Three essays on transport CBA uncertainty

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Abstract

Cost Benefit Analysis (CBA) has for a long time been used in transport planning, but it is often questioned. One main argument against CBA is that the results depend largely on assumptions regarding one or a few input factors, as for example the future fuel price or valuation of CO_2 emissions.

The three papers included in this thesis investigate some aspects of uncertainty in transport CBA calculations. The two first papers explore how changes in input data assumptions affect the CBA ranking of six rail and road investments in Stockholm. The first paper deals with the effect of different land-use assumptions while the second deals with the influence of economic growth, driving cost and public transport fare. The third paper investigates how alternative formulations of the public transport mode choice and route choice affect travel flows, ticket revenues and consumer surplus. These are important factors previously known to affect CBA results.

The findings of the first two papers suggest that CBA results are robust concerning different land-use scenarios and single input factors. No change in rank between a road and a rail object is observed in the performed model calculations, and only one change between two road objects. The fact that CBA results seem robust regarding input assumptions supports the use CBA as a tool for selecting transport investments. The results in the third paper indicate that if there is detailed interest in, for example, number of boardings and ticket income from a certain transit line, or the total benefit of a price change, a more detailed formulation of the public transport mode choice and route choice will provide more reliable results. On the other hand, this formulation requires substantially more data on the transit line and price structure than the conventional formulation used in Swedish transport planning, especially in areas with many different pricing systems.

Sammanfattning

Kostnad-nytto-analys (CBA) har använts inom transportplanering under lång tid men användningen är ofta ifrågasatt. Ett vanligt förekommande argument mot CBA är att resultaten till stor del beror på antaganden gällande en eller ett fåtal indata, som till exempel framtida bränslepris eller värdering av CO_2-utsläpp.

I denna avhandling ingår tre artiklar som undersöker vissa aspekter av osäkerhet i CBA-beräkningar. De två första artiklarna undersöker hur förändrade indata-antaganden påverkar CBA-rankningen av sex järnvägs- och väginvesteringar i Stockholm. Den första artikeln behandlar effekten av olika markanvändningsantaganden medan den andra behandlar påverkan av olika antaganden om ekonomisk tillväxt, körkostnader för bil och biljettpriser i kollektivtrafiken. Den tredje artikeln undersöker hur alternativa formuleringar av färdmedels- och ruttvalsmodellen för kollektivtrafiken påverkar resenärsflöden, biljettintäkter och konsumentöverskott. Dessa är viktiga faktorer som vi sedan tidigare vet påverkar CBA-resultat.

Resultaten från de två första artiklarna tyder på att CBA-resultat är robusta gällande olika antaganden för markanvändningsscenarier och enskilda indata. I modellberäkningarna har inga rankningsförändringar mellan väg- och järnvägsobjekt observeras, och endast en förändring mellan två vägobjekt. Det faktum att CBA-resultaten verkar vara robusta angående förändrade indata-antaganden stödjer användningen av CBA som ett verktyg för att välja mellan potentiella transportinvesteringar. Resultaten från den tredje artikeln tyder på att en mer detaljerad formulering av färdmedels- och ruttvalsmodellen för kollektivtrafiken sannolikt ger mer tillförlitliga resultat vid studier av till exempel antalet påstigande och biljettintäkter från en viss kollektivtrafiklinje, eller den totala samhällsnyttan av en biljettprisförändring. Å andra sidan kräver denna formulering väsentligt mer ingående uppgifter om kollektivtrafiklinjer och biljettprisstrukturen än den konventionella formulering som används i svensk transportplanering, särskilt i områden med många olika biljettpriser.

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Stockholm, March 2015
Peter Almström

Contents

1. Introduction

Cost Benefit Analysis (CBA) has for a long time been used in transport planning. For example, the Swedish transport investment plan for 2010-2021 was significantly influenced by the ranking of the investments from a CBA point of view [1]. However, the use of CBA in order to choose between different investments is often questioned. One common argument is that the results of the CBA, and the relative ranking of investments, to a great extend depend on particular input assumptions. Since the time frame for transport CBA often is 20-30 years, the inputs have to be forecasted for this time frame. This naturally induces uncertainty in them. If this uncertainty in a certain input has a large impact on the CBA results, and the ranking of investments, CBA becomes less relevant as a decision support tool. There are, however, very few studies that investigate this often debated relationship. One such study is [2], which finds that different time table assumptions (headway and travel time) has a large impact on the relative ranking of rail investments.

