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# Modelling cross-border transport: Three cases in Öresund<sup>1</sup>

Paper for the 44th ERSA congress in Porto,  
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<sup>1</sup>This is an abridged version of the paper “Modelling cross-border transport in Öresund: Scenario assumptions, model results and a before-and-after database” in my Licentiate thesis *Modelling transport, accessibility and productivity in Öresund* (2004).

## Abstract

Transport models, and transport/land-use interaction models, are important decision support tools for large-scale infrastructure investments, for example in the road network. A bothersome feature of these tools are their distant forecasting horizon of 10–30 years ahead, and the uncertainty following from this. Although widely used, these models have rarely been put to test after this period have passed. The predictive power of a transport model is dependent on its ability to reproduce reality, which is assessed by validation. Apart from modelling the specific transport demand, which is based partly on socio-economic (demand) factors and partly on the supply of transport facilities (infrastructure), a number of scenarios of the future socio-economic development must be set up, called the *scenario assumptions*. In this paper we will present three different transport models: FREDRIK/SSV, COMVIN and SAMPERS/Skåne, out of which the first two have been used to model the transport across the Öresund Strait. The model structure, forecast results and scenario assumptions are considered in order to identify the key sources of uncertainties, and to prepare for the estimation of the true model error versus the error caused by incorrect scenario assumptions.

**Key words:** infrastructure planning, transport models, validation, Öresund, before-and-after data.

# 1 Background

Transport models are important tools when decision makers are about to take decisions on large-scale infrastructure investments, e.g., in the road network. Together with cost-benefit analysis (CBA) and environmental impact assessments (EIA) they contribute to the decision-making process by increasing the knowledge about the consequences for the economy, the environment and the society at large. In the case where the financing of the investment is dependent of the generated traffic, as for the bridge across the Öresund Strait, transport models also provide information on conditions for obtaining the traffic that is needed for the road to be paid off. A prominent feature of these tools, however, are the long time-scale that they work with, and thus the uncertainty following from this. This is of course a consequence of the length of the planning period (10–15 years) and the long-term character of the investment.

The Öresund fixed link has been discussed for more than a hundred years, and is also expected to have a life span of at least a hundred years. It was finally opened on July 1, 2000, after an investment of around 19 billion DKK (3 billion USD), not counting the connections on land of additionally 10 billion DKK. The full impacts from such an investment will not be seen until ten or twenty years from when the construction work is finished.

In the case of the Öresund fixed link, the first serious attempts to predict the traffic started in the early 1960's, which have been updated regularly at least five times since then. The greatest effort was probably made in the years 1975–78, covering all kinds of effects: except for the effects on personal and freight transport, it included technical matters (construction), effects on business activities, households, and the environment (Öresundsdelegationen, 1978b). In the early 1990's, the emphasis was on the environmental effect on the Baltic Sea. Later on in the 90's, a new model, COMVIN, was implemented in order to assess the impact of different pricing schemes on the revenues of the tolled bridge.

## 2 Introduction

The paper is arranged as follows: the next section presents the motivations behind the investigation, a model for the separation of error sources, and a short note on the included transport models. Next follows a section with a general discussion of transport model structure, and a “comparative framework” is established by the distinction of what is scenario assumptions, and what is inherent in the model structure itself. This is followed by more extensive descriptions of the treated models, with focus on the aspects in which they differ. The scenario assumptions of each model are reviewed, and the model results presented. Both of these are

summarised in a section where “error elasticities” are calculated for the total forecast errors. A section with concluding remarks and directions for future research ends the paper.

## 2.1 Validation of transport models

In order to assess the predictive power of transport models, validation is essential. In the 1980’s, integrated transport and land-use models for planning purposes were studied by the International Study Group of Land-use/Transport Interaction (ISGLUTI). One of the main conclusions from the group was referring to the need for high quality and long-term before-and-after database related to major infrastructure investments for validation studies:

“The need to learn more about these long-term effects is so important that the difficulties of such a study should not discourage the search for a suitable scheme nor an interested authority from pursuing an appropriate study. If those who have responsibility in this area are always deterred by the magnitude and the time scale of the task, we will still be faced by the same questions in 20 years time.” (Webster, Bly and Paulley, 1988)

Still in 2000, Hensher and Button repeat that “very little *ex post* analysis has been done on the accuracy of forecasts”. In the context of the Öresund fixed link, we might have a unique opportunity to establish the required before-and-after database: we have a major investment with potentially enormous impacts on the region, we have data on the situation and travel behaviour before, and all we have to do is to collect data from the situation after and organise a coherent before-and-after database.

Lundqvist and Mattsson (2002) list four types of validation, constituting a checklist “for analysing how well a transport model system functions and serves the purposes for which it has been designed”: *practical*, *theoretical*, *internal* and *external* validation. Here we will consider the latter two. *Internal validation* involves goodness-of-fit measures, controlling the signs of parameters and sensitivity tests, and basically reflects the ability of the model to reproduce the base year situation. *External validation* is the ability of the model to predict other independent data, like traffic counts *not* used in the calibration, a future year (or backwards, a previous year), and the correspondance of elasticities with other studies (Lundqvist and Mattsson, 2002, p. 9). The errors found in an external validation can be divided into a) model error and b) errors caused by erroneous scenario assumptions (Lundqvist, 2001). Scenario assumptions are all kinds of assumptions that are made for the future scenario, which can be divided into assumptions about the

*demand*, e.g. the *macro-economy*: economic growth, total population, total employment; and the disaggregated *socio-economic* decision units (households and firms): car ownership, income, household composition, car competition, car pooling, values. On the other hand, we have policy related assumptions about the *supply* in the road network and public transport (among these we usually find the scenario alternatives that we want to evaluate): links, transit frequency, toll levels, taxes and tax deductions; and assumptions about *geographic structure* or the distribution of the before-mentioned variables in space: e.g., agglomeration effects, land-use effects, migration (see further subsection 3.1).

It is virtually impossible to summarize the above assumptions into a comprehensive, one-dimensional measure which would be needed for an evaluation of the effects of scenario assumptions on the model outcome. Some of the variables are also of a discrete nature. In this paper we will therefore concentrate on the macro-economic, demographic and employment scenario assumptions. For comparative reasons, and inasmuch it is possible, we try to hold other assumptions constant between models. For example, we leave out freight transport and land-use changes from the COMVIN model, since they have no counterparts in FREDRIK and SAMPERS. In COMVIN, the comparison is complicated by the fact that the reported forecast (Øresundskonsortiet, 1999b) includes a part of<sup>1</sup> an assumed integration process, that actually is beyond the capabilities of a short-term equilibrium model<sup>2</sup>. This means that 9.1 % of the forecast volumes has to be subtracted from the presented results in order to be comparable to the results of FREDRIK and the earlier models of the Öresund Commissions, which were pure equilibrium models (see subsection 5.3). The models of car ownership differ as well, but it is slightly more difficult to find out how large the resulting amounts are. None of the scenario assumption forecasts are reported explicitly, but they are more or less available in the model system or the documentation in the form of data tables, matrices and coefficients. In SAMPERS, the car ownership model is an optional module, so there it might be easier to maintain control over the car ownership scenario assumptions.

As dependent variables, we use total single trips across the Öresund Strait and on the fixed link. More complex dependent variables are of course possible, for example one could use a global, multidimensional measure of fit like a sums of squared differences, or entropy measures of deviations from the base distribution of trips (in zones or on links).

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<sup>1</sup>More precisely, 30 % of this integration is assumed to take place instantaneously, and that in a couple of decades there will be a 100 % ("full") integration between the Danish and Swedish side, i.e., no barriers in language, culture, economy, institutions, laws or regulations etc.

<sup>2</sup>In this context, this means that the adjustments of the traffic to new routes and links is instantaneous. No changes of workplace, residence or business location occur. The only change taking place is the addition of the new link.

