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Transport infrastructure invest- ments and decision support sys- tems

Moshøj, Claus Rehfeld; Leleur, Steen; Nielsen, Otto Anker

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Claus Rehfeld

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Claus Rehfeld

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This report presents the main results of my Ph.D.-study at the Institute of Planning, Transport Studies at the Technical University of Denmark. The study period lasted from May 1995 to April 1998. In addition to this report an abstract has been accepted to the 38th European Conference of the Regional Science Association in Vienna, August 1998. Four additional papers have been published covering elements of the findings from the study. These are listed in the overview of activities.

Alongside the Ph.D.-study I have had the pleasure of working on the EUNET and CODE-TEN projects funded by the European Union as part of the 4th Framework Programme on strategic transport research.

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A number people have contributed to the completion of the study and their support, inspiration and comments deserve to be mentioned.

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Claus Rehfeld Moshøj

Institute of Planning, Transport Studies
The Technical University of Denmark

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Claus Rehfeld

II Summery

This thesis is about the planning of large transport infrastructure investments. The title of the thesis is Transport Infrastructure Investments and Decision Support Systems. The thesis is made up of two main parts. The first part forms the conceptual basis concerning the influence of uncertainty on project performance. Based on these findings an outline is made of the interrelation between uncertainty and scenario-based thinking. The first part ends up by outlining the prevailing modelling context. This outline forms the point of departure of the second part. The second part is methodological and presents a new scenario-based appraisal methodology – SEAM. The potential of the scenario-based appraisal methodology is illustrated through a case study. To accompany and illustrate SEAM a comprehensive computer model of the methodology has been developed. Each of the two parts consists of four chapters. The thesis also comprises three appendices that present information about detailed aspects relating to the second part.

Model uncertainty is often divided into exogenous and endogenous uncertainty. Through an analysis it is shown that the endogenous model uncertainty can be categorised into objective, adaptive and subjective uncertainty. A review of scenario analysis reveals the influence scenarios have on model uncertainty. These findings form the basis for a new conceptual model for the understanding of the interrelation between models and future uncertainty. This conceptual model is graphically illustrated in Figure 3.9.

A review of appraisal methodologies indicates a four-stage development that comprises the rational comprehensive planning approach, sensitivity testing, multi-criteria analysis and scenario painting. A combination of scenario painting and the conceptual model for the understanding of future uncertainty sets out the background for a methodological formulation.

The methodological formulation involves a scenario-based appraisal methodology – SEAM. This new methodology incorporates the interdependencies between models and scenarios in a context of transport planning. The SEAM methodology acknowledges the influence from possible futures on the modelling at multiple levels and hereby performs a scenario-based envelopment of planning uncertainty. Guidelines for project evaluation in a context of scenario-based planning have been included for practical application. The structure of SEAM is seen in Figure 5.1.

A computer model for practical planning incorporating the specifics of the SEAM methodology has been implemented. Along with some case study results this enhances the appreciation of what information a scenario-based appraisal methodology can provide that cannot be obtained by the use of more traditional appraisal methodologies. As a natural part of a further development the SEAM methodology includes and utilises the existing appraisal techniques as part of the approach.

The potential of the application of SEAM for the appraisal of major transport infrastructure investments has been examined by the use of the Copenhagen Harbour Tunnel case. It has been beyond the resource possibilities of the Ph.D.-study to consider and model all aspects of the project, but the calculations carried out show that a full SEAM analysis can improve the information about project consequences and robustness considerably.

Some of the features of SEAM are made possible by the use of geographical information systems (GIS). This concerns especially the assessment of impacts with territorial affiliation. The application of GIS in the modelling structure has led to the development of a new type of exposure model. This exposure model applies GIS tools for the conversion

of emissions into air pollution exposure. The use of air pollution exposure is a more realistic expression of the change in welfare than the simple calculation of emissions.

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III Dansk resumé

Denne afhandling omhandler planlægningen af store infrastruktur projekter. Afhandlingens titel er: Trafikinfrastrukturinvesteringer samt beslutningsstøttesystemer. Afhandlingen er opdelt i to hoveddele. Den første del danner den konceptuelle basis for den indflydelse usikkerhed har på infrastrukturprojekters ydelse. På baggrund af disse konklusioner beskrives sammenhængen imellem usikkerhed og en scenario-baseret tænkemåde. Den første del afsluttes med en beskrivelse af de eksisterende metodiske rammer for projektevaluering. Den anden del tager sit udgangspunkt i denne beskrivelse. Denne anden del af afhandlingen er en metodisk del, der præsenterer en ny scenario-baseret evalueringsmetodik – SEAM. Potentialet af den scenario-baserede evalueringsmetodik er illustreret ved et case studie. Parallelt med og for at illustrere SEAM er der udviklet en omfattende computer model af metoden. Hver af rapportens to hoveddele består af fire kapitler. Afhandlingen indeholder også tre appendiks, som indeholder information om detaljerede aspekter vedrørende den anden del af afhandlingen.

Modelusikkerhed opdeles ofte i eksogen og endogen usikkerhed. Ved hjælp af en analyse vises det, at den endogene modelusikkerhed kan inddeles i objektiv, adaptiv og subjektiv usikkerhed. En gennemgang af scenario analyser klarlægger den indflydelse scenarier har på modelusikkerhed. Dette resultat danner basis for en ny konceptuel model for forståelsen af sammenhængen imellem modeller og fremtidsusikkerhed. Denne konceptuelle model er illustreret i figur 3.9.

En litteratur gennemgang af evalueringsmetodikker indikerer en fire trins udvikling bestående af den rationelle planlægningsmodel, følsomhedsanalyse, multi-kriterie analyse og scenario farvning. En kombination af scenario farvningen og den konceptuelle model for forståelsen af fremtidsusikkerhed danner baggrund for en metodisk formulering.

Den metodiske formulering består af en scenario-baseret evalueringsmetodik – SEAM. Denne nye metodik inkluderer afhængigheden imellem modeller og scenarier i en trafikplanlægningskontekst. SEAM metodikken tager hensyn til indflydelsen fra mulige fremtider på modelleringen på flere niveauer of foretager herved en scenario-baseret indhyldning af planlægningsusikkerheden. Retningslinier for projektevaluering for scenario-baseret planlægning er inkluderet for den praktiske anvendelse. Strukturen af SEAM ses i figur 5.1.

En computermodel der indeholder elementerne fra SEAM metodikken, er blevet udviklet til praktisk planlægning. Sammen med nogle case studie resultater vil dette forøge forståelsen for, hvilke typer af information en scenario baseret metodik kan levere, som ikke kan opnås ved de traditionelle metoder. Som en naturlig del af en udvikling indeholder og udnytter SEAM metodikken eksisterende evalueringsmetodikker som en del af tilgangen.

Potentialet for anvendelsen af SEAM til evalueringen af store infrastrukturinvesteringer er blevet undersøgt ved hjælp af et case om en mulig Havnetunnel under Københavns Havn. Det har været ud over de tilgængelige ressourcer for et Ph.D.-studie at gennemføre og modellere alle aspekter ved projektet, men de gennemførte beregninger viser, at en fuld SEAM analyse vil kunne forbedre den tilgængelige information om projektets konsekvenser og robusthed betydeligt.

Nogle af egenskaberne ved SEAM er gjort mulige ved hjælp af geografiske informationssystemer (GIS). Dette vedrører specielt modellering af konsekvenser med rumlig effekt. Anvendelsen af GIS i modelstrukturen har ledt til udviklingen af en ny type eksponeringsmodel. Denne eksponeringsmodel anvender GIS værktøjer for en konvertering af

trafikkens emissioner over i et eksponeringsmål. Anvendelsen af eksponeringsmålet er et mere realistisk udtryk for velfærdstabet end simple beregninger af emissioner.

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1 INTRODUCTION

The future is inevitably characterised by a great deal of uncertainty. Looking back at the last century of western European history, changes have occurred that have been so radical that it could not have been predicted by simple fixed assumptions of key variables: The Wall Street crash in the 1930s, the industrial development and subsequent boom in car use, the women's liberation in the 60s, the oil-crisis in the 70s and the disruption of existing social ties, the slow economic growth in the early 1980s with the highest unemployment rate ever and the highest rate of double income families in Western Europe as well as the fall of the Berlin wall in the beginning of the 90s are just a few of many examples. Even though these examples relate to parts of the political, economic, technological or social sectors of society they still influence all aspects of transport planning and they influence each other in constantly evolving process.