The absolute level of the CBA is often less relevant than the relative ranking of alternative investments. An example of this fact is the Swedish national transport investment plan where the budget is set first, and the investments are chosen in a later step [3]. Investments are chosen until the budget is used, with the highest prioritized investments chosen first. When making the priority list, hundreds of proposed investments must be evaluated and ranked. CBA ranking is one part of the evaluation process.

The different steps of a transport CBA is summarized in Figure 1 and all steps contain uncertainties. Most existing studies of uncertainty in CBA outcome has dealt with travel forecasts (and not the following CBA results). A review of uncertainty in travel forecast can be found in [4]. Using the Dutch national model and Monte Carlo simulation, the same paper also compares the level of uncertainty in transport model outputs due to errors in the model parameters to the uncertainty level due to model input assumptions. The findings suggest that the uncertainty in predicting travel demand due to model inputs is greater than the uncertainty due to model errors. Also [5] reach this conclusion. Most studies do however focus on the certainty due to model errors [6], [7]. There are studies that focus on input uncertainty, for example [8] and [9] who study the distribution of transport model outputs due to uncertainty in inputs. Uncertain socioeconomic forecasts are found to be a significant source of model outcome uncertainty in [10], [11] and [12].

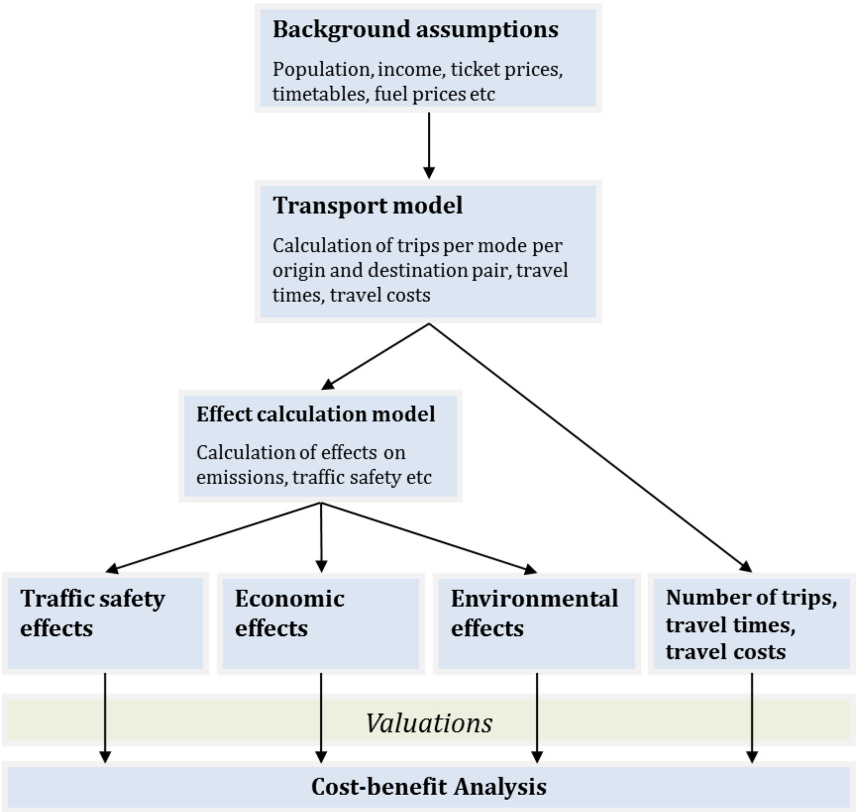

Figure 1 Illustration of the different steps in transport CBA. The two top steps are in focus for the thesis.

Two of the papers included in the thesis (papers I and II below) concentrate on how changes in different background assumptions affect transport CBA results, and in particular the relative ranking of different transport investments. These two papers investigate how changes in the top box in Figure 1 propagate though the calculations and affect end results. The third paper included in the thesis (paper III below) concentrates on the second box in Figure 1, the transport model. The paper investigates how alternative formulations of the public transport mode choice and route choice affect travel flows, ticket revenues and consumer surplus. These are important factors affecting the CBA results.

2. Papers

The papers included in this thesis are the following:

Paper I

Maria Börjesson, R. Daniel Jonsson, Svante Berglund and Peter Almström (2014): *Land-use impacts in transport appraisal.* Research in Transportation Economics vol 47, pages 82-91, special issue on Appraisal in Transport.