The validation of transport models requires some general framework with specified variables that are common to most of the models and in which we can study how the different models have solved the tasks. It is also important that we are able to study the relative impacts of different solutions on the predictions of the models. In order to do this, we need a way to quantify these solutions and their effects. Data requirements for the validation of models of transport, land-use and environment interaction are listed in the Appendix of Petersen (2004); see also Lundqvist (2001).

In validation we will follow a scheme developed by Lundqvist (2001) and presented in revised form in Figure 1 (page 5). The before-study is used to estimate the model parameters, and together with projections of exogenous conditions for the forecast year, the model can be used for *ex ante* forecasts. With before-and-after data available, data from the after-study can be used to extract observed exogenous conditions, which together with the estimated model can be used for an *ex post* model run, or “prediction” of the now past forecast year. The model is validated (“external validation” according to the above) by comparing the *ex post* prediction with the actual situation of the forecast year.

We can discern three kinds of errors in the figure: model error (1), error in scenario assumptions (2) and total observed (forecast) error (3). The only *ex post* observable error is the latter, the other two must be assessed using external validation. (A bracket between the “complete description of the base year situation” and the *ex ante model* prediction, on the left side in the figure, would represent an internal validation according to above.)

The model error is the error generated by the model *despite perfect knowledge* about the forecast year situation, and all exogenous variables replaced by their true values. The “complete descriptions” in the base and forecast years include *all* factors, exogenous and endogenous to the model; i.e., both inputs (e.g., car availability, employment) and outputs (e.g., land-use, CO<sub>2</sub> emissions). The factors represented by the exogenous variables are input to the *ex post* analysis.

It is important to point out that although a model makes a correct forecast, it might be the result of internal, counteracting effects which both are wrong but have different signs, adding up to a reasonable result; or, similarly, the forecast could be right but for the wrong reason (for example, a zero development of the population growth could be compensated by a stronger growth in car ownership).

The object of this study is cross-border transport models, which means that one major input and source of error is the balance between the two countries in terms of economic development, currency exchange rates, population growth and migration, differences in taxes and rules and regulations of the social security systems etc. All these differences will have a major effect on the travel and transport across the border, and so the forecasts will be very sensitive to relative differences in the

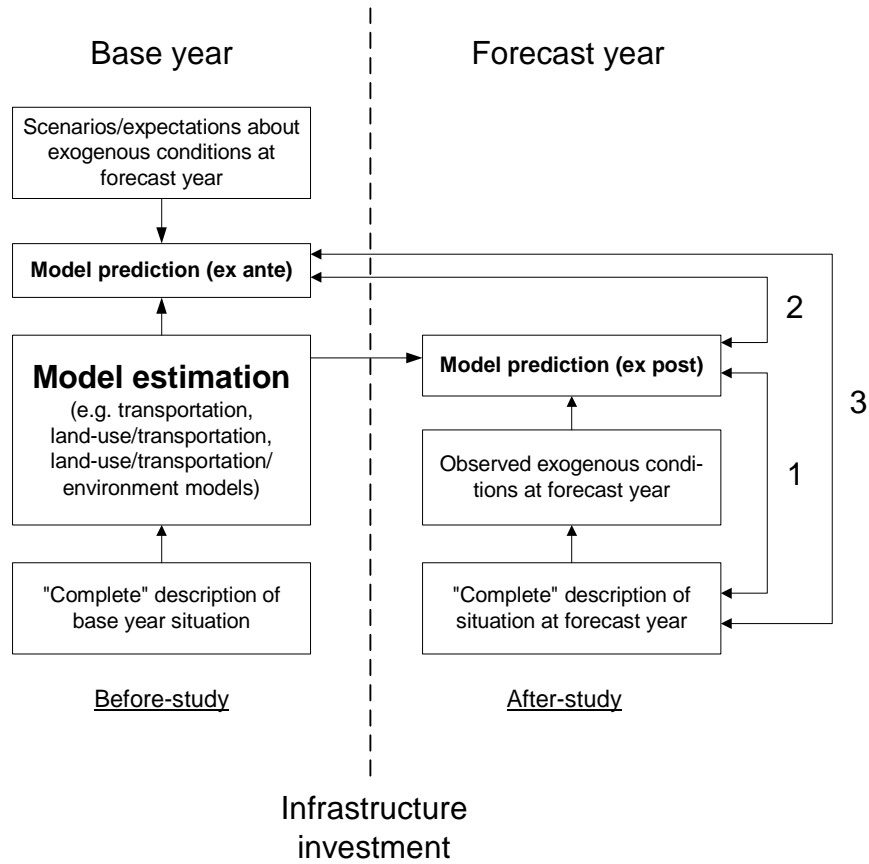


Figure 1: Modelling infrastructure impacts in the context of before-and-after data (adapted from Lundqvist, 2001). 1: true model error, 2: error caused by erroneous scenario assumptions, 3: total forecast error.



predictions of these quantities, represented by exogenous variables, on each side of the border. Not only the variables as such, but the difference between them will be a source of error. Therefore, it is also essential that definitions, methods, forecasts and statistics, are consistent across the border. Another consequence is that, in order to measure the impact of scenario assumption errors, it is not sufficient to measure the global errors, but rather the *distribution* of the errors on the two sides of the border.

An important aspect in this context is also the speed and the equilibrium level(s) of the so-called *integration effect*—i.e., the gradual harmonisation and equilibration of the above-mentioned differences, and the reduction of cultural, economic and insitutional barriers. As far as we know, there are no empirical studies leading to estimates of the rate of change and final equilibrium of this process, which might also be called the *market penetration* (e.g., on the land-use and transport markets) of the new infrastructure investment.

## 2.2 Treated models

In this paper, we will study three models around the Öresund Strait in some detail: FREDRIK/SSV, COMVIN and SAMPERS/Skåne. FREDRIK was a regional transport model used in many Swedish regions from around 1990, and the Scania model was adapted for the Öresund region by extension to the Greater Copenhagen area in Denmark and inclusion of a ferry mode for crossing Öresund. There were several versions of this model, but the predictions of FREDRIK for the traffic over Öresund that we will use were made in 1991 (Transek, 1991). COMVIN was a joint venture of three consulting firms, COWI (Denmark), MVA (United Kingdom) and Inregia (Sweden). The base year for the data of COMVIN is 1995 and the predictions were made in 1999. SAMPERS/Skåne has not yet been used for predictions on the traffic across Öresund, although the model has been calibrated both for the before- and the after-situation. The base year of the data is 1997. Both FREDRIK and SAMPERS were developed by the Swedish consulting firm Transek. COMVIN and SAMPERS are complex and flexible model systems consisting of several submodels—for comparisons we will here only focus on the short distance models, encompassing the Greater Copenhagen area and Scania.

## 3 Comparative framework and model descriptions

There are several factors to be considered in the comparison of transport models. One approach could be to specify all sources of error of models in general, and compare in which different ways these sources have been mitigated in each model. Another approach, which will be adopted here, is to specify what constitutes the

different scenarios considered in each model. The scenarios, however, might not be specified in a similar manner between models, which makes comparisons more difficult.

First, we shortly note that all three models are based on gravity- and (nested) logit-type submodels in the traditional four steps:

1. Trip Generation (G),
2. Trip Distribution (or “Destination choice” in a random utility framework, D),
3. Mode split/Mode choice (M), and
4. Trip Assignment (on a network of routes and links, A)

We normally refer to this model structure as a four-step model (G-D-M-A). Steps 2 and 3 could be in reverse order, in which case we have a reverse four-step model (G-M-D-A). Out of the models we study here, FREDRIK and COMVIN have the traditional structure, whereas SAMPERS has the reverse structure<sup>3</sup>. In addition to this structure, for cross-border trips, FREDRIK and COMVIN have an extra route choice step between the mode choice and assignment steps, for the choice of crossing (Helsingborg-Helsingør or Malmö-Copenhagen). In COMVIN, the mode and route choices are mixed together, resulting in a rather complicated choice structure (see subsection 3.5). SAMPERS makes use of the network assignment system Emme/2 instead (the bus mode is substituted for the ferries on links across the Strait). In this respect, SAMPERS is not (and was never intended to be) a model of the Öresund traffic, but is more like an extended Swedish model, where part of Denmark has been incorporated in the Swedish network and travel behaviour is entirely based on Swedish travel surveys.