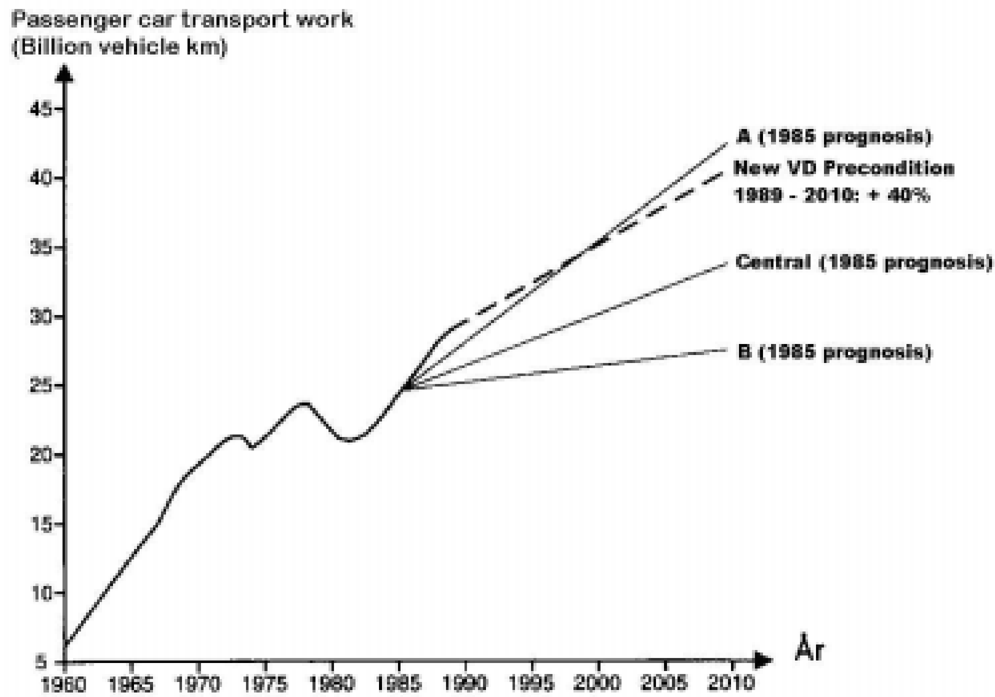
1.1 TRANSPORT PROGNOSES

In transport planning it is more often than not assumed that fundamental variables are fixed in time. And to be fair it is an approach, which has proven itself by promoting solutions that both in shorter and longer time frames have been politically viable. Politically viable in the sense that after the completion of a given network change, virtually all discussions have diminished since it proved a solution that worked without creating too severe side effects. The network change proved a satisfying solution to the problem.

Traditionally transport planning has been based on <u>one</u> set of assumptions concerning future development, potentially expanded by sensitivity analyses framing a possible area of development for certain key variables. Such a prognosis is normally based on trends found in historic data by means of more or less sophisticated statistical analyses. Forecasting methods comprise simple regression analyses, polynomial fitting, multiple regression analyses etc. For a thorough discussion see e.g. Makridakis, S. et al. (1998). A prognosis has its starting point in the present and changes are made with reference to the present magnitude and development trend of the variable. For the prolongation of variables into the future a linear development over time is most often assumed, but it may equally be a polynomial, exponential or a logistic prolongation depending on the analysis and the historic data.

The Danish Road Directorate has every 3 to 5 years made a prognosis of the expected growth in the passenger car transport work (Jørgensen, N.O. & Leleur, S., 1994). An example of such prognoses from 1985 and 1989 is seen in figure 1. The prognosis from 1989-90 is based on a regression analysis of the correlation between the gross domestic product (GDP) and the transport work undertaken by COWI (Trafikministeriet, 1990). The prognosis applied the results of the Danish national economic model (ADAM) based on the governments economic plan from 1989 (Jørgensen, N.O. & Leleur, S., 1994). This last prognosis was overtaken by the actual transport growth in 1990. In 1993 the passenger transport work amounted to 34.8 billion passenger km (Danmarks Statistik, 1995).

Figure 1 **The 1989-prognosis for the passenger car travel work until the year 2010, compared to 1985 prognosis (Jørgensen, N.O. & Leleur, S., 1994, p.280).**



It is noteworthy that the development in the transport work over the last three decades has experienced two major diversions from an otherwise continuously increasing trend. The decrease in transport work following the 1973 oil-crisis and the very long period of low-growth in the beginning of the 1980s.

1.2 PLANNING TIME HORIZONS

The time horizon of a prognosis may vary according to the certainty of the trend in question. Makridakis, et al. (1998, p.553) states that "*in the short-term, forecasting can benefit by extrapolating the inertia (momentum)…as changes in established patterns are not likely over a short time span….*" Variables are often prolonged independently on this basis in the expectation that no great influence on the key variables is probable in the time span and that their relationship remain fixed. In long term planning however, such assumptions are doubtful. Makridakis, et al. (1998, p.558) furthermore states that "*the challenge is to determine, preferably through scenarios, how such trends will affect us and how new technologies…will influence the future environment… The farther away the time horizon of our predictions, the lesser the accuracy of our forecasts, since many things can happen to change established patterns and relationships. The purpose of forecasting in such cases is to build scenarios that provide general directions to where the world … is heading.*"

Both prognoses and scenarios focus on the prediction of future key variables, but their scope and methodology are fundamentally different. A scenario as defined by Ayres (1969) is "*…a logical and plausible (but not necessarily probable) set of events, both serial and simultaneous, with careful attention to timing and correlation's wherever the latter are salient*". This definition is rooted in the 'bottom-up' tradition of scenario construction, which sees a scenario as incorporating not only the future state but also the path to get to this future state. Scenarios may however exclude a description of the path and solely constitute a description of a possible and probable future. Scenarios are discussed in greater detail in chapter 2.

The time horizon in long range planning will vary according to the planning context from only a few years to more than thirty years or even longer. One type of classification of planning time horizons is:

Table 1 A classification of planning horizons (based on Sarlos, G. 1993).

TIME HORIZON	PERIOD	DESCRIPTION
Short term	Up to 5 years	On a short-term basis an analysis will in most cases be a prediction or prognosis which offer tactical solutions to a planning problem. Predictions of this kind are relevant to minor road infrastructure investments such as bypass roads in rural areas.
Medium term	From 5 to 20 years	A medium-term time scale basis is a sufficiently long period of time for the full effect of a strategic decision to materialise. Equally, the variables may well develop over time. This opens for the possible use of scenarios. However, prognoses have and probably will continue to be used for this time span. Prognoses of this type should include quite substantial sensitivity testing of key variables
Long term	More than 20 years	Long term planning differs from the medium term by the extensiveness of the possible political, technological, economical, social and environmental changes both in structural relationships, single variables as well as parameters. In such a planning environment scenarios are helpful in widening the scope of the analyses.

A prognosis will often operate in a short to medium term time frame whereas scenarios are characterised by their rather long time horizon. A 'rule-of-thumb' for the use of prognoses and scenarios is that prognoses should be used over a period of time in which stability with respect to the starting point is likely. A scenario on the other hand, should have a time horizon of at least the same length as the economic obligation of the project or a time horizon in which the changes described in the scenario are probable (see e.g. Linneman, R.E. & Kennel, J.D., 1977). In practice the borderline between when to start using scenarios and to stop using prognoses will often be blurred.

1.3 LONG RANGE PLANNING UNDER UNCERTAINTY

Social cost-benefit analysis (SCBA) is an example of the rational comprehensive planning approach. The objective of rational comprehensive planning is the optimal use of limited funds. The methodology is comprehensive in the sense that it aims at incorporating all values, opportunities and consequences which relate to the planning problem and objectives. In the words of Rosenhead (1980a) "*the pure rational comprehensive methodology puts its emphasis on prediction and certainty, and neglects the problems which may result from uncertainties…(sensitivity analysis is a partial exception to this rule. But…it is carried out* *on decisions already singled out as optimal)*". This optimising planning approach is at risk of reducing the breadth of the planning exercise.

In the short-term, optimising planning is a feasible alternative to very comprehensive long range planning. Short-term optimal planning solutions are however not without influence in the long term. Schofer & Stopher (1979) identified some important points concerning the interaction between long range and short-term planning (adapted from Schofer, J.L. & Stopher, P.R., 1979):

- Short-term actions have long-term impacts
  The failure to assess the long-term impacts of short term actions may well lead to the adaptation of short-term strategies that in the present context seem appropriate, but which may generate new and more serious problems in the future.

- Short-term actions are rarely isolated and independent events
  Short-term actions contribute to the development of the transport system, and may foreclose other future actions. Hence short-term actions may be associated with an important opportunity cost.

- Long range planning allows the exploration of major policy or facility options
  Long range planning permits the planner or decision-maker to identify potential future problems and prepare for them in advance. Short-term planning tends to be reactive whereas long range planning provides the opportunity for normative actions.