Peter did the needed model development for the land-use model used. He performed the land-use and transport analyses (not the CBA:s). Peter participated in writing the method, results and conclusion sections of the paper.

Paper II

Peter Almström, Svante Berglund, Maria Börjesson and R. Daniel Jonsson (2012): *The impact of travel costs and economic growth on cost-benefit analysis rankings*. Presented at Nationella Konferensen i Transportforskning (NKT) 2012.

Peter performed the transport analyses (not the CBA:s) and participated in writing the introduction, method, results and conclusion sections of the paper.

Paper III

Peter Almström, Leonid Engelson and Staffan Algers (2011): *Modelling the effect of transit supply and price structure on mode choice and route choice*. Presented at European Transport Conference (ETC) 2011.

Peter did the model implementation, performed the analyses and formulated the conclusions (conclusions in cooperation with Leonid Engelson). Peter wrote the paper for ETC 2011.

3. The model system

The model system used in the three papers included in this thesis is shown in Figure 2. The system consists of a land-use model and a transport model connected to a model for CBA calculations. While the entire model system is used in papers I and II, paper III concentrates on the transport model (but also consumer surplus calculations).

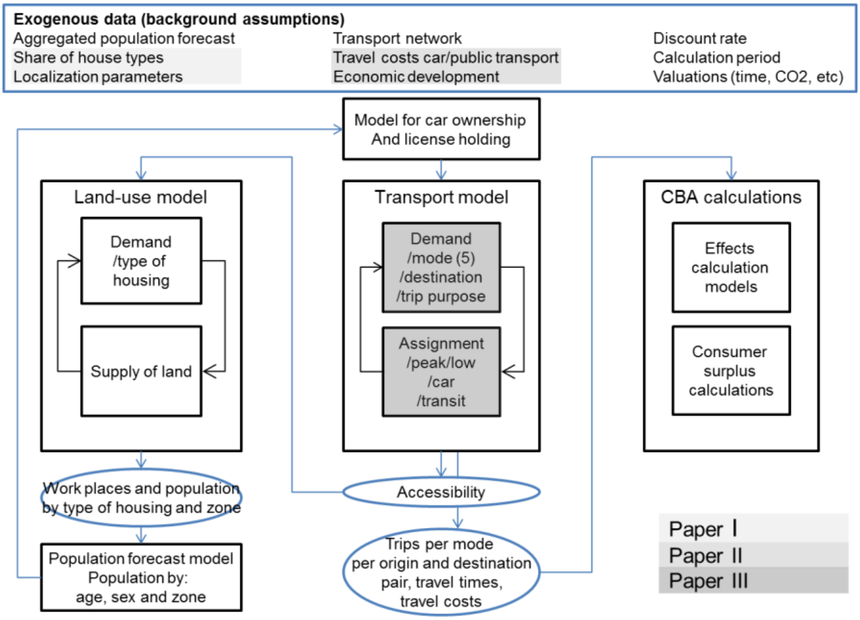

Figure 2 The model system

Each of three main parts of the system is fed with exogenous input data. There are also models for population forecast (or rather population disaggregation) and car ownership and licence holding which can be seen as sub models to the land-use and transport models, respectively. Note that the land-use and transport models are integrated in the sense that the accessibility calculated in the transport model is fed into the land-use model and that the population and work places from the land-use model is input data to the transport model. In the following subsections, the land-use and transport models will be described briefly.

The author of this thesis has not been involved in the formulation and development of the model for CBA calculations. Nor has the author used it hands-on. Therefore it has no dedicated subsection in this thesis. Results from the CBA calculation model are used in papers I and II, while paper III only calculates ticket revenues and consumer surplus. The model for CBA calculations was developed by R. Daniel Jonsson at KTH. The aim was to reconstruct the functionality of the Swedish national CBA calculation model SAMKALK reasonably well while making some simplifications. Simplifications were mainly made in order to reduce the complexity in inputs. Details about assumptions are given in papers I and II.

In papers I and II changes are made to the background assumptions (or exogenous data) fed into the models. How these changes affect the CBA of different transport investments are the issue at hand in the papers. In paper III, an alternative modelling of public transport mode choice and route choice is tested. The part of the model system that is in focus in each paper, i.e. changed in order to see effects on CBA results, is marked with colour shadings in Figure 2.