Another feature that is different from model to model is the zonal subdivision, which brings us face to face with the modifiable areal unit problem (MAUP) (see for example Berglund, 2001; Openshaw and Taylor, 1979). It states that all other things equal, the result of an analysis will depend on which zonal subdivision we choose. All three models in this study use different zonal systems (see Table 4).

The model structure is determined by assumptions about the statistical properties of sub-models and correlations between different variables and choice sets. Other model-specific properties connected to the model structure are:

- the scope of the model in terms of types of transport that are modelled (personal trips, goods transport, transport/land-use interaction);

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<sup>3</sup>Basically, except that the “public transport” mode is divided into bus and train *below* the destination choice level.

- the scope of the model in terms of origin and destination of trips (merely regional, or including also trips going in and out of the region, transit traffic or “through trips”);
- the geographic scope (e.g., inclusion of adjacent areas), discretisation of space (zonal subdivision and network link system), trip purposes, socio-economic groups (age, sex, income).

For cross-border models, we have in addition differences in the treatment of

- the barrier effect, i.e., the reduction in trade and transport caused by the national and geographical border;
- the crossing over the border (mode and route choice).

### 3.1 Scenario assumptions

As one definition of scenario assumptions we could adopt “everything that is exogenous in a model”. Exogenous variables are the ones that the modeller has to assign a value before running the model. Unfortunately, this definition would also include some parameter values (e.g. different value-of-time values in the case of the COMVIN model) that we would rather see as inherent in the model itself.

Here some factors are listed that are important for a future scenario:

*Demand factors:*

- assumptions about macro-economic variables from the base year of the data until the forecast year (GDP<sup>4</sup> or regional GDP development, business cycle assumptions), currency exchange rates, taxes on specific goods (like alcoholic beverages, coffee, sugar, cars);
- assumptions about socio-economic factors (specific for the population): income and income distribution, household composition, car ownership, car competition, car occupancy rates, demographic constitution of the population (people in workforce, employment rate);
- assumptions about price and tax policies, tax deductions for car, car pooling, etc;

*Supply factors:*

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<sup>4</sup>Gross Domestic Product

- network assumptions: assumptions on the construction of new links in road or public transport network, preservation/maintenance of old links;
- assumptions about policies and prices: fuel prices, parking possibilities and prices (e.g. park-and-ride, kiss-and-ride<sup>5</sup>), tolls on fixed link, other road pricing, fare schemes for public transport, etc;

*Geographic factors:*

- assumptions about land-use<sup>6</sup>: location of work places, shopping centres, proportion of work places to residence;
- assumptions about changes in the long-term land-use pattern, agglomeration, the speed of reduction and final level of the cultural and economic barriers, migration, administrative and trade barriers, barriers in the labour markets, in the social security systems, etc;

*General:*

- choice of forecast year (distance of the forecast horizon).

The list is quite generous and extensive. Naturally, many of these factors can not be measured or forecasted in a simple way, like prices, taxes and policies, and are therefore not part of the models. Still, as in all economically sound modelling, there is a point in considering what general assumptions are made, even if the assumption is only that this or that variable is held constant.

In our discussion of a three- or four-step model, “scenario assumptions” will mainly refer to the assumptions about the development of variables controlling the trip generation, such as growth in population, employment, income or regional GDP, and car ownership. We will also concentrate on the forecast year 2000.

## 3.2 FREDRIK/SSV

This model is an adaptation of the Swedish regional modelling system FREDRIK, extended with the Greater Copenhagen area on the Danish side and the inclusion of boat trips in the mode choice set, which are not present in any other FREDRIK implementation. The model consists of 340 zones (or centroids), whereof 261 in

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<sup>5</sup>*park-and-ride*: generates one car trip from point *A* to point *B*, and one public transport trip from *B* to point *C*; *kiss-and-ride*: generates a round trip by car from *A* to *B* and back, and one public transport trip from *B* to *C*.

<sup>6</sup>The term land-use in this context has the narrow definition of “location of employment”; i.e. the destination of work trips and shopping trips.

<i>Available modes</i>	<b>Scenario</b>	
<b>Crossing</b>	<b>Ferries</b>	<b>Link</b>
Helsingborg/Helsingør	car, train, walk, bic.	car, train, walk, bic.
Malmö/Copenhagen	walk, bic.	N/A
Limhamn/Dragør	car, walk, bic.	car, train

Table 1: Available modes by crossing and scenario (*bic.* = *bicycle*). The link modes are shown in the Limhamn/Dragør cell. N/A = not available.

Sweden (Scania) and 79 in Denmark. A few (7) of the centroids are so-called remote centroids, which connect the transports in the model area with the outside. On the Swedish side, apart from the zones in the largest cities Helsingborg, Malmö and Lund, municipalities are divided into one zone for the densely built-up area, and one zone for the surrounding countryside.

The travel behaviour is estimated on Swedish travel survey data (RVU), so it assumes that Danes travel in a similar manner as the Swedes. When the destination and origin zones are on different sides of the Strait, the choice of route (Helsingborg/Helsingør, Malmö/Copenhagen or Limhamn/Dragør—henceforth also labelled HH, MC and LD) is modelled simultaneously<sup>7</sup> with the mode choice (car or public transport, which also includes walk and bicycle during the passage across the Strait; henceforth called PT). First, car and PT assignments are made in Emme/2 on respective network to get generalised costs (GC) between zones. Cost matrices for all mode/route combinations ( $2 \times 3 = 6$ ) are treated separately. Not all modes are available for all routes, see Table 1. For cross-border trips, the GC for the part pertaining to the internal travel to the border is added to a part calculated for the crossing, separate for each mode/route alternative, and this is finally added to a GC for the partial trip on the other side. The last part is given by the GC from six port zones (“shore points”) corresponding to the end points of the crossings (three on each side of the Strait) to the final destination zone. Then models are run as usual for all different trip purposes, and probabilities and number of trips are calculated for all socio-economic groups. The results are added to six demand matrices.

After this, network assignments for each of the demand matrices are carried out, forcing the demand matrix pertaining to the “car via HH route” to be assigned to the corresponding network and link in Emme/2, and the same for “PT via HH”, “car via LD” etc. (6 assignments). The total assignment is the total linkwise summation of all assignments.

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<sup>7</sup>A simultaneous choice in a nested logit framework means that the choices are made on the same level in the decision tree, i.e., the logsum parameter of one level of choice with respect to the other is 1.

This configuration could lead to inconsistencies, since a different number of alternatives will add different utilities to the logsum, which in turn influences the destination choice (model documentation and Transek, 1991). This affects mainly the walk and bicycle modes, having the number of crossing alternatives reduced from three to one; the other modes have the same number of alternatives as before. Furthermore, the approach assumes that the routes on each side of the Strait are identical, and that the unobservables (the random part of the choice) of the choice of crossing has the same characteristics as the choice of transport mode. In other words, the choice of route is already fixed before assignment of the traffic on the network. An alternative specification could have treated the choice of crossing route as a separate nest, but this was not possible in this model, because there was no knowledge about the size of the logsum parameter for that nest.

The original FREDRIK model did not include parameter values for ferry trips, why they had to be added. This was done using the parameter estimates from the work of the 1975 Öresund Commission (Öresundsdelegationen, 1978a). The relevant parameters are related to travel cost, headway and travel time. However, there was no estimate for the headway parameter, and the travel cost parameter was not specified for the ferry mode alone, but as a general travel cost parameter (which was already included in FREDRIK). These two models worked with different scales, so the *relation* between the ferry travel time parameter and the other parameters, rather than the value itself, was transferred to a ferry travel time parameter in FREDRIK.