- Avoid the clear association between the size of investment and the planning horizon
  Traditionally low capital investments are analysed through an optimising planning approach whereas only methodologies wider in scope have been applied to large-scale capital investments. For the reasons outlined above this approach should be avoided and instead the implications for future choices should be reviewed and assessed.

Due to the problems related to optimising long range planning approaches, different authors have agitated for a new broader planning framework, which explicitly deals with long range planning uncertainty. (e.g. Gupta, S.K. & Rosenhead, J., 1968; Gilbert, D. & Jessop, A., 1977; Schofer, J.L. & Stopher, P.R., 1979; Rosenhead, J., 1980a,b). Rosenhead (1980b) suggests a methodology based on robustness, whereas Schofer and Stopher (1979) advocate for the application of a scenario-based methodology. The methodology based on robustness is made up of a succession of activities (adapted from Rosenhead, J., 1980b):

1. Construct a set of measures, and agree on corresponding acceptance levels
   The measures used in transport infrastructure appraisal are often concerned with the economic feasibility of the decision, measured as the net present value or other more informal measures. The acceptance level will relate to the whether these measures jointly meets decision-maker requirements.

2. Identify a representative range of alternative futures
   The futures should be relevant, possible or likely states of the environment of the system being planned for. The selected futures must be comparatively few in number (for tractability), each representative for a range of futures differing in parameter values and selected to be meaningfully different from each other.

3. Identify a set of possible decision sequences

   The identification of possible decision sequences will involve some sort of scanning or screening process eliminating unfeasible strategies.

4. Model the consequences of different decision sequences for each identified future

   For each of the decision strategies the relevant impacts are modelled as a forecast of system performance for each possible future. The result forms the foundation for the appraisal of each planning strategy.

5. Select initial decision or decision-sets, which are components of a wide range of acceptable decision sequences, under most or all of the identified futures.

   The robustness analysis may relate either to components across strategies or to entire strategies. Based on the measures and the acceptance levels the appraisal will contain an analysis of the degree of goals achievement for each identified future.

The methodologies developed by Schofer and Stopher (1979) and by Rosenhead (1980) are however not contradictory, but form a logical unity. The remainder of this thesis is concerned with the development of an appraisal methodology for transport planning, which explicitly deals with long range planning uncertainty.

1.4 CONCLUDING REMARKS

This introduction has briefly outlined some problems about the use of prognoses for transport prediction and project appraisal in the long-term. The lack of responsiveness of the optimising methodologies to uncertainty in the planning process has been emphasised. This led to a request for a broader and more flexible planning framework of which two was outlined: One methodology based on robustness and another scenario-based methodology. The suggested methodologies involve the use of varying futures or scenarios as an integrated part of the planning process. On this basis this report aims at developing a methodology that is responsive to the general problems listed above.

Chapter 2 discusses methods and approaches for the identification of possible and probable futures in scenarios.

1.5 LITERATURE

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2 SCENARIOS AND LONG RANGE PLANNING

According to Schnaars (1987) the current methodologies for scenario construction are rooted in defence related projects at the Rand Corporation in the 1950s. One of the earliest applications of scenario techniques in the transport sector was the Chicago Area Transportation Study from 1976. Virtually parallel to this study, a Danish transport study, the Traffic 2000 study used scenario techniques. This latter study was commissioned by the Danish Academy for the Technical Sciences (ATV, 1977). Another well-known transport scenario study undertaken by Allport et al. (1986) concerned Belfast in Northern Ireland. A Danish application example is found in Brix & Kousgaard (1994). A compilation of different international transport related scenario studies is found in Pearman (1988). The literature contains evidence of a variety of scenario approaches ranging from the application of advanced mathematical operations research methods to 'soft' descriptive scenario techniques. The remainder of this chapter is devoted to the presentation and discussion of some aspects of scenario techniques in a context of multi-modal transport planning.

2.1 ON SCENARIO CONSTRUCTION

There are two main schools of thought regarding methodologies for scenario construction (Schnaars, S.P., 1987):

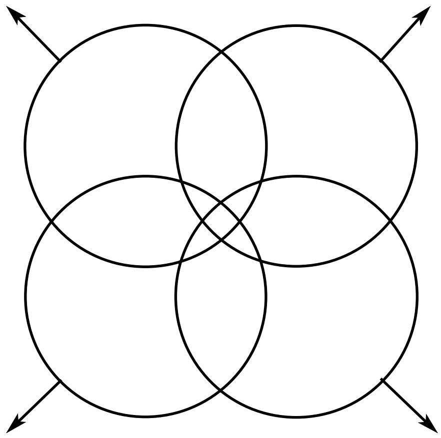
- Quantitative scenario construction
- Qualitative scenario construction

The quantitative scenarios use mathematical programming techniques for constructing scenarios based on expert judgements on probability distributions for different variables and the correlation between them. The results of these analyses are multiple scenarios ranked by their probability of occurrence. The best known examples of this approach are the Delphi-method and the Cross-impact analysis. The idea of assessing probabilities for the future is however questionable even though the fundamental rational for these methods is sound. Namely that it represents a recognition that many variables and events are interdependent (Schnaars, S.P., 1987). These methods will not be discussed in any more detail.

The qualitative methods cover a wide variety of approaches, some of which involve mathematical programming. The fundamental rational as described by a pioneer of scenario writing Herman Kahn, is that the most important part of scenario construction is to think about the problem and not deceive yourself with complex mathematical methods. Different authors have through time produced 'best-practice' lists covering the principles for scenario construction. A good overview of different approaches is provided by Schnaars (1987) for scenario construction in general and by Pearman (1988) for transport specific scenarios.

Elements in the general guidelines to qualitative scenario construction are common to all authors. One of these common guidelines concern the number of scenarios to construct. More than 4 to 5 scenarios should be avoided as a larger number makes it difficult to distinguish the scenarios qualitatively from each other (Allport et al., 1986; Schnaars, 1987). By keeping the scenarios distinct, the scenarios are arrayed in a future space and ideally they stretch out as illustrated in Figure 2. A sufficiently large share of the future space should be covered so as to include the future that will eventually arise. If the scenarios are too alike there is a risk of only covering a share of the possible future space and hence a risk of the scenarios being to narrow in scope. Such self-restriction may stem from overconfidence in key variables, a problem well known in forecasting (Makridakis, et al., 1998).

Figure 2 The future space with distinct scenarios stretched out to cover a sufficiently large proportion of the future space (based on Palludan et al. 1996).



Scenarios are normally developed by accentuating or emphasising tendencies found in the present planning environment. With respect to applying scenarios to transport planning, each scenario should "*reflect one consistent set of possible conditions, including land-use patterns, economic characteristics, population size, lifestyle (family size, labour force participation rates) and travel behaviour characteristics to which the future transportation system must respond appropriately*" (Schofer, J.L. & Stopher, P.R., 1979). Another point promoted by Pearman (1988) is that some attention should be paid to any higher-level scenarios, as to avoid inconsistencies. Otherwise there may be a risk of reducing the acceptability of the scenario in the decision-making process. This should however not reduce the breadth of the scenario construction process. This also stresses the importance of including decision-makers in the scenario construction process. Particularly as concerns the arraying and definition of important variables and interrelationships, so that the decision-maker participates in the definition of the planning environment. From an application point of view the decision-maker's acceptance of the preconditions for the planning is imperative.

2.2 SCENARIO TYPES

Pearman (1988) subdivides qualitative scenarios into two major groups according to their starting point:

- Top-down scenarios
- Bottom-up scenarios

A 'Top-down' scenario is constructed through a (holistic or normative) specification or description of a possible and probable future. 'Bottom-up' scenarios on the other hand have their starting point in the most important input variables relevant to securing the consistency of the scenario. A further dimension to the general scenario classification is whether the scenarios include an explicit dynamic or path by which the future is reached. According to both Schofer and Stopher (1979) and Pearman (1988) little attention has generally been paid to the path in transport applications. This path may be normal or routine implying a future similar to the present, evolutionary in some direction or even revolutionary (Bourne, 1982). In transport planning the path is as important as the future state to the assessment of project performance. This will be discussed in greater detail in chapter 4. Some main types of scenarios are:

- Normative scenario
  Fulfils a given set of objectives at the end of the time horizon of the scenario. The planning objectives may in many cases be attained by different means. As a consequence these scenarios offer the possibility of making an analysis of the efficiency of a strategy.

- Extreme case scenario
  Extreme case scenarios involving force majeure such as war, significant economic recession, revolution or other very improbable occurrences should not be considered. Such abnormalities in society are avoided due to their extremity and their low probability.

- Project specific scenarios
  The scenarios are written with a view to reflecting the consequences for a given project in order to assess whether these will be good, bad or neutral. This type of scenario equally well includes the maximum cases developed to test project efficiency, such as e.g. a significant land-use development scenario.

