	*427*
Transport variants in compact urban development scenario 2040							
Variant 1: Limited road investments							
Total effect	271		259		3	1	9
Trip production effect	*26*		*15*		*2*	*1*	*8*
Transport cost and destination effect	*245*		*244*		*1*	*0*	*1*
Variant 2: Road pricing [a]							
Total effect	-2778	(1122)	-2915	(985)	12	1	124
Trip production effect	*38*		*-93*		*12*	*0*	*119*
Transport cost and destination effect	*-2816*		*-2822*		*0*	*0*	*5*
Variant 3: PT and road pricing [a]							
Total effect	-2563	(1337)	-2876	(1024)	119	72	122
Trip production effect	*45*		*-96*		*12*	*2*	*128*
Transport cost and destination effect	*-2609*		*-2780*		*107*	*69*	*-5*
Variant 4: Road investments and pricing							
Total effect	-2516	(1384)	-2664	(1236)	19	4	125
Trip production effect	*88*		*-59*		*18*	*3*	*127*
Transport cost and destination effect	*-2604*		*-2604*		*1*	*0*	*-2*

Note: Figures between brackets are accessibility benefits for car users taking into account that road taxes and 25% of the car purchase tax are abolished when the kilometre charge is introduced. Revenues are forecasted at €3.9 billion/year for 2040.

The accessibility benefits from land-use policies can be much higher than those from investment programmes for road and public transport infrastructure: the compact urban development scenario can lead to €1.5 billion per year, by 2040, compared to €0.2 to €0.3 billion per year for the road-transport or public-transport (Table 4). This difference is related to the scale of investments. As an illustration, investments in the public-transport and road-infrastructure, examined here, are estimated at €18 to €23 billion (€0.1 to €0.5 billion per year over a 30-year period), whereas the additional transition costs of urbanisation for the Compact Urban Development scenario are estimated at €0.8 to €1.3 billion, also during a 30-year period (MNP, 2007).

Logsum compared to rule-of-half accessibility benefits

The logsum method should produce similar estimates of user benefits as the rule-of-half when estimated at the same level of detail and land-use is fixed, using the same transport model and consistent values of time. To test if this is the case in our case study, we compared the difference in rule-of-half and logsum estimations for a road infrastructure investment package. The rule-of-half benefits result from a computation of travel-time savings at the disaggregate trip and travel-time matrices, and similar purpose-specific values of time, as used in the logsum computations. Table 3 presents the accessibility benefits from the additional road investment package (of about €14.5 billion), computed as the difference between the compact urban development scenario (which includes the road investment package) and the planned road investment scenario (excluding the road investment package, variant 1).

Table 3: Logsum and rule-of-half accessibility benefits from the additional road investment package in 2020 and 2040

	Benefits in € million/year	
	Rule-of-Half	Logsum
2020	147	248
2040	196	271

Table 3 shows that the rule-of-half method yields significant effects from the road investment package. The effects are similar but a bit lower compared to the logsum measure, since the logsum also incorporates the effects of minor changes in origin and destination patterns (e.g. residents moving house), modelled by the TIGRIS model as the result of the road investment package. Table 4 presents the accessibility benefits from the different land-use policies for 2020 and 2040, as computed by the rule-of-half and logsum methods, compared to the baseline scenario.

Table 4: Logsum and rule-of-half accessibility benefits from the different land-use scenarios in 2020 and 2040 compared to baseline scenario.

	Benefits in € million/year	
	Rule-of-Half	Logsum
2020:		
Compact Urban Development scenario	27	697
Controlled Flooding scenario	26	107
Uplands scenario	31	-579
2040:		
Compact Urban Development scenario	27	1,535
Controlled Flooding scenario	0	539
Uplands scenario	81	-1,343

Table 4 first shows significant logsum accessibility benefits from the Compact Urban Development scenario, amounting to €697 million per year by 2020, and to €1535 million, by 2040. The logsum accessibility benefits in the Controlled Flooding scenario are moderate, which can be expected from the assumptions underlying this scenario. The restricted locations for urbanisation are usually near river beds and suitable for flooding, and in general have a poor accessibility. The Uplands scenario involves a rigid shift of urban development to less densely populated eastern parts of the Netherlands, also to locations with lower traffic intensities on motorways, but with limited employment and population nearby. As a result, the logsum method yields significant negative accessibility benefits in this scenario.

Table 4 shows large differences in accessibility benefits between the rule-of-half and logsum measures. The rule-of-half does not pick up all accessibility impacts resulting from the land-use changes. This is a form of misspecification of the appraisal method that uses outcomes from the transport model. The accessibility impacts from the land-use scenarios are largely due to changes in trip production and destination utility, not incorporated in the rule-of-half method. The logsum calculations show that the accessibility effects of land-use strategies can be very large, so ignoring them would lead to serious biases. The indication of the accessibility impact may also be wrong, for example, the rule-of-half method yields small positive benefits from the Uplands scenario due to reduced congestion levels on the main motorway network, whereas the logsum yields strong disbenefits resulting from negative trip production effects; inhabitants in this scenario have – on average - lower levels of access to spatially distributed opportunities by all transport modes.