Furthermore, Transek (1991) states that modelling travel across Öresund lies on the borderline between *regional* and *international* travel modelling, and that it is very uncertain how large proportion of the travelling of that time should be referred to one and how much to the other. When FREDRIK was developed, the latest complete survey of the travel across the Öresund Strait had been conducted in 1975/76 and was consequently already a bit dated.

### 3.3 COMVIN

COMVIN is so far the most complete and ambitious model, specialised for transport crossing the Öresund Strait. It tries to solve the ambiguity between regional and international travel modelling by including both models for short and long distance personal travel, and furthermore models for freight transport and a long-term model of land-use change, IMREL (Øresundskonsortiet, 1999a). COMVIN is the only one of the three models presented here which contains a land-use model; FREDRIK/SSV and SAMPERS/Skåne are only models of personal transport.

COMVIN was developed after the decision on the bridge had been taken, but before the opening. Its main objective was therefore not to be a decision-making tool at the level of the infrastructure investment itself, but rather a “comprehensive

strategic planning tool” for evaluating the effects of “a wide range of planning and policy assumptions”, such as:

- different fare policies on the fixed link and competing ferry crossings,
- public and private transport services,
- macro-economic development,
- changed restrictions on land-use,
- different transport policy options, e.g. fuel taxes.

Furthermore, the bridge is financed with private capital (although guaranteed by the Swedish and Danish states), so there was a need for an assessment of the future revenues for the reimbursement of the investment capital. The revenues for the Øresund Bridge Consortium depend to a major extent on the vehicle traffic on the bridge (cars, buses, lorries, motorcycles etc.), which contribute with variable, per vehicle revenues, and only to a smaller extent on the trains, which contribute with a fixed but index regulated yearly revenue.

COMVIN uses a growth factor model for total trip generation and a “pivot-point” (growth factor) method for trip distribution, which is doubly constrained in the work trip model (i.e., adjusted to fit the employment at the destination). The trip distribution for the forecast year is calculated by

$$T_i^{p(1)} = T_i^{p(0)} \cdot \frac{T_i^{p(1)est}}{T_i^{p(0)est}}$$

where  $T_i^{p(1)}$  is the number of trips generated in zone  $i$  for trip purpose  $p$  in the forecast year,  $T_i^{p(0)}$  is the survey values for trips in the base year, and  $T_i^{p(1)est}$  and  $T_i^{p(0)est}$  are the estimated trip numbers for the forecast year and the base year, respectively. They are calculated from estimated linear functions of population, income and employment (and in one case a dummy for Scania), different for each trip purpose. The ratio between these two amounts is the “growth factor”. The growth factor method is described in Ortúzar and Willumsen (2001, pp. 127 ff. and 166 ff.).

The transport modes are a mixture of mode and route choice. The mode alternatives consist of three parts, depending on where the traveller is along the route: mode on the origin side, during the crossing and on the destination side. A mode alternative can thus be “car on origin side, disembarkment<sup>8</sup> on ferry and

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<sup>8</sup>Disembarkment is the term used for passengers who are not in a vehicle when crossing Øresund.

public transport on destination side”, which would be designated “CDP”. There are six such mode combinations: CCC, BBB (bus or train all the way), CDC, CDP, PDC, and PDP. In this way, it could be suspected that a dependency between the such constructed mode alternatives is introduced, which negatively affects the performance of the nested logit model (Sørensen, Nielsen and Schauby, 2001). In contrast to FREDRIK/SSV, the change in number of alternatives is handled by levelling differences in the utility functions that do not reflect true differences in the travellers choice situation. These differences occur both in the mode choice and the choice of crossing. In practice, the amount  $\ln K$  is subtracted from the utility function, where  $K$  is the number of alternatives facing the traveller.

### 3.3.1 Known limitations of the model/Validation issues

Rather soon after the opening of the bridge it was clear that the predictions made with the COMVIN model were exaggerated. If not immediately—the bridge opened in the midst of the peak season in summer 2000, and with the “novelty effect” the actual traffic was a bit higher than normal—at least during the following autumn and winter months, the daily number of vehicles had decreased to about half of the predicted vehicle traffic on the bridge. However, the passenger numbers on the Øresund trains on the bridge exceeded the predicted ones. In total, the number of single trips<sup>9</sup> on the bridge, and across the Øresund Strait including the ferries, increased and is still increasing (+30 % from 1999 to 2002). Still, the model forecast was regarded as a failure, and in February 2002 the Øresund Bridge Consortium decided to discontinue their work with the COMVIN model<sup>10</sup>.

In Sørensen et al. (2001) and Bruzelius and Holmberg (2002), the main drawbacks and possible sources of error of COMVIN are listed. Bruzelius and Holmberg (2002) includes a more or less complete internal validation of COMVIN. Among the points taken up in these papers we especially note:

- the dependence between different mode choice/choice of crossing alternatives;
- the use of incremental models for trip generation (growth factor method) and choices at all levels, which requires that the changes in utilities be small;

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<sup>9</sup>A single trip represents one person travelling one way.

<sup>10</sup>In order to estimate the actual price elasticity on the bridge, a real world experiment is conducted during 2003. The elasticities calculated by the COMVIN model, as well as those calculated from a series of revealed preference studies, made twice a year since 2000, have all been regarded as too high by the Øresundsbro Consortium. This should be seen in the context of the view from parts of the public, and also from some researchers, that the toll on the bridge should be lowered in order to increase social benefit.



- a missing alternative for park-and-ride on the Swedish side, with parking in direct connection to the last railway station before the bridgehead (in Svågertorp);
- destination choice and attraction parameters that are zero for trips on the same side, and positive for cross-border trips. In combination with the incremental design of the model, this means that trips across the Strait will be increasingly attractive the more distant in the future the forecast horizon is set, while trips on the same side remain at zero utility (Øresundskonsortiet, 1999a, p. 35). The documentation states (on the same page) that these coefficients are estimated from the destination choice of travellers crossing the border (in “sectors B and C”, see in subsection 3.5 below), but not why trips on the same side (“sectors A and D”) are not included in the estimation. The choice between the sectors A–D is used for the estimation of the barrier parameters, why the data might have been considered exhausted for this purpose. Furthermore, COMVIN was primarily designed for the modelling of cross-border trips (a “corridor model”), which could be another explanation;
- the initial distribution of vehicles taking the southern crossing (Limhamn-Dragør or, from 2000, the fixed link) versus the northern (Helsingborg-Helsingør) was modified in the long-distance model in favour of the fixed link alternative, since early model results yielded higher market shares for the fixed link than for the Limhamn-Dragør ferries. Thus, because the model is incremental and dependent of a reasonable starting value, the real share of vehicles taking the southern route, 18 %, was increased to 35 % in the base year. This resulted in a predicted 70 % share of the long-distance cars the bridge versus Helsingborg-Helsingør. The real outcome of the shares is about 60 % for the link (COWI, 2001a, 2001b, 2002a, 2002b );
- according to Bruzelius and Holmberg (2002), the prices in the opening year were actually lower than in the forecasts, depending on competition from the ferry lines in the northern part of Öresund. However, this error would work towards a better fit of the forecast;
- car availability is modelled as shares of the households with a car available (different for different trip purposes), which are increased by zone with an exogenous rate of change (common for all purposes), applied on the *percentage* (“pro rata”). This means that the higher the original share, the greater will the growth in car availability turn out. In principle, in the long run this could lead to shares above 100 %.