- Probability of occurrence
  By assessing the probabilities of the different scenarios it becomes possible to apply probability theory to the planning problem. It should be noted that probabilities have a tendency of giving unwarranted security. The future is by definition unpredictable and consequently probabilities have little meaning.

- Inductive scenario
  Emphasis is put on one key variable, such as the economic development, the development of the European Union etc.

- Deductive or thematic scenario
  Thematic or deductive scenarios are also sometimes known as scenario writing and are normally based on a societal logic found in the present society and given a qualitative description defining a possible and probable future. The description may include quantitative measures.

The general classification of scenarios provided above does by no means imply that the options are contrasting. Moreover they exemplify some broad types of approaches to scenario construction. Many scenario studies do in practice incorporate elements from many of the scenario approaches described above. Elements from each scenario type may be mixed to obtain the best composition of scenarios applicable to the planning context.

2.3 SCENARIOS IN PHYSICAL PLANNING

Upon defining the planning environment it may be helpful to break the system down into its components. One approach involves three levels. The first level concerns the overall structure of society. The second level concerns general groups of variables or determinants that make up the domain of each sub-system, and finally the third level concerns indicators and development variables. Indicators may be quantitative as well as simple qualitative descriptions. The transport sector is under influence of a wide variety of determinants relating to all elements of society.

Depending on the scenario approach an appropriate definition of the planning environment may take place sooner or later in the scenario construction process. The most likely procedure involves an iterative approach, as the impact of each scenario is becoming fully perceived. A hierarchic matrix illustrating the planning environment and its determinants and indicators and development variables applicable to transport planning is illustrated below.

Table 2 Suggested hierarchic division of the planning environment into determinants and indicators/variables for the use in scenario construction. The development variables and indicators column offer an incomprehensive list (based on Sarlos, G. 1993 & ATV, 1977).

SUB-SYSTEM	DETERMINANTS	INDICATORS/DEVELOPMENT VARIABLES
International economic system	World economic growth Cost of raw materials International labour division	-Descriptive -International economic growth -Cost of petrol -International trade agreements
Socio-economic system	Demography Urbanisation Economic growth Industrialisation	-Size of the population -Age distribution -% urban population -Car ownership -Economic growth rates -Descriptive
Social system	Family structures Labour market	-Descriptive -% single households -Social preferences -Weekly working hours
Political system	Social policy Land use policy Industrial policy Transport policy Economic policy Environmental policy Energy policy International agreements	-Income redistribution -Residential location -Industrial location -GDP structure -Transport system structure -Taxation structure -Descriptive -National/International regulation
Environmental system	Global environment Regional environment Local environment	-Global environmental quality -Regional environmental quality -Local environmental quality -Descriptive
Technology associated system	State of the technological evolution	-Descriptive of new technologies -Load of lorries

The application of a hierarchic structure is a way of minimising the risk of inconsistencies in the scenario. Scenarios should always be assessed with respect to their consistency and plausibility in order to achieve both political and public acceptance. The coherence is assured by a logic hierarchic structure of the determinants and indicators, which makes interdependencies obvious through correlation or description. Plausibility is assured through:

1. A comprehensive inclusion and assessment of variables and indicators
   This involves the inclusion and assessments of the sufficient number of variables in order to distinguish one scenario from the other, and keeping all other variables fixed. In this way the general tendency of the scenario remains clear.

2. A plausible description of the development of change over time
   Not all variables evolve linearly or equally fast for that matter. Some interdependencies involve delays, some changes are very intense over a short period of time, others again develop more continuously. Each scenario should be assessed with respect to a plausible and consistent development profile.

The assessment of each development variable or indicator should be related to the present in order for decision-makers and the public to evaluate the plausibility of the changes.

2.4 A REVIEW OF DANISH TRANSPORT SCENARIO STUDIES

As an illustration of different scenario types, three Danish scenario studies are reviewed. Their development was quite different both historically as well as with respect to the planning context. The review offers an overview of different approaches to obtaining scenario consistency and plausibility. The two first scenarios, Traffic 2000 and the Elsam scenario study, were constructed during the 1970s and 80s, whereas the most recent 'The Future of the Transport Sector' is from 1995. The latter will be discussed in the most detail.

2.4.1 TRAFFIC 2000

In 1972-73 the Danish Academy for the Technical Sciences (ATV) funded a research project whose aim it was to assess the influence of possible futures on the transport sector for the year 2000 (ATV, 1977). This is the earliest application of scenarios in the transport sector in Denmark. The scenario study, which is quite renowned, was constructed in the period 1975 - 1977. The study was inaugurated due to a growing discussion of the worlds limited natural resources and the emerging environmental problems. In the beginning of the 1970s the car consumed between one fifth and one sixth of the energy used in Denmark, and the acceptability of this was questioned. Particularly the debate book 'Limits of growth' added to this discussion (Meadows et al., 1972). At the same time the sudden oil-crisis showed that the continuous economic growth experienced through the 1950s and 60s would perhaps not last forever.

The objective of the scenario study was to analyse the consequences of a combination of specific transport policies and economic growth rates. The Danish economy was assumed to pass through either a period of high or low economic growth which was combined with two transport policy strategies. This amounted to four scenarios. A Fifth scenario involving planned low growth was equally included. The five scenarios developed in this study are seen below in Table 3.

Table 3 **The Traffic 2000 scenarios (ATV, 1977).**

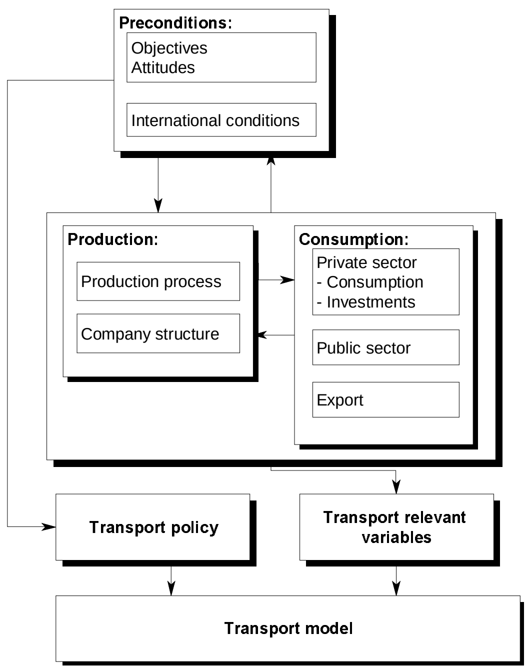
BASE YEAR 1975 SCENARIO YEAR 2000	INDIVIDUAL TRANSPORT POLICY (I)	PUBLIC TRANSPORT POLICY (K)
High Growth Society (HV)	HVI	HVK
Crisis Society (KS)	KSI	KSK
Planned Low Growth (PL)		PL

The scenario writing was based on significant feedback between an economic model and the scenario writing. The reason for this was twofold (ATV, 1977):

- To assure the consistency of the assumptions, both internally and with respect to higher level scenarios
- The description should include the necessary information in order to perform the transport analyses

The scenarios were thought of as a series of extreme cases. If a general trend should occur in all scenarios, it was argued that these were likely predictions as opposed to those predictions that differed significantly between the scenarios. The structure of the planning environment is illustrated in Figure 3.

Figure 3 **The structure of the modelling system used in the Traffic 2000 scenario study. The structure was two-stringed consisting of a quantitative modelling part and a qualitative descriptive part (ATV, 1977).**



The scenarios were made up of the following main components:

Table 4 Overview of the five scenarios in the Traffic 2000 study (based on ATV, 1977).