5. Conclusions

We have examined the accessibility benefits from some land-use policy strategies for the Netherlands that anticipate, to a greater or lesser degree, on expected climate changes. A disaggregate logsum measure of benefits was computed by using the national land-use/transport interaction model TIGRIS XL. The logsum accessibility measure can be concluded to provide an elegant and convenient solution to measure the full direct accessibility benefits from land-use and/or transport policies, when a travel demand model (using discrete choice models) is available that already produces logsums. This approach may form an important step towards improving the current standard practice of accessibility appraisal. The logsum measure accounts for changes in (generalised) transport costs, destination utility and trip production, and is thus capable of providing the accessibility benefits from changes in the distribution of activities, due to transport or land-use policies. The case study shows that logsum accessibility benefits from land-use policy strategies can be large compared to investment programmes for road and public transport infrastructure. The accessibility impacts from the land-use scenarios are largely due to changes in trip production and destination utility, which are not measured in the standard rule-of-half measure. The logsum benefit measure thus goes beyond the current practice of rule-of-half benefit calculations. Ignoring accessibility benefits from land-use changes resulting from transport investments may lead to serious biases. Moreover, the accessibility benefits from land-use or integrated land-use/transport scenarios computed by the standard rule-of-half measure may be strongly under- or overestimated, and have the wrong sign.

In standard accessibility evaluation with the rule-of-half method, the accessibility disbenefits from land-use changes are not measured and would need to be measured in the land-use system (e.g. using property values or land rents). In practice, it is quite difficult to identify and measure these benefits within the land-use system, especially in regulated land markets and housing markets. Additional applications, however, will be necessary to firmly establish the added value of the logsum accessibility method in transport-project appraisal.

The logsum accessibility measure is a comprehensive measure of direct accessibility benefits, but only a partial measure of location benefits. Accessibility is but one of many variables determining location quality and value; other variables, such as dwelling attributes, availability of green areas, and environmental quality are important, too. A strategy of compact urban development may, thus, provide accessibility benefits, but generates overall losses in property values and location values, as it does not match residential and job-location preferences. Some attempts have for example been made to use logsum accessibility measures as explanatory variables in hedonic pricing models to compute land and property value changes. Within a land-use/transport framework, such as the TIGRIS XL model, the overall land-use welfare changes, in principle, could be derived from the residential and job-location models where the logsum accessibility measure is used as input variable.

For some cases, the use of the rule-of-half method as a complementary analysis tool along with the logsum method has been suggested, as it would ensure consistency and add to the scheme-impact analysis. In the Netherlands, it is not uncommon to use quite simple and aggregate rule-of-half measurements in transport infrastructure appraisal. This obviously has the advantage of the ease of calculation and interpretation, but does not result in accurate user-benefit computations. Although it is practically infeasible to estimate rule-of-half measures at the same level of segmentation and, thus, as accurately as the logsum measure, it does seems worthwhile to examine the level of segmentation and the type of transport projects in which the rule-of-half measures are sufficiently accurate and where they can still be applied in practical transport appraisal.

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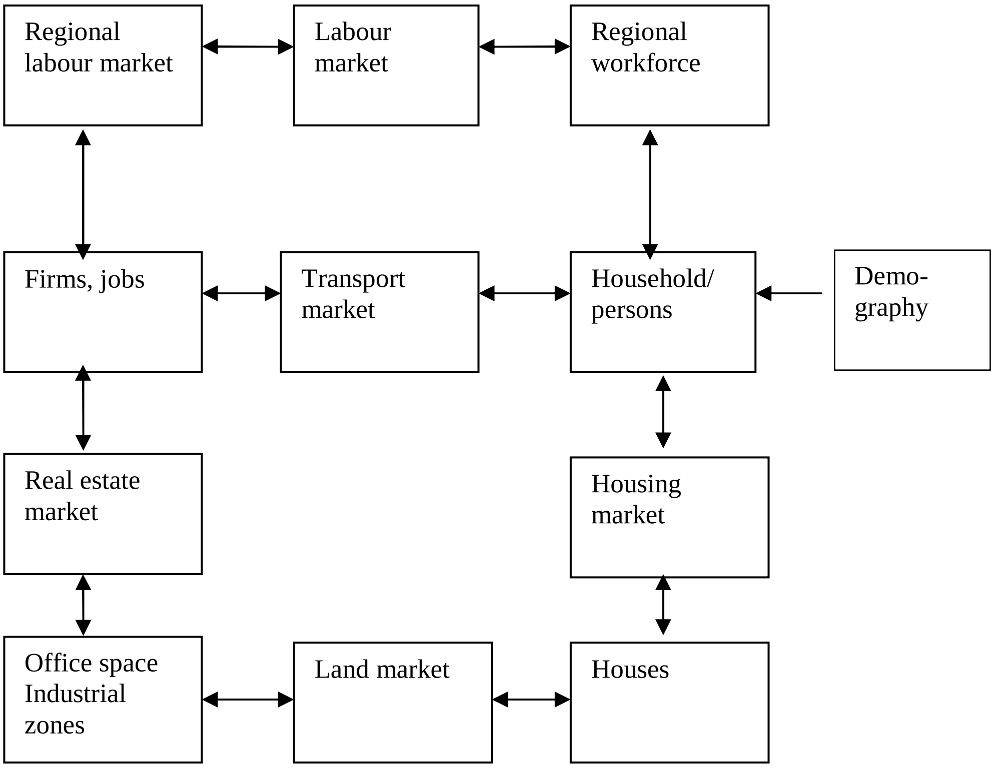

Figure 1: Functional design of the TIGRIS XL model