### 3.4 SAMPERS/Skåne

SAMPERS consists of five regional models, a national long distance model, and an international model. The model used here is the submodel for Scania, which also includes the Greater Copenhagen area in Denmark. The model was delivered during 2002 and is still being developed. For this reason, no forecasts have been made with SAMPERS with respect to the traffic across Öresund. Anyhow, the model was calibrated on the network level (in Emme/2) to fit the traffic in the base year 1997. A similar calibration has been made for the year 2001 (which is the first full year of the situation with the fixed link), although based on socio-economic data from 1997 <sup>11</sup>. Fares and time tables in public transport and travel are at 2001 levels, and the network scenario is associated with 2010, and besides the fixed link includes the City tunnel, which is a railway tunnel underneath Malmö. It has not been possible to combine the regional model with the national long-distance model or the international model <sup>12</sup>. This means for example that comparisons with COMVIN are limping, in that COMVIN also accounts for through traffic to and from all European countries north and south of Öresund. In FREDRIK, this is handled by “remote nodes” which account for all travel demand and attraction outside the model area. The through traffic accounted for about 33 % of the trips, measured in number of passengers, and 40 % of the car traffic in 1999.

With the SAMPERS scenario calibrated on 2001 trip levels, it should be possible to make an *ex ante* forecast with the historical 1997 SAMS data. Having “full” information about both the before and the after situations (although the after situation, unfortunately, only based on 1997 SAMS data), we can assess the model error directly (number 2 in Figure 1). The other approach would be to await the 2001 year SAMS database (with an update on the Danish side) and run the model calibrated on 1997 trip levels on this new dataset.

### 3.5 Treatment of the barrier

The part of the modelling venture that is most difficult and susceptible to errors is perhaps the calibration and forecasting of the travel across the barrier between the two countries—which in the Öresund case is also the very purpose.

Historically, the cross-border trade in Öresund has varied with not only the general economic development and business cycles, but also with the differences in the supply and taxation of specific goods, like coffee, sugar, butter, and especially

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<sup>11</sup>Paul Larsson, Banverket (the Swedish National Rail Administration). Socio-economic data (SAMS) for 2001 will be available during 2004. It seems however that this will not contain an update of the data on the Danish side.

<sup>12</sup>The reason is that the networks used in these models are quite extensive, and require a larger license key than the one used here.

alcoholic beverages. After the bridge opening, the yearly rate of Danish citizens relocating to Sweden have quadrupled (from around 500 persons per year in 1997 to 2,200 in 2002), much because of the lower real estate prices. Keeping their jobs in Denmark, where wages are higher, this means an equal rise in the commuting over the Strait. The number of commuters is now estimated to 6,000 (in 2002), a doubling compared to 2,000 (Öresundskomiteen, 2003)<sup>13</sup>.

Relocation of households is only treated in the COMVIN model, run together with IMREL (which only includes work trips). The effect of including IMREL land-use changes is an increase of the passengers crossing the Strait with 8 % and in the number of cars with 16 %. Dynamic changes in the barrier is not handled at all in the models; in COMVIN, it is based on assumptions about percentual decreases of the barrier constants (economic and cultural), which are set exogenously. In the forecasts, the barrier was assumed to decrease by 30 % immediately after the opening.

The models differ in the treatment of the cross-border trips in at least two respects: the modelling of the mode/route choice across the Strait, and the calibration (see also Table 4, page 19). In FREDRIK, the mode choice and choice of disembarkation point is modelled as one simultaneous choice: for each mode alternative (car, train or passenger by foot) there are different number of alternatives for the crossing (HH, MC or LD)—see subsection 3.2. The calibration is carried out via multiplicative constants, separate for each purpose.

In COMVIN, trips in the short distance model, which encompasses the Greater Copenhagen area (Hovedstadsområdet, HOV) and Scania, are divided into four categories, representing each one model: A, B, C and D. A and D trips have origin and destination on the same side (A on the Swedish and D on the Danish side), B represents trips from Scania to HOV and C trips in the opposite direction. As in FREDRIK, only the modes available at that crossing are considered. Trips in A and D do not change mode during the trip, i.e., they either take car or PT. The trip matrices from generation and destination steps are divided according to car availability for the modes including car. Barrier constants (for “cultural”, “economic” and “composite” barriers, where the constant for latter is the sum of the two previous) are estimated from logit models for each of the trip categories B and C, from the shares of Swedish and Danish travellers in different directions of travel and of total travel. A questionable assumption in this context is that the labour market is already homogeneous in the Öresund region<sup>14</sup>, and thus that the economic barrier is the same for a Swede and a Dane going to Denmark, as well as it is the same for a Swede and a Dane going to Sweden. The monetary values,

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<sup>13</sup>However, nothing is said about the frequency of the commuting. Also, different sources do or do not include studying commutes in this figure.

<sup>14</sup>Not segmented with respect to occupation.

	Scania to HOV			HOV to Scania		
<b>Trip purpose</b>	<b>Comp.</b>	<b>Cult.</b>	<b>Econ.</b>	<b>Comp.</b>	<b>Cult.</b>	<b>Econ.</b>
<i>Work</i>	+31	−44	+55	−245	−41	−219
<i>Shopping</i>	+168	−32	+198	−43	−33	−10
<i>Business</i>	−49	−63	+11	−8	−54	+43
<i>Other</i>	+18	−42	+56	−4	−38	+30

Table 2: COMVIN: The estimated composite, cultural and economic barrier constants in monetary values. HOV = Greater Copenhagen area. Source: Øresund Consortium (1999), p. 39.

based on the other estimated parameters in the utility functions, of the barriers are shown for different trip purposes in Table 2.

In SAMPERS, the crossing is handled entirely in the network assignment (Emme/2) system. The bus mode in the network is adjusted by new volume-delay functions into “ferries” across Öresund, and costs for headway and travel time are calibrated to fit actual cross-border traffic.

One of the rationales to use the solution for FREDRIK, with a route choice included in the model, was that big “lumps” of transport demand, represented by remote nodes for long-distance trips, could make the trip assignment across Öresund very unstable (the long distance travel represented 40 % of the travel across the Strait at the time). In SAMPERS, this danger is partly mitigated by the method to surround the model area by large border zones, and besides, national and international travel are handled in separate models (which are not included in this study).

### 3.5.1 Processes of integration

In order to sort out different sources of forecast errors, we need in particular an interpretation of the nature of *integration* across the border. As shown in Table 3, there is not just *one* process of integration but several, and they all exert influence on different parts of the travel flows. As a consequence, assumptions about the integration process concerns different parts of the model, and the performance of each one of these submodels affects the performance of the model representation of the integration process. As an illustration, we can sort out the following processes of integration, their influences on travel pattern and their respective submodel (trip purposes are borrowed from the COMVIN model)(see Table 3).

Process of integration	Affected (cross-border) trip purpose	Submodel
migration	commuting	disaggregated population forecast and trip generation
land-use change	commuting, business, freight	land-use model (e.g., IMREL)
reduction of cultural or economic barriers	all, but differently: + commuting, business, other, freight; – shopping	destination choice

Table 3: Processes of integration, affected trip purposes and associated submodels.

### 3.6 Car ownership

The models use different approaches for car ownership forecasts: in the SSV implementation of FREDRIK, no specific car ownership model was used. Car ownership was increased by simple growth factors, applied on the ratio of car license holders per household. The growth factors differ for four categories of built-up areas: Copenhagen, Malmö, the rest of the Greater Copenhagen area and the rest of Scania. Forecasts of car ownership were based on the forecasts of Transportrådet (1989), which in turn were based on assumptions on private consumption, petrol price and investments in public transport. In their base scenario, a balanced growth between car and public transport was projected: an expanded public transport and dampened growth of car ownership in the denser regions, and the opposite development in smaller cities and sparsely populated areas.

In COMVIN, car ownership shares are calculated on the basis of the stated preference studies by zone and trip purpose. These shares are increased by an exogenous rate of change on the share (“*pro rata*”); in the forecast of 2000, this rate was 0.5 %, uniformly applied in all zones. In SAMPERS, a cohort based car ownership model is implemented, based on individual entry and exit propensities for car ownership (SIKA/Transek, 2000; Jansson, 1989). The model was developed by the Swedish National Road and Transport Research Institute, VTI (Jansson, Cardebring and Junghard, 1986) and gives zonewise car ownership levels. The main independent variables are income, fuel price, age and the proportion of company cars in the car fleet. However, as SAMPERS is modular, it is up to the modeller to include a car ownership step in the forecasts or not.