SCENARIO	SPECIFIC	COMMON
HVI	Individually oriented transport policy. Significant investments in road infrastructure.	Growth of 4 % in the gross income per year. Increased international labour division. Continuation of the economic growth from 1960s. Unchanged income distribution.
HVK	Public transport oriented transport policy. The environment and traffic safety are main factors. Taxation directed at individual transport. Significant investments in public transport.	
KSI	Individual transport oriented transport policy and a reduction in the public transport service. Reduction of energy use important. Reduced investment rate for transport infrastructure.	Reoccurring economic crises. Growth of 1.3% in the gross income. Increasing social division. The development of the European community is hampered. Increased unemployment and limited public funds
KSK	Public transport oriented transport policy. Some weight is put on the environment and traffic safety. Taxation directed at individual transport.	
PL	Public transport oriented transport policy. Change in attitudes as concerns material goods and priority is directed at the environment and leisure time. The service sector is particularly important. Traffic calming and public transport improvements are the main concerns in the transport policy. Strict land-use policy.	Planned low economic growth. Economic growth of 1.5% in the gross income per year. Reduction of the working periods

On the basis of each scenario a number of key variables were assessed on a national level. The passenger transport analyses were performed by the use of a sequential model that involved several steps:

1. A regional centre-model for urbanisation, population and production.
2. Family structure model
3. Income model
4. Car ownership model
5. Car accessibility model
6. Trip production model
7. Travel pattern model
8. Modal split model
9. Public transport service

A similar model was developed for the goods transport. The model included 19 different production sectors. The model included the following steps:

1. Specification of distribution pattern
2. Assessment of quantities
3. Assessment of trip lengths
4. Determination of market shares for road, rail and short sea shipping

The modelling approach was used for an assessment of the key variables. These included the transport work for goods and people, the number of accidents, the energy consumption, the modal split etc. One of the main results was that regardless of the development in the economy and the choice of transport policy, the passenger transport work would only change slightly until the year 2000 (55 billion passenger km ± 27 % were the figure in 1975 was 50 billion passenger km. In 1993 the figure was approximately 71 billion passenger kilometre (Danmarks Statistik, 1995b)). It also showed that the modal split is relatively insensitive towards the transport policy and only quite substantial initiatives can alter this fact. The number of cars was however quite sensitive from one scenario to the next. The crisis scenario assessed the number of cars to between 1.2 and 1.4 million whereas the in the growth scenarios the number was between 2.1 and 2.5 million cars (in 1993 the number was 1.6 million (Danmarks Statistik, 1995b)). Accordingly the access to cars is substantially different between the scenarios. It proved very difficult to assess the goods transport as it turned out to be very sensitive towards the structure of production. Limited changes were found with respect to the modal split for goods (8-11% for rail and 11-15% for short sea shipping). The energy use and the accidents did however vary significantly between scenarios. In the growth scenario the energy consumption is estimated to increase with about 45% and the number of accidents by 18%, whereas the low growth scenarios experienced reductions of approximately 30% and 65% respectively.

2.4.2 THE HIGH-SPEED RAIL STUDY

Elsam is a major electricity producer, that had a number scenarios constructed for the energy sector in 1993 (Elsam, 1993). This study is included in this review for two reasons:

- To illustrate the wide applicability of well worked out scenarios, since they often include a broad enough description of societal determinants to be applicable in other sectors.
- The scenarios have been used in an evaluation study of a possible high-speed rail connection between Copenhagen and Hamburg (Brix, J.W. & Kousgaard, U., 1994).

The planning horizon for the scenarios is the year 2010.

Table 5 **The Elsam scenarios which were originally developed for the energy sector (Elsam, 1993). The scenario have however also been applied to a high-speed rail appraisal study.**

BASE YEAR 1993 SCENARIO YEAR 2010	SCENARIO
European integration and economic growth	Growth
Economic stagnation and uncertainty	Crisis
European disintegration and sustainable development	Environmental

On the basis of the general tendencies and structure found in the Elsam scenarios Brix and Kousgaard (1994) developed the scenarios further. The key elements are found in Table 6.

Table 6 The Elsam scenarios with the general planning environmental conditions and the transport related additions from the Brix and Kousgaard study (1994).

SCENARIO	GENERAL	TRANSPORT RELATED
Growth	Continued European integration with the Eastern European countries. The political climate is pragmatic and even though environmental issues are important changes are slow. The importance of borders is subsiding	Significant increase in cross-border transport. Increasing efficiency of the car and air transport compared to rail. The transport policy will attempt to get more goods transport to use rail
Crisis	Europe is to an increasingly larger degree experiencing unrest and civil wars. The war in the Balkans is just the beginning. The transition in Eastern Europe is slow and authoritarian regimes are re-emerging. The economic growth is slow and the European integration is stagnant.	There is recession or stagnation in the transport sector. Price becomes the primary competition parameter.
Environmental	The development towards an increasingly integrated Europe stops and disintegration commences. The national identities are increasingly important and international agreements are becoming bilateral. The environment, health and sustainability are key issues	The transport policy aims at reducing the negative impacts from transport and promoting rail transport over road transport. The international traffic will increase at a lower growth rate.

On the basis of the general tendencies found in each scenario, a weight profile expressing traveller preferences with respect to a variety of impacts was assessed (through a limited stated preference survey). These weight profiles were used to generate shadow prices for the impacts. These unit prices were used for all years in the planning period.

Based on the shadow prices a number of high-speed rail solutions from Copenhagen to Hamburg were appraised. The analyses assumed that a fixed link had been built between Germany and Denmark across Fehmarn Belt. The bridge itself was however not included in the survey.

The study applied a scenario-based evaluation procedure based on the first year rate of return to perform a robustness analysis of the investigated projects. This was equally combined with a sensitivity test for different preference sets within each scenario.

2.4.3 THE FUTURE OF THE TRANSPORT SECTOR

In 1995 the Danish Ministry of Transport and the Transport Council commissioned a scenario study from the Institute of Future Research in Copenhagen (Palludan et al., 1996). The objective was to form the basis for a discussion of the future transport policy. Each scenario was assessed with respect to what the expected future transport work would be. Each scenario was constructed around a trend found in the current society. These trends are:

- Deregulation in the transport sector
  Due to EC directive 91/440 the transport sector is becoming deregulated. The former national railroad companies must be divided into an infrastructure provider and a transport supplier, making room for competition between private rail transport operator. The same applies to air transport, where national companies have had some sort of monopoly on

certain destinations. In order to survive alliances are emerging between airline companies. This may also happen in the railroad sector in the future.

- The increasing environmental awareness
  The environmental awareness is increasing at all levels of society. Ecology and sustainability are key concerns in agriculture as well as in transport. The local values and self-regulation are seen as measures against the international deterioration of the environment. The sensitivity towards air pollution is increasing even though the level of emissions has been relatively stable for many years (Danmarks Statistik, 1995b). The global heating is a concern for many.

- Continuing European integration
  Many Eastern European countries are on the brink of entering the European Union. The common currency seems to be a reality within a foreseeable future, and an increasing amount of decisions are being taken at an international level. The United Nations are attempting to play a central role in attaining international agreement on global heating as well as in peace keeping missions.

- The technological development
  The engine efficiency of passenger cars has been increasing over the last 20-30 years and may well continue to do so. The decision of the State of California in The United States to require that a fixed percentage of all cars sold must be low emission vehicles by a given year, has increased the research into battery technology and alternative combustion. This may well lead to a technology jump in a foreseeable future. Also, the home computer is becoming so widespread that working at home is becoming an option.

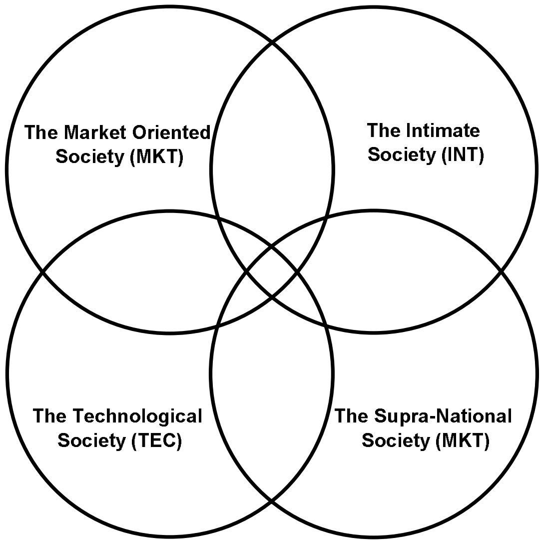
On the basis of these trends four scenarios were constructed forming possible and probable futures for the transport sector. The scenario horizon is the year 2015 by which time each trend is assumed to be fully fledged. The scenarios are:

Table 7 The four scenarios from the scenario study 'The future of the Transport Sector' (Palludan et al. 1996).

BASE YEAR 1996 SCENARIO YEAR 2015	TREND	THEME
Economic growth and European integration	Liberal economic thinking	The market oriented society (**MKT**)
Emphasis on local society and soft values	Social soft values	The intimate society (**INT**)
European integration and international environmental agreements	Global Environmental problems	The supra-national society (**SUP**)
Technological revolution	Technological development	The technological society (**TEC**)

The scenarios were based on a coherent and plausible logic formed around the trends listed above. The scenarios were presented as 'stories' constructed from 'what-if' questions as part of the process in order to secure the internal logic of each scenario. How would we behave, legislate, use our technology etc. provided that certain conditions prevail. The scenarios are seen as extreme in the sense that it is hard to imagine a future that purely reflects one scenario. The future will most likely consist of elements from all scenarios. This is illustrated below.