In subsections 3.1 and 3.2, respectively, the land-use model LuSIM and the transport model LuTRANS are described. Subsection 3.3 describes the alternative formulation of public transport mode choice and route choice.

3.1 Land-use model – LuSIM

LuSIM was developed in 2006-07, by Svante Berglund at WSP to be used for the regional plan for Stockholm, RUFS 2010 [13]. The model comes with inspiration and ideas from UrbanSIM. See [14] and [15] for an overview of UrbanSIM. LuSIM has later been further developed on several occasions by Peter Almström, Olivier Canella and Svante

Berglund. Within the land-use model package there are actually two separate models; the actual land-use model and a population forecast or population disaggregation model. The two models are briefly described in this section. A more thorough description of LuSIM can be found in the user manual [13].

Land-use model

LuSIM is a GIS-based model that allocates a fixed number of inhabitants and workplaces to Stockholm county (and also the surrounding counties in the Mälardalen region). The initial purpose was to allocate population and workplaces according to principles given by the user. Thus, it is not primarily a model intended for making forecasts of future land-use patterns, but rather a model that can be used to produce different possible scenarios for the future land-use and evaluate the consequences of these. Each scenario can then represent what may happen if a particular driving force is the most influential one on the future land-use. By producing several scenarios, both desirable and threatening ones, the sample space can be plotted. In recent years, a version of the model with statistically estimated parameters has been developed. The estimated parameters are similar in size and sign to the ones used when producing different future land-use scenarios.

LuSIM uses the same zones as the transport model LuTRANS (1240 zones in Stockholm county). This makes it very easy to use output from one of the models as input to the other. New inhabitants to the county are allocated by single/multi family houses and workplaces by type (central offices, population-based activities, area-consuming activities). The model is time sequential, usually using five year steps. The supply of land is modelled rather simplistic and governed by an incremental annual increase of the allowed development density. Certain zones, as for example areas pinpointed for development in plans, can be given a higher pace for the increase. Zones can also be blocked for further development and each zone has an individual upper bound for density. Demand is governed by accessibility and density (and possibly other aspects as defined by the user). The density of a zone is used as a proxy for local accessibility but has also negative influence in terms of crowding. There is a special model for conversion of summer houses to permanent housing. The overall model structure is shown in Figure 3.

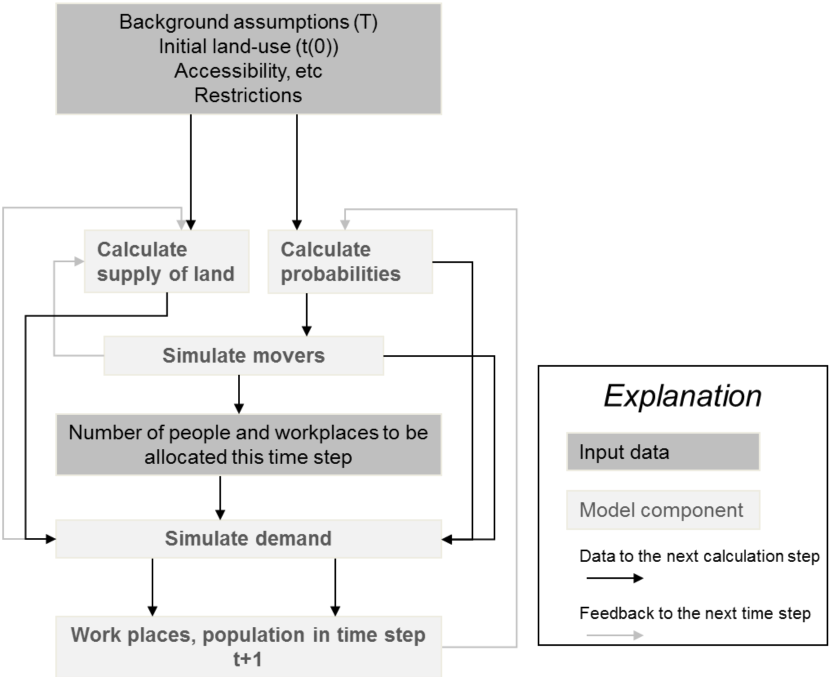

Figure 3 Overall model structure for LuSIM

Validation of the model results include comparisons to outputs from the model SAMLOK (see [16] for a description of SAMLOK) in regards of induced relocation effects as a result of the Stockholm bypass. SAMLOK is estimated at municipality level and produce expected effects on salaries, population and work places due to increased accessibility. Looking at the modelled population change in the municipalities along the road (especially in Ekerö), both models give similar results. Results from LuSIM have also been studied by and discussed with several experienced planners at multiple occasions to ensure that the model produce reasonable results.