	FREDRIK/SSV	COMVIN/ Short Distance	SAMPERS/ Skåne
Base year	1990	1995	1997
Estimation data	Øresund Comm. 1975, RVU 1978, 1984	SP/RP data 1995/96	RVU/RES 1994–97
No. of zones	340	53	948 (SE) + 381 (DK)
Network	Emme/2	TRIPS	Emme/2
Geographic scope <sup>a</sup>	HOV + Scania	HOV + Scania	HOV + Scania + adj. SE coun- ties
System scope <sup>b</sup>	R-to-R, R-to-G, through trips	R-to-R, R-to-G, through trips	R-to-R
Trip purposes <sup>c</sup>	w, b, sc, se, sl, r, sh, o, K, v	w, b, sh, o, K, sa	w, b, sc, sl, r, o
Modes	car, public transport, walk, bicycle	car, train, bus, ferry, walk	car, bus, train, etc.
Barrier treatment	calibr. constant, in Distribution step	estimated from SP data, in Dis- tribution step	in Assignment (time and cost matrices)
Land-use model	no	IMREL	no

Table 4: Summary comparison of the models. <sup>a</sup> HOV = Hovedstadsområdet, Greater Copenhagen area. <sup>b</sup> R = regional, G = global. <sup>c</sup> Trip purposes: w (work), b (business), sc (school), se (service), sl (social), r (recreation), sh (shopping), o (other), K (Kastrup), v (vacation), sa (just sailing).

### 3.7 Model comparison

Here we compare the models in terms of *model structure*, see Table 4.

Other components, except for those in the table, are tax deductions for car use, for example business car or travel to work, and parking costs. These are taken into account in both FREDRIK and SAMPERS, but they are not included in the COMVIN model.

## 4 Scenario assumptions

Here we comment on common aspects of the measurement of scenario assumptions: we have already mentioned that the scenario assumptions are multi-dimensional and partly discrete in character, and therefore do not lend themselves to one-dimensional measurements. Another feature of the assumptions is that they are often made as yearly, percentage increments (as in the case with GDP). A problem with this is that, due to the different forecast horizons, the absolute deviation from the real level in the forecast year will depend also on the time span of the forecast. Mostly, the yearly increments are also transformed internally in the models into new matrices of transport demand and cost, in absolute figures. For comparison, we should therefore transform all yearly increments into absolute values in the forecast year.

### 4.1 Early models

The early models laborated with assumptions on different locations of the fixed link (northern, HH, or southern, MC/LD route), which transport modes should be included (car, car and railway, car and special bus lane etc.) and capacity (2, 4 or 6 lanes). The scenarios presented in Figures 2 and 3 (pages 22–23) represent the scenarios that best agrees with the actually chosen one: a 4-lane combined car and train link in MC/LD.

### 4.2 FREDRIK/SSV

FREDRIK/SSV was run with several alternative scenarios, varying types of fixed link, crossing charges (several combinations of pricing schemes, varying the relative price levels of the northern and southern routes, differentiated or non-differentiated public transport charges etc.), rates of GDP growth (1.6 % and 2.2 % per year, according to the Long Term Forecast in 1987 and in 1990, Ministry of Finance, 1990)<sup>15</sup> and forecast year (2000 and 2020). In this way, a sensitivity analysis of the model is made: if important determinants (in this case, GDP/income growth) of the model are changed, the span of possible outcomes/forecasts can be observed. The scenario used here is the one with the best agreement as regards GDP growth and crossing charges (LU90, scenario S1 in Transek, 1991).

### 4.3 COMVIN

The macro-economic variables relevant for the forecasting in COMVIN were total income, population and employment.

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<sup>15</sup>The Long Term Forecasts are abbreviated LU87 and LU90.

The exogenous variables (on the demand side) in COMVIN include population change, change in car availability, change in land-use (for residence and employment), fuel price and fuel consumption, income change, GDP change, inflation, and employment change. On the supply side we have passage time and check-in (waiting) time for all crossings between the Scandinavian Peninsula and the Continent, as well as ferry frequencies and fares (and toll in the case of the bridge).

Most of these growth rates are given on a zonal level. For comparisons, we need to aggregate them in order to obtain total growth of population etc.

#### 4.4 SAMPERS/Skåne

SAMPERS has not been used for forecasting purposes in Öresund (see however subsection 5.4).

### 5 Forecasts

First, we note some facts about the real development since the opening of the bridge in 2000: the car ferry between Limhamn (Malmö) and Dragør (Copenhagen) was discontinued already in the autumn of 1999, because of the usual low winter traffic. The original plan was to run it until the bridge opened, but not after that. The other major change was that the railway traffic between Sweden and the continent was completely transferred from the ferries between Helsingborg and Helsingør to the fixed link. Also, although the intention of officials (Governments of Sweden and Denmark, 1999, p. 55) and the Øresund Consortium was to maintain the same price level as the Helsingborg-Helsingør ferries, the prices for crossing have actually decreased since the opening of the fixed link, because of the competition between alternative routes (Bruzeliuss and Holmberg, 2002).

Secondly, we present and compare the outcome (and eventually, the performance) of the different models with actual traffic as per 2000/2001. We choose scenarios and measurement units in order to maximise comparability, and can for example choose among these:

- single trips across Öresund,
- single trips using the bridge,
- no. of vehicles across Öresund and using the bridge,
- public transport vs. disembarkment on ferries and car,
- disaggregated with respect to trip purpose.



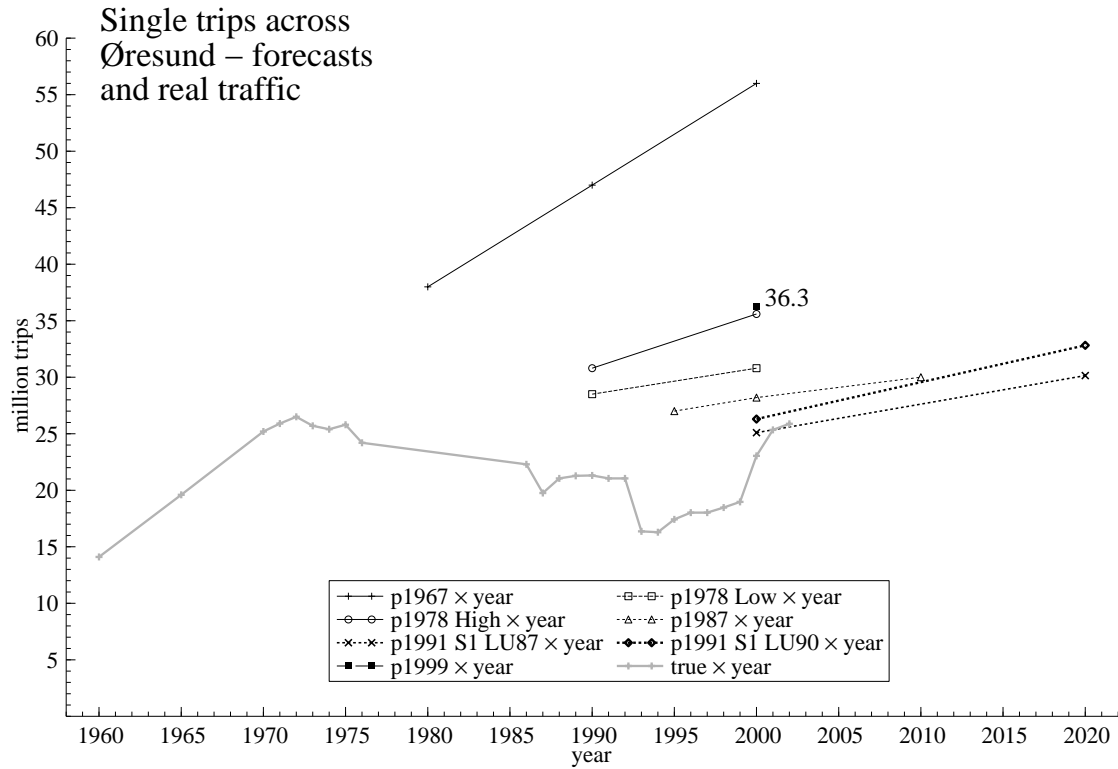


Figure 2: Total number of trips across Öresund; real traffic and forecasts 1960–2020. Between 1977 and 1984 there is no data in the figure. Sources: Bruzelius and Holmberg (2002), Copenhagen Statistical Office, Transek (1991), Öresundsdelegationen (1978a).