Figure 4 **The future space with the four scenarios from the 'Future of the Transport Sector' study (Palludan et al. 1996). MKT – The market oriented society, INT – The intimate society, SUP – The supra-national society and TEC – The technological society.**



The four scenarios are presented briefly below (Palludan et al. 1996) (original text in Danish):

2.4.3.1 The market oriented society (MKT)

"*Denmark and Europe experience an economic growth, which remains the main objective. The open market is developed with deregulation in a number of sectors such as telecommunication, transport and postal services. The common European currency is a reality. The common agricultural policy is abandoned. The opening towards Eastern Europe is primarily of an economic nature. The stabilisation of the relationship with Eastern Europe is obtained through free trade and economic support, which contributes to the economic growth and democracy in the region.*"

2.4.3.2 The intimate society (INT)

"*An ethical wave washes across Denmark. An attempt is made to stop the polarisation of the social classes and the social alienation through a reorganisation of society. The working hours are cut substantially in order to increase employment and 'citizen wage' is implemented. The family and home play a more central role in everyday life, and the extra spare time is used in spiritual activities such as religion, yoga and education. The career is substituted by 'mental equilibrium' as a status symbol. Politically, the society should also be in equilibrium, which influences both the economic, European and environmental policy.*"

2.4.3.3 The supra-national society (SUP)

"*The political and economic integration in Europe continues. At the same time a number of binding international agreements concerning human rights, economic co-operation (interest rates and budget co-ordinating) and the environment concerning CO_2 are ratified. The UN is appointed to monitor that the agreements are observed and is given authority to intervene. The countries on the Northern Hemisphere* *have to a larger extent opened their markets to the countries in the Southern Hemisphere, and different types of development aid are offered to the countries in need hereof. Both on the conditions that certain criteria concerning the environment, workers rights' and democracy are observed.*"

2.4.3.4 The technological society (TEC)

"*A technology jump occurs around the turn of the millennium. A string of new technologies reach maturity more or less simultaneously which radically changes society. Especially the combination of previously disparate technologies such as video and computer technology creates a decisive qualitative change. The development is aided by the new generations that have grown up during this significant technological change, and now are entering the labour market. These generations are capable of responding in an active way to the changes. In the same way that machines automated the industry, large parts of the service sector is now being automated.*"

2.4.3.5 Assessment of the scenario impact

As noted a combination of elements from all scenarios is probably the most likely. Figure 4 illustrates that the most likely main combinations of scenarios are (Palludan et al., 1996):

- Market-oriented (MKT) combined with the Intimate (INT) scenario
  A distinctively market oriented society with well-developed local democracy which is relatively closed towards the surrounding world (The 'Swiss' model). Another element is a market oriented environmental policy.

- Intimate (INT) combined with the Supra-national (SUP) scenario
  The wish to address the environmental problems is made both locally and globally. The local values and national identity combined with international measures. A global subsidiarity principle could combine these.

- Supra-national (SUP) combined with the Technological (TEC) scenario
  The integration and development of the trans-european networks (TEN) is increased. The global or international arrangements on telecommunication or energy production and distribution etc. are developed further.

- The Technological (TEC) combined with the Market-oriented (MKT) scenario
  Privatisation in the telecommunication and transport sectors, where the technology is used as a building block for the European open market.

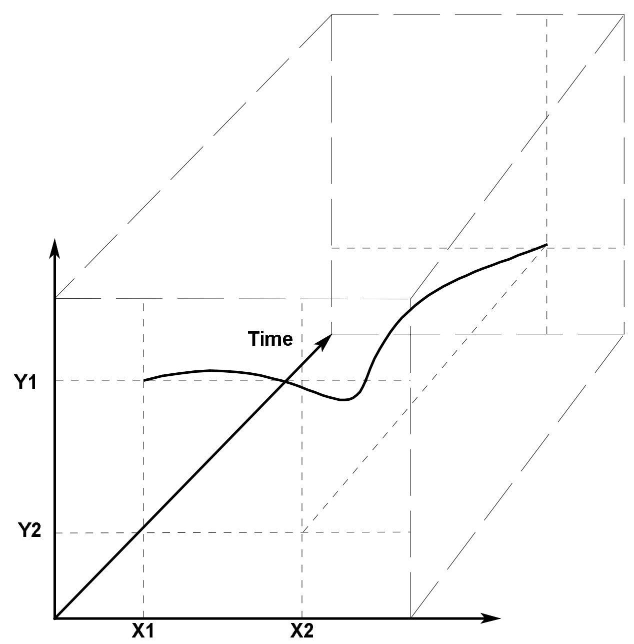
These combinations have the effect of 'softening' the very clear definition of each scenario, and in that sense increasing their plausibility. The combinations can be used as a sort of litmus test for this type of scenarios. Those scenario that appear impossible to combine with others are probably too extreme to be applicable as scenarios.

These short verbal and qualitative descriptions of four possible and probable futures are as such not directly applicable to transport planning. However through a subdivision of the determinants available from the description, development variables may be assessed as was illustrated in the Brix and Kousgaard study (see paragraph 2.4.2). The Future of the Transport Sector scenarios have been used as inspiration and have been applied for scenario painting in chapter 5 and for the case study in chapter 8. Reference is consequently made to the scenarios of this study throughout: The Market-oriented scenario (MKT), the Intimate scenario (INT), the Supra-national scenario (SUP) and the Technological scenario (TEC).

2.5 A NOTE ON THE ROBUSTNESS OF SCENARIOS

Having reviewed three Danish scenario studies, a discussion concerning the robustness of scenarios over time seems required. Are the scenario principles applied and the scenarios themselves from e.g. Traffic 2000 still valid today? If not, then why are they not valid and when does a specific scenario stop being representative for a possible future? One suggestion is found by looking at the development over time of important indicators. They may be assumed moving along a continuous time vector in a multi-dimensional space. For a two indicator space, the development over time could look as seen below.

Figure 5 Example of an indicator space with a time vector.



Going back in history, it would then be possible to follow the trajectory over time. From such a 'flight' the more or less significant changes in indicators at historically important points would be deemed noticeable when the angle of the trajectory had changed notably. Consequently scenarios can be said to be valid as long as no noticeable changes in indicators have yet occurred. Whether such a period of time is 1, 5 or 10 years is difficult to say. This further implies that the base years and scenario years are of less importance, as long as the scenarios are consistent with existing trends and seem plausible in the present as well as for the future year in question.

This point of view would have made the fundamentals of the Traffic 2000 scenarios applicable for about 8-10 years until the mid-80s. Hereafter attitudes, technology and the economy etc. had changed too much compared to the period of economic recession found in the 1970s. Equally, rapid changes could be envisaged which would make the Palludan et al. (1996) scenario study inapplicable.

Another issue concerning scenario robustness concerns the specific application of the scenarios. Not all projects or policies are influenced to the same extent by all indicators. Some scenarios may have only limited influence on a project. This may be the result of the application of a set of very sector specific scenarios or the fact that the initiative is relatively robust with respect to the important indicators for the scenario. An indicator with a direct effect on only e.g. international transport would be changes in the European Unions political and economical co-operation with Eastern Europe. This may greatly influence some transport projects of international importance, but only have secondary and minor influence on local national transport projects.

The application of older scenarios is accordingly feasible provided, as mentioned above that the significant and influential indicators have not changed too much. This should however be assessed individually from case to case.

2.6 CONCLUDING REMARKS

In the review above, some qualities and methodologies have been reviewed concerning scenario construction and the way the scenarios can be included in the planning process. These approaches covered were:

1. A highly quantitative scenario study using extensive mathematical modelling to secure the consistency of scenarios.
2. The application of scenarios constructed for an entirely different purpose, which illustrates the flexibility of well-developed scenarios.
3. A mostly qualitative scenario study with some added expert judgement of the assessment of impacts without any quantitative modelling.

The scenario studies illustrated some of the points made previously concerning scenario construction. The scenarios illustrated different methods for ensuring scenario plausibility and consistency. The Traffic 2000 study used a modelling approach where the other were mainly descriptive in the structuring of scenario and systems consistency. Common to their approach was however the determination of key development variables important in the planning context. Only the Traffic 2000 study did consider the development profile, as this was required for the modelling system to work. None of the scenario studies did however consider exactly what path to apply. The issue of path or development profile is important in a context of project appraisal. This problem and methods for deriving development profiles for the scenarios are discussed in chapter 5.

For the purpose of this study it seems useful to apply a common definition of the term scenario. In chapter 1 a definition provided by Ayres (1969) defined a scenario as " *…a logical and plausible (but necessarily probable) set of events, both serial and simultaneous, with careful attention to timing and correlation's wherever the latter is salient.*" In this study a more restrictive definition is applied, so that (Rehfeld, C., 1996):

> A scenario is a plausible description of the exogenous (economic, social, environmental, political and technological) conditions in a possible and probable future with attention to timing.