Population forecast or population disaggregation model

The population forecast, or rather population disaggregation, model uses the age of the houses and share of single/multi family houses in a zone to calculate a population forecast that is disaggregated in terms of age class and sex. The used method is called the standard age method (standardåldersfördelningsmetoden in Swedish) [17]. The underlying assumption (based on statistical data) is that the demographical composition of the population on average depend on the age of the building they live in and that this dependency will not change in the future (for example, the age and sex distribution for people living in 50 year old buildings will look the same in the future as it does today). This dependency on the age of the building is most apparent for newly build areas and the fluctuations tend to decrease in size as the buildings get older. The model also makes sure that the population per age class and sex on county level is consistent with an external population forecast.

3.2 Transport model – LuTRANS

As the land-use model LuSIM, the transport model LuTRANS was also developed to be used for the regional plan for Stockholm, RUFS 2010 by (mainly) Staffan Algers and Svante Berglund at WSP [18]. Also LuTRANS has since been further developed on several occasions by Peter Almström, Olivier Canella, Svante Berglund and Leonid Engelson. LuTRANS consists of two integrated models; a model for car ownership and licence holding and a four-step transport model. The two models are described in this section. A more thorough description of LuTRANS can be found in the user manual [18].

Car ownership and licence holding model

The car ownership and licence holding model is of logit type and produce forecasts of the share of the population in a zone that has a driver's licence and the share that live in households with access to a car. Also car competition is modelled. The model is sensitive to land-use characteristics in the zone i.e. the share of single family houses, density and, relatively recently added, the difference in accessibility between car and not car. In addition to these land-use characteristics, the model also considers variables as age structure and income (square root transformed).

Transport model

LuTRANS is a simplified version of the Swedish national transport model SAMPERS. See [19] and [20] for a description of the SAMPERS model. LuTRANS is a nested logit model with two trip purposes, work and other, with a tree structure for each trip type as shown in Figure 4. The travel modes in the model are car (driver and passenger), public transport, walk and cycle.

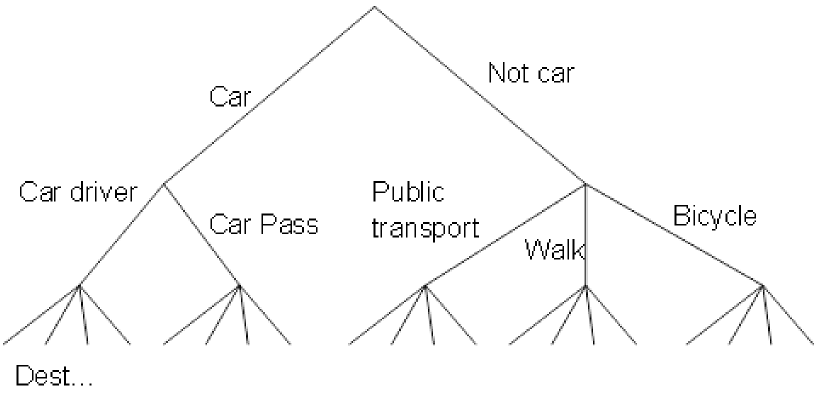

Figure 4 Tree structure for the nested logit model in LuTRANS

The aim was to have a model that can be used to evaluate transport system effects of different land-use scenarios and also evaluate accessibility (and land-use) effects of different transport systems. The simplifications (compared to SAMPERS) was carried out in order to get a model with a considerably reduced turn-around time and simpler input data handling. This was achieved by reducing the complexity in the socioeconomic inputs to the model and by reducing the number of trip types to two mentioned above – work and other. The model is currently used with Emme 3, but can be ported to other systems.

3.3 Alternative public transport mode choice and route choice model

Conventional regional traffic models used for transportation planning in Sweden (Sampers, LuTRANS, etc) use a constant value of time. The cost for public transport trips in these models does, as a rule, only depend on the origin and destination of the trip (and not line choice as it generally does in reality). This makes analyses of the impact of changes in headway, ticket prices and transit line alignment not entirely reliable. To be able to perform these types of analyses, the model presented below was developed in paper III. The model explicitly consider different price structures and variations in value of time. For a more thorough description of the model, see paper III.