The basic unit of a forecast model is normally single trips, why this unit seems like a good start. The number of vehicles immediately involves an assumption about the number of persons occupying a vehicle (vehicle occupancy), which is different for different trip purposes and modes (car, bus, lorry truck etc.).

## 5.1 Early models

The results of the earlier models (the Øresund Commission in 1962, 1967, 1978 and 1989) are shown in Figure 2 and Figure 3. The first forecast, from 1962, is more or less an extrapolation of earlier growth rates into the future. The oil crisis in the beginning of the 1970's cuts the trend of the trip frequency sharply, and not until after the opening of the fixed link the trip frequencies attained the same level as in 1972. The later forecasts exhibit a less and less optimistic pattern. In the 1978 forecast, as well as in the one made in 1991, two different growth scenarios

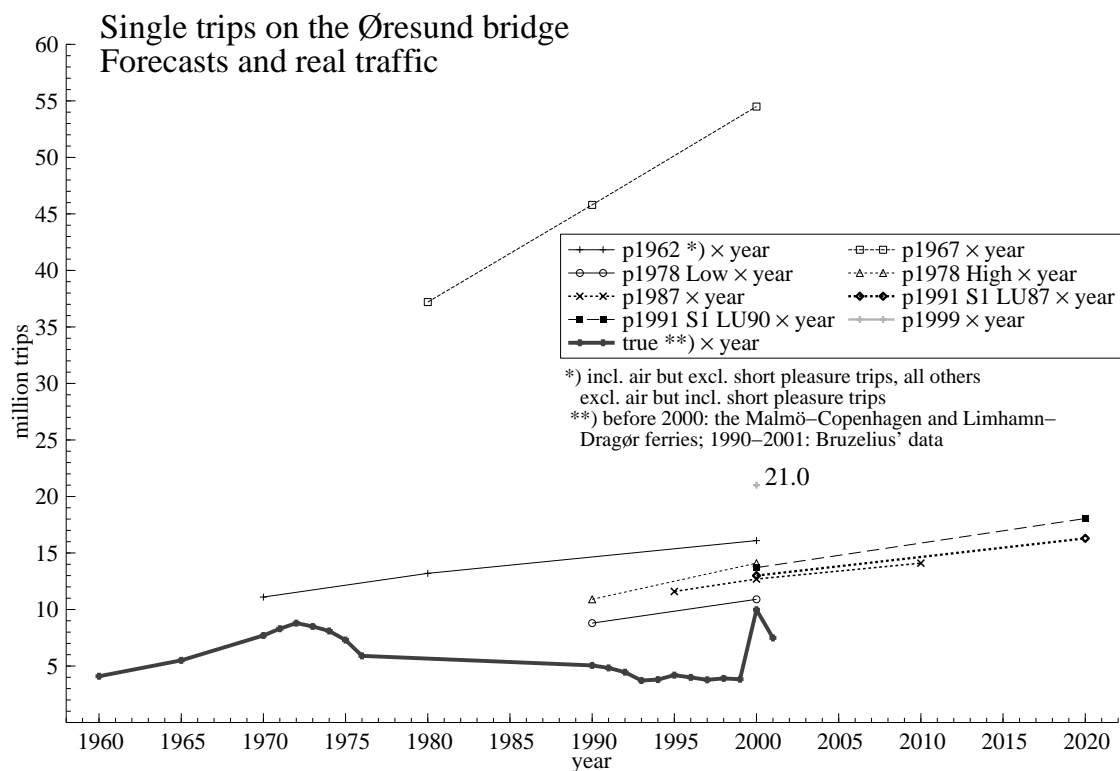


Figure 3: Trips on the Malmö–Copenhagen link; real traffic and forecasts 1960–2020. Between 1977 and 1984 there is no data in the figure. Sources: Bruzelius and Holmberg (2002), Copenhagen Statistical Office, Transek (1991), Öresundsdelegationen (1978a).

were applied for a sensitivity check. This is a recommendable way to get a sense of the variation of the model, as well as the span of possible outcomes.

## 5.2 FREDRIK/SSV

The forecasts according to Transek (1991) were 26.3 million trips in total over Öresund, and 13.8 million over the fixed link (1991 S1 LU90 in Figures 2 and 3), very close to the realised 27.3 and 14.0 millions in the second half of 2000 (extrapolated to one year) (Bruzelius and Holmberg, 2002). The corresponding number of cars, however, was not forecasted equally well: 3.3 and 2.3 million vehicles (total Öresund and fixed link, respectively) compared to the real outcome of 5.0 and 2.9 millions. In the LU87 growth scenario, the total number of trips were 25.1 million per year and 13.1 million over the link; for vehicles, the numbers were 3.1 million and 2.2 million, respectively.

## 5.3 COMVIN

The forecast of the Øresund Bridge Consortium is hitherto the most optimistic one with a predicted trip frequency across Öresund of 36.3 million per year (Øresundskonsortiet, 1999b). However, this forecast is not quite comparable with the others, since it includes some of the “integration effect” that is anticipated, due to land-use changes, changes in habits, relocations of workplaces and households, commuting across the Sound etc. The model includes a land-use model, IMREL, although it only deals with work trips. A lot of interest and effort was invested in the modelling of freight, since the traffic with lighter vans was thought to increase as an effect of the integration between the countries. It was also hypothesised that heavier trucks would take the faster route over the fixed link, instead of crossing the Baltic Sea on a ferry. However, freight traffic was *not* included in earlier models, so it has been subtracted in the numbers presented in Figure 2 and Figure 3.

The treatment of the cross-country barrier in COMVIN is the most sophisticated among the models; the development team estimated barrier constants in a logit framework for cultural and economic barriers in both directions. In the forecast including the integration effect, these barrier constants are thus set to zero, implicating complete integration—the only things that matter for destination choices are the usual attraction, time and distance factors, not whether it is on one side or the other, or if it implies dealing with Danes or Swedes, and the economic incentives are equalised across the border. But this is not the scenario reported in Øresundskonsortiet (1999b); it includes only 30 % of the integration effect, meaning that 30 % of the difference to the “full integration” scenario is added to the base scenario of “no integration”. This results in a forecast which is overstating the comparable equilibrium flows of the other models with 9.44 %.

	Scenario errors				Forecast errors			
					Tot. Öresund	Fixed link		
Model	Pop.	Emp.	GDP	Inc./cap.	trips	veh.	trips	veh.
COMVIN	−2.5	−1.4	−9.2	−5.5	25	36	52	73
FREDRIK/SSV								
LU90	−8.4	−3.1			−3.8	−34	−1.4	−20
LU87					−8.1	−38	−6.4	−24

Table 5: Scenario and forecast errors in percent for FREDRIK/SSV and COMVIN. The reference year is the forecast year, 2000.

As a result, all forecasts of short distance trips from COMVIN should be divided with 1.0944 (or 9.1 % should be subtracted). For example, the mark in Figure 2 of 36.3 million single trips per year should be adjusted downwards to 33.2 million, and in Figure 3, 21.0 should be 19.2 million in order to be comparable to the other forecasts.

In fact, the addition of the 30 % of the integration traffic was made on basis of the number of cars on the fixed link in the *short distance* model, so the numbers might not be exactly the ones presented here for single trips; different trip purposes have different car occupancy rates, and the long distance travellers are also included in the graph. The forecasted vehicle traffic (except freight trucks and lorries) was 5.0 million vehicles on the fixed link and 6.8 million in total over Öresund (compared to the real outcome, 2.9 and 5.0 million, respectively).