The definition implies that the preconditions for the development variables and models are within influence of the scenario. This issue will be discussed in detail in chapter 3.

2.7 LITERATURE

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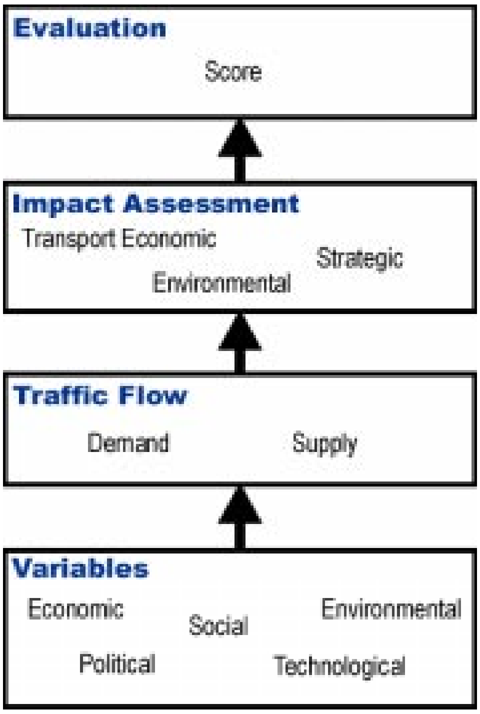
3 SCENARIOS AND MODELS

In the previous chapter a review of scenario techniques led to the adoption of a definition of scenarios as applied in this study. This aim of this chapter is to outline the interrelation between model uncertainty and future uncertainty in a scenario-based planning context. To achieve this, a discussion of the socio-economic modelling process is undertaken in a context of scenario based planning.

Figure 6 **A simple modelling framework for socio-economic appraisal. The figure illustrates the flow of data and the logical modelling approach used for project evaluation. The structure of the impact assessment is taken from the EUNET evaluation frameworks as presented in appendix A (Based on Rehfeld, C., 1996).**



In Figure 6 a traditional modelling framework is illustrated. This modelling framework presents the modelling structure of infrastructure appraisal. The modelling framework is made up of four main steps. The modelling approach is for simplicity indicated as a linear process but is in practice far more searching and repetitive and including interdependencies and feedback between elements. The four elements as listed are:

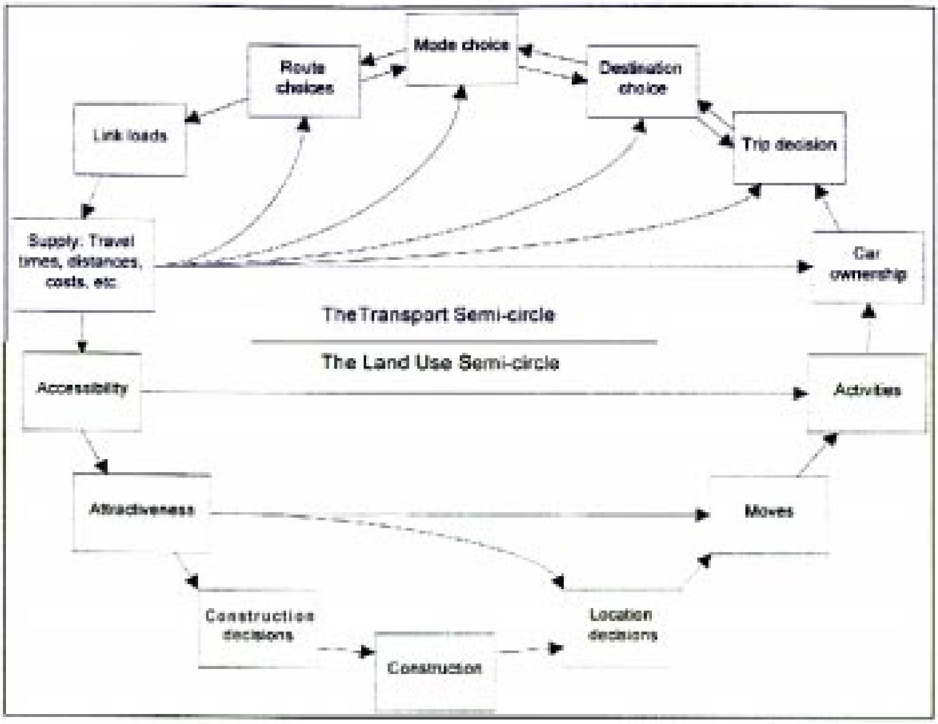
- Assessment and prediction development variables
- Prediction of traffic flows
- Assessment of impacts
  - Evaluation

The modelling framework serves as an illustration of the interconnection between the development variables, the modelling of traffic flows, the impact assessment and the evaluation, each of which may involve highly complex modelling exercises. The first three steps of the modelling framework are discussed in this chapter, whereas the evaluation issue is dealt with in chapter 4.

3.1 PREDICTING TRAFFIC FLOWS FOR EVALUATION

Changes in multi-modal transport systems by way of transport initiatives are rarely isolated events that occur in a secluded part of the transport system. Changes for one mode may through changes in the modal split, transport demand, traffic distribution over time, location patterns for businesses and residences etc. affects the entire transport system. Prediction of these changes is a highly complex matter, and will only be discussed insofar as the subject relates specifically to project appraisal. Depending on the planning context several different approaches for assessing traffic flows may be applied. Wegener (1998) has outlined the modelling interdependencies in transport modelling as seen below.

Figure 7 The land-use transport feedback cycle (from Wegener (1998) in Leleur et al., 1998)



This figure outlines the extent of interaction found in the behaviour of the transport system. The upper half of the cycle reveals the interrelationships found for the transport system alone. The lower half includes the relation to the land-use patterns. The application of models for the description of these interdependencies will depend on the planning context.

In the simplest case where the demand is fixed only the upper left corner of the cycle come into play. If the project in question involves a substantial change in the generalised transport cost, the responses may be even more complicated as the modal split, induced traffic and changes in job patterns and car ownership may get affected. Even further on these changes may affect the land-use part of the cycle, which involves the relocation of businesses and people. The full implications of such interdependencies are normally overlooked, but some land-use models include elements of the circle.

The forecasts of the changes in traffic flows and land-use patterns are normally made for a limited number of calculation years (e.g. two to four forecasts for a 20 year planning period). This mainly due to the modelling complexities and due to the inertia of the system that sometimes involve substantial time lags. The following categorisation divides the elements of the land-use transport feedback cycle according to their response time (Wegener, M., 1998):

- Immediate changes occur with respect to the redistribution of goods and passenger transport on the transport network as these quickly adjust to changes in the travel resistance (Planning period is within one year).
- Fast changes concerns the employment opportunities and the relocation of the population to adjust to changes involving the creation as well as the abolishment of job opportunities (The planning period is within five to ten years).
- Slow changes relate to the physical location of the workplaces and houses that contain the businesses and the population. These take time to develop and are very stable (A planning period beyond ten to twenty years).
- Very slow changes relate to the physical transport network, which is very permanent over time.

Depending on the planning context and the planning horizon these elements may be development variables to consider when modelling transport flows in the long range.

3.1.1 THE ASSESSMENT OF TRAVELLER BENEFITS

Following the completion of the M25 motorway around London significant discussions on the induced traffic surfaced (See e.g. Goodwin, P.B., 1996). In Denmark the traffic growth over time on a road link is traditionally divided into four main groups (Leleur, S., 1995, pp. 75-76):

- Existing traffic
  The existing road traffic plus traffic diverted from other links (route changes) and modal changes

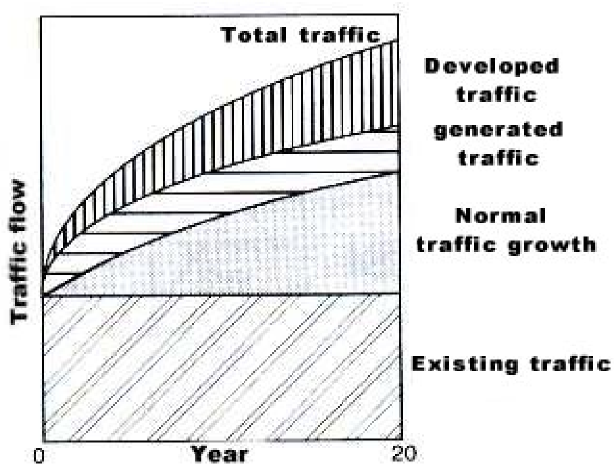
- Normal traffic growth
  The aggregate growth stemming from the population growth and the growth in car density, and decreases in the vehicle occupancy rate

- Generated traffic
  Increases in trip frequency stemming from a decrease in the generalised cost of travel. These trips were earlier suppressed.