For each possible origin-destination pair, there are a number of public transport passes available. Each pass is associated with a travel time and a travel cost. Given these and the traveller's value of time the preferred pass is chosen. The value of time is either fixed in the population (multi-nominal logit, MNL) or simulated (mixed logit, MXL).

The model uses a demand matrix for work trips (car plus public transport) from a transport model, such as LuTRANS, or other source. Based on travel times and travel costs for car and public transport the mode choice is made. The route choice comes in two steps. The choice of public transport pass gives access to a defined set of transit lines (a subnet) and within this subnet the route is chosen.

In paper III, three different versions of the model was tested, called BASE-MNL, PASS-MNL and PASS-MXL. BASE-MNL is the standard model in SAMPERS and LuTRANS. There is only one pass available giving access to all public transport lines and hence the fare only depends on origin and destination. The entire population has the same value of time. In PASS-MNL there are several public transport passes available, all giving access to different subnets. The value of time is still fixed. In PASS-MXL the value of time is simulated from a distribution. This means that the choice of mode and public transport pass not only depends on origin and destination (as it does in PASS-MNL) but also on the individual value of time.

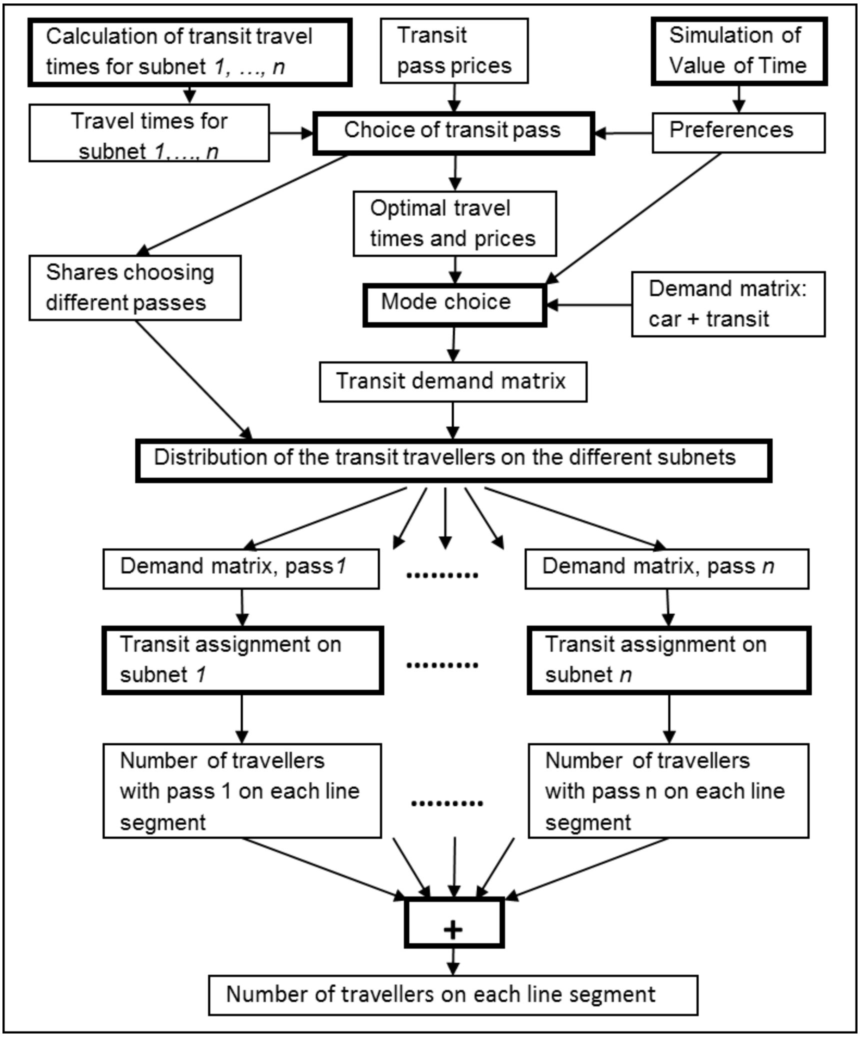

Figure 5 Flowchart for the developed public transport mode choice and route choice model

4. Results and discussion

4.1 Paper I

Paper I uses the full model system described above to investigate how different land-use assumption affect the CBA results of six different rail and road investments in Stockholm. Of particular interest is whether the relative ranking of the objects change. For two objects, Stockholm bypass and a commuter train investment, the induced land-use effect and its impact on the CBA results is studied. For all six investments, CBA is carried out for three different land-use planning scenarios called Trend, Central and Peripheral. The land-use scenarios differ in the tolerance for density in the built environment, in the share of the population growth that live in multi-family and single-family dwellings, and whether accessibility by car or public transport influences location choice for new housing and work places.