## 5.4 SAMPERS/Skåne

No forecasts were made using SAMPERS before the opening of the fixed link. Recently, however, a forecast of the Öresund traffic was done, in collaboration with the Danish model KRM: an assessment of the effects of a new tunnel between Helsingborg and Helsingør, in the northern part of Öresund (Atkins/Transek, 2003). The results are not really comparable to the rest in this paper, and are consequently not reported here.

## 6 Summary of scenario assumptions and forecasts

The scenario and forecast errors of FREDRIK/SSV and COMVIN are summarised in Table 5 and 6. In the future, the tables can be supplemented with for example car ownership errors, and some of the gaps hopefully be filled in. Other objective variables for the forecast errors, based on global fit measures (sums of squared residuals or information measures), are also conceivable.

	Scenario errors	
	W.P. <sup>a</sup>	G.E. <sup>b</sup>
FREDRIK/SSV, LU90	−11	−14

Table 6: Additional scenario errors for FREDRIK/SSV (percent). <sup>a</sup> Working population, i.e.,  $\geq 16$  years. <sup>b</sup> Gainfully employed.

In order to achieve comprehensive and comparable measures of the performance of different models, we can define elasticities of the forecast errors with respect to scenario errors:

$$E_{err} = \frac{\text{transport forecast error (\%)}}{\text{forecast error of scenario variable (\%)}} = \frac{\frac{\text{trp forecast}}{\text{trp outcome}} - 1}{\frac{\text{scen.var. forecast}}{\text{scen.var. outcome}} - 1}$$

When there are results from several growth scenarios, like in FREDRIK, there will be more than one point estimated of the elasticity, with the possibility to form a line or curve approximation of the total forecast error. Unfortunately, only scenario data from the LU90 scenario was readily available in the backup of the model, and it is at present unclear whether it will be possible to reconstruct the LU87 projections on this disaggregated regional scale. In the attraction data (population and employment) and category data (working population and gainfully employed) of the LU90 scenario, there are projections disaggregated on zonal level, made up by the Swedish National Road Administration.

## 6.1 Error elasticities

At this point, we can define and calculate point estimates of the error elasticities of the (total) forecast error (number 3 in Figure 1, page 5) with respect to different (aggregated) scenario variables, like population, employment, income, and car ownership. Later, when a model has been run on actual data for the forecast year, it will also be possible to calculate error elasticities of the *model* error (number 1 in Figure 1) and subsequently also the scenario error.

In the case of COMVIN, the negative sign depends on the fact that while the population and employment are underestimated by 1.4 and 2.5 %, the traffic is overestimated by 25 and 52 % for single trips (total Öresund and fixed link, respectively) to 36 and 73 % for vehicles (see Table 5). Since the forecasts of total GDP is relatively more understated than the population forecasts, the resulting GDP/capita forecast is also understated, by 5.5 %. The model performs worse for the fixed link and for vehicles.

In the elasticity with respect to income per capita (see Table 7), income refers to regional GDP per capita for Scania and Greater Copenhagen area together.

<i>Model error elasticities</i>		<b>COMVIN</b>	
		<b>Öresund</b>	<b>Fixed link</b>
single trips	population	−9.8	−20.5
	employment	−17.5	−36.9
	income (GDP/cap.)	−4.5	−9.4
vehicles	population	−14.4	−28.8
	employment	−26.0	−51.8
	income (GDP/cap.)	−6.6	−13.2

Table 7: Point estimates of the error elasticities for total forecast error in COMVIN.

<i>Model error elasticities no barrier reduction</i>		<b>COMVIN</b>	
		<b>Öresund</b>	<b>Fixed link</b>
single trips	population	−5.5	−15.3
	employment	−9.9	−27.5
	income (GDP/cap.)	−2.5	−7.0
vehicles	population	−9.8	−22.9
	employment	−17.6	−41.2
	income (GDP/cap.)	−4.5	−10.5

Table 8: Point estimates of the error elasticities, no barrier effect reduction.

According to ØRESTAT, the real increase of regional GDP<sup>16</sup> from 1995 to 2000 was 24.3 % (from 63.6 billions to 79.2 billions). The COMVIN figure was 60.6 billion USD in 1995 and 68.4 billions in 2000, an increase of 12.9 %. The resulting forecasted amount is 9.2 % less than the real figure. Since there is no agreement between the starting values, we compare the percentage growth of the separate variables to ensure consistency between data of different years. The percentage differences are calculated with the values in the forecast year, 2000, as reference.

These elasticities are based on the forecasts reported by the Øresund Consortium (1999b), which include a 30 % barrier reduction. If we subtract the increased traffic caused by this reduction (9.1 % of the reported forecasts), we arrive at a better fit and subsequently lower elasticities (see Table 8).

The error elasticities for FREDRIK are shown in Table 9. Generally the fits of the forecasts are better than those of COMVIN, they understate the real traffic by only 3.8 and 1.4 % (single trips, total Öresund and fixed link, respectively) and 34 and 20 % (vehicles). In contrast to COMVIN, FREDRIK/SSV performs better for the link and for vehicles. On the other hand, the forecasts for population and employment are greatly underestimated by 8.4 % (population), 3.1 % (total employment), 11 % (working population,  $\geq 16$  years) and 14 % (gainfully employed,

<sup>16</sup>Measured in 1994 US dollars (fixed prices).

<i>Error elasticities, LU90</i>		<b>FREDRIK/SSV</b>	
		<b>Öresund</b>	<b>Fixed link</b>
single trips	population	0.45	0.16
	employment	1.2	0.44
	working pop. †	0.35	0.13
	gainfully empl	0.27	0.10
vehicles	population	4.0	2.4
	employment	11	6.5
	working pop. †	3.1	1.9
	gainfully empl	2.4	1.4

Table 9: Point estimates of the error elasticities for total forecast error in the FREDRIK/SSV model. There are no elasticities with regard to income/GDP, because the model is based on a 1980 census and there are no data on regional GDP so long ago. † Working population is population  $\geq 16$  years.

in households). Especially the latter variable is underestimated for the Greater Copenhagen area: the forecast anticipated a *decrease* of the gainfully employed with 21.8 %, while the outcome was +1.3 %. This fact results in lower error elasticities with respect to that variable. The elasticity estimates are already very low, which is a result of the good fit of the forecast with the LU90 scenario assumptions; with the LU87 assumptions, the picture is different. The forecast errors with LU87 growth assumptions are larger,  $-8.1$  % for total trips and  $-6.4$  % for link trips, and  $-38$  % and  $-24$  % for the total and link vehicles, respectively.

## 7 Conclusions and future research

We have presented three transport models dealing with the forecasts of the Öresund traffic before and after the creation of the fixed link. We have also tried to contribute some kind of framework for comparisons between models that, despite a common theoretical base, differ in important respects. Some of the more critical features, where the models differ, are the treatment (calibration) of the barrier, the modelling of the mode and route choice across the barrier, the inclusion of land-use and other long-term (“integration”) effects, the treatment of car ownership etc. Of course, the availability of relevant survey and network data are as well crucial, but this aspect is more or less shared equally between models, often sharing the same data sources.

We have also presented a framework and the prerequisites for an *external validation* of transport models, by means of re-running an old model on a new set of data: i.e., the actual outcome of the projected scenario variables. In that way, an

estimate of the internal model error could be achieved. This might be possible in FREDRIK, for example, if data can be adjusted to the old zonal level. SAMPERS has not been used or developed for Öresund forecasts, but it could still be validated “backwards” (backcasting), for example by using a calibrated 2001 scenario and running it with data from the base year 1997. In this case, the time difference is not that great, so the effect might not be as distinct. Validation of COMVIN will prove more difficult, since it has been discontinued by the Øresund Bridge Consortium; all files are saved for the future, however.

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