- Developed traffic
  Traffic growth caused by either a change to more remote destinations or origins. This includes changes in land-use as e.g. the location of a new plant.

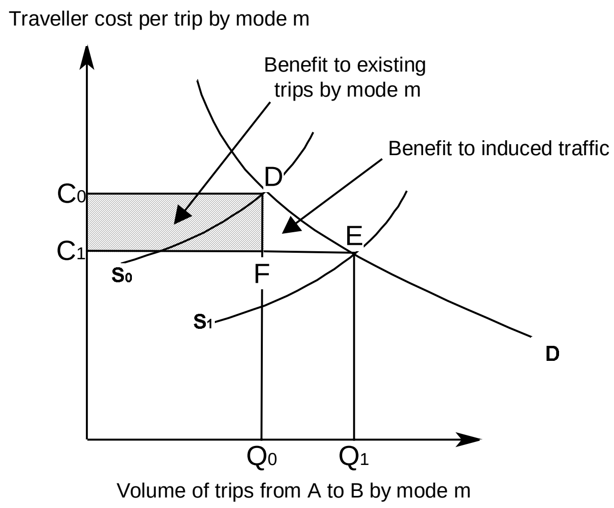
The different elements of traffic growth is seen graphically below:

Figure 8 Elements of traffic growth (Leleur, S., 1995).



The traveller benefits stemming from infrastructure or land-use changes may be assessed through the changes in the generalised cost and the number of trips between zone pairs. These benefits are for each mode calculated as known from traditional microeconomics (see Figure 1.2). The rectangle C0DFC1 is the traveller benefit that accrues to the travellers that are already undertaking trips by mode m between zone pairs. The benefit triangle DEF are benefits to a range of travellers, comprising the generated and developed trips as well as the existing trips where the traveller changes mode from mode n to mode m or vice versa (induced traffic).

Figure 9 The trip demand seen in relation to the generalised cost of travel by mode m between zone pairs (Mackie, P., 1996).



The travellers represented by the triangle DEF were previously not willing to pay to undertake the trips between two zones by mode m. Due to the reduction in travel cost, the new trip by the traveller with the highest willingness to pay gets the full benefit (C0 – C1), whereas the new traveller with the lowest willingness to pay is indifferent to undertaking the trip or not. This is true assuming that the marginal utility of a trip is decreasing across the population. The total traveller benefit (B) for each zone pair for each mode is according found as:

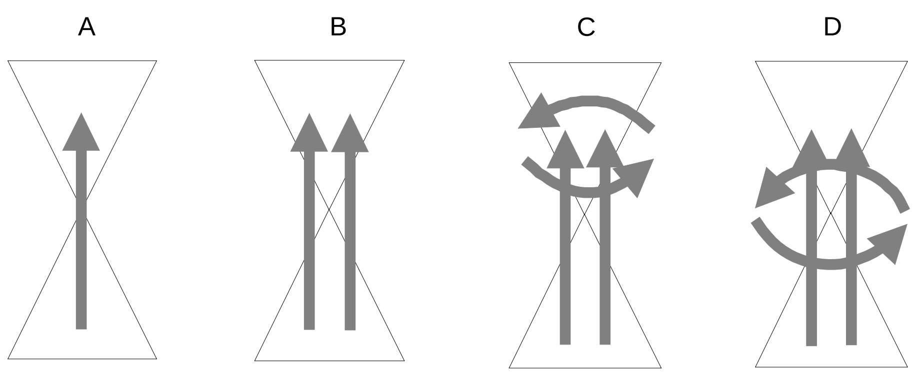
Eq. 1 $$B = (C_0 - C_1)\cdot Q_0 + ½(Q_1 - Q_0)\cdot(C_0 - C_1) = \Delta C \cdot Q_0 + ½\Delta C \cdot \Delta Q$$

Not all of these benefits can however be assessed using a traditional four-step traffic model. A fixed vehicle-trip matrix can assess the existing traffic (Hills, P.J., 1996). This assessment only covers the rectangle C0DFC1 in Figure 1.2. By way of a fixed person-trip matrix the traveller benefits including the benefits for the travellers that have changed mode, can be assessed. Neither of these approaches can however determine the traveller benefits of the generated and developed trips. The evaluation of these traveller benefits requires that the traffic model be based on a variable trip matrix. The practical benefit assessment is however the same in all cases. The assessment and modelling of the many and complex aspects of assessing both the variable trip matrices as well as the accompanying traveller benefits has been investigated by Williams in several of papers (Williams, H.C.W.L., 1976; Williams, H.C.W.L. & Moore, L.A.R., 1990; Williams, H.C.W.L., Lam, W.M., 1991; Williams, H.C.W.L., Lai, H.S., 1991; Williams, H.C.W.L. et al., 1991; Williams, H.C.W.L. & Yamashita, Y., 1992, Buus, N., 1994).

3.2 INTEGRATIVE MODELLING

As it appears the level of interconnectivity between the impact assessment and the traffic prediction is proportional to the complexity of the planning problem. This has been graphically illustrated in Figure 10. The lowermost of the pyramids exemplify the modelling effort associated with traffic models, whereas the uppermost pyramid exemplify the modelling effort associated with impact modelling. The interconnectivity between the two modelling efforts is in practice often very limited. This is illustrated by the fact that the peaks of the pyramids are facing each other. The connection between the two modelling areas is obtained through a data transfer from the traffic model to the impact models.

Figure 10 **The data transfer and interconnectivity between traffic models and impact models in project appraisal. Type A & B illustrate the interconnectivity for uni-modal and multi-modal traffic models respectively. Type C & D illustrates the semi-integrative and the integrative approaches where scenarios are used for painting the model structure.**



Type A in Figure 10 illustrates the lowest level of interconnectivity. In this case the interconnectivity and data transfer is that of a traffic model based on a fixed vehicle-trip matrix. Type B illustrates the data transfer and interconnectivity in the case of a traffic model involving fixed person-trip or variable trip matrices. The data transfer is somewhat larger whereas the interconnectivity remains virtually unchanged. Type C illustrates a semi-integrative approach where scenarios are used for painting the development variables of the impact models into a consistent and plausible composition of variables and values reflecting each scenario. In this case there is still limited interconnectivity between the set-up of the traffic model and the impact models. The flow of information and data is still one-way. Finally type D is an illustration of the integrative approach of scenario based modelling. In the integrative approach the scenarios are used for painting not only the impact models but the entire modelling system.

In the review of Danish scenario studies undertaken in chapter 2, different levels of integration were found. The most model intensive of the studies, the ATV study (1977) used an integrative approach that to some extend did include scenario specific elements in the analyses of the future transport demand. The scenarios did however not paint the planning system in the sense that fundamental assumptions remained fixed. This may in fact be the reason for the limited variation found in the study. Also the study was rather fixed as concerned the breadth of the scenarios. As concerns the Brix and Kousgaard study (1994) they applied weight profiles for the assessment of traveller preferences and assessed the travel demand accordingly. This study addressed the issue of painting attitudes but not models as e.g. the travel pattern remained fixed in all scenarios, which limits the future space.

3.2.1 INTEGRATING MODELS

As concerns the interconnectivity between the modelling activities, there is ample room for further integration. There is quite a lot of information available within traffic models that impact models would benefit from. The data output from traffic models is often aggregated, even though the modelling approach used is more sophisticated than the results reveal. As an example a traffic model may operate with multiple types of goods transport on specifically designated vehicle types, even though the output only reveals the total flow of per link. To avoid this problem of aggregation, emissions could be calculated for each link alongside the traffic assignment. Another example is the simulation of emissions in intersections based on arrival patterns, green waves etc. which would provide a more detailed picture of the emissions. A similar approach would be useful for the modelling of vehicle operating cost. Yet another example relates to the cold start problem stemming from the fact that for cold engines the catalytic converter will not be in operation. Consequently, the emissions are far greater in the beginning of such a trip than after approximately 3 minutes when the engine and catalytic converter is hot and running optimally (Bendtsen, H. & Thorsen, J., 1994).

3.3 SCENARIOS AND MODEL INTERACTION

The modelling system as outlined above is a complex matter with many elements of uncertainty. Friend & Jessop (1967) analysed this uncertainty in the planning process. They divided uncertainty in the planning process into three broad classes (p.89):

- The external planning environment uncertainty (UE)
  Uncertainties concerning the planning environment that relate to the structure of the world, external to the decision making system. This also includes the future uncertainty with respect to the pattern of change.

- The related fields of choice uncertainty (UR)
  Uncertainties with respect to the choices that might be taken with-in the decision making system.

- The value judgement uncertainty (UV)
  Uncertainties with respect to the relative importance put on different impacts, impacts to different incidence groups or impacts that concern different time periods.