A main conclusion is that CBA results seem robust regarding changes in land-use assumptions (both for induced land-use and different planning policies). If land-use demand and supply are assumed to be ruled by market forces, benefits of rail investments are found affected by an induced land-use to a larger extend than road investments. The sample is, however, limited with induced land-use effects calculated for only one rail and one road investment. The result that accessibility improvements due to rail investments are more concentrated (and thus giving more concentrated induced land-use effects) is though fairly general. A conclusion in the paper is that large land-use adaptation, structuring or dispersing, cannot be expected just to appear but has to be deliberately planned for. It is from the results in the paper not obvious whether rail or road investments are influenced more than the other by different planning policies. On the other hand, the planning policy is found to have a larger impact on accessibility and vehicle kilometres travelled than individual investments. It is important to note that the conclusions apply to Stockholm, where the urban form and transport system is already structured/developed.

With a considerably larger sample size than the six investments studied in the paper, say 100 investments, one would of course expect more changes in the CBA ranking of the investments than found in the paper. This would occur simply because the Benefit to Cost Ratio (BCR) of the investments arguably would be closer to each other (most investments would probably have a BCR in range between the highest and lowest of the studied investments). However, it is still expected that the BCRs would be fairly constant and investments that change rank with each other would most likely be ones with similar BCRs to begin with. If investments with similar BCRs to begin with change rank, this is a much smaller issue than if investments with very different BCRs change rank. Still, having a larger sample would of course give a more reliable inference. Performing CBA calculations for 100 investments is, however, a daunting task and would require thousands of man hours. It is therefore outside the scope of the paper.

Another note is that the paper (as well as paper II) deals with strategic planning. In the case of, for example, physical planning, where several alternatives to solve the same problem is studied, other results might occur where the CBA ranking changes due to changes in background assumptions. However, for physical planning other aspects than CBA as, for example, intrusion effects, effects on city planning, actual noise levels, etc., will arguably be given a large weight in the final investment decision.

4.2 Paper II

Paper II uses the same model system and infrastructure investments as in Paper I. Instead of changing the land-use, travel costs by car and public transport, and also economic growth is changed. The base scenario uses the same assumption as in Paper I for these input parameters. Added to this base scenario are scenarios with lower and higher marginal travel cost by car, higher public transport fare and lower economic growth. For all six investments all scenarios are studied, resulting in 35 model simulations.

A main conclusion is that CBA results seem robust regarding input value changes regarding travel costs and economic growth. There is no change in the relative ranking of the studied investments. According to the results, too optimistic assumptions about GDP growth favour road investments, while too optimistic assumptions about public transport fare favour rail investments. As for Paper I, it is important to note that the conclusions apply to Stockholm, where the urban form and transport system is already structured/developed. Furthermore, the same cautions as for paper I regarding the investment sample size and the strategic planning viewpoint holds for paper II.

4.3 Paper III

Paper III concentrates on the transport model. The paper investigates how alternative formulations of the public transport mode choice and route choice affect travel flows, ticket revenues and consumer surplus. These are important factors for the results of the CBA calculations. Three different models are tested. The models are only developed for work trips but can be expanded to also model other trip purposes. The first model is the same as used in conventional method in Swedish transport modelling (as in SAMPERS and LuTRANS), and called BASE-MNL. The second (PASS-MNL) and third (PASS-MXL) models add the fact that depending on which public transport pass the traveller purchases, the cost will differ and different sets of lines will be available. The two models differ in that PASS-MXL accounts for the distribution in the value of time.

The results indicate that if the interest is in overall mode share and overall travel flows BASE-MNL will suffice. If the interest is more detailed, for example concerning number of boardings and ticket income from a certain transit line, or the total benefit of a price change, the PASS-MXL (and sometimes the PASS-MNL) method will give more reliable results. On the other hand, these methods also require substantially more data on the transit line and price structure than BASE-MNL, especially in areas with many different pricing systems.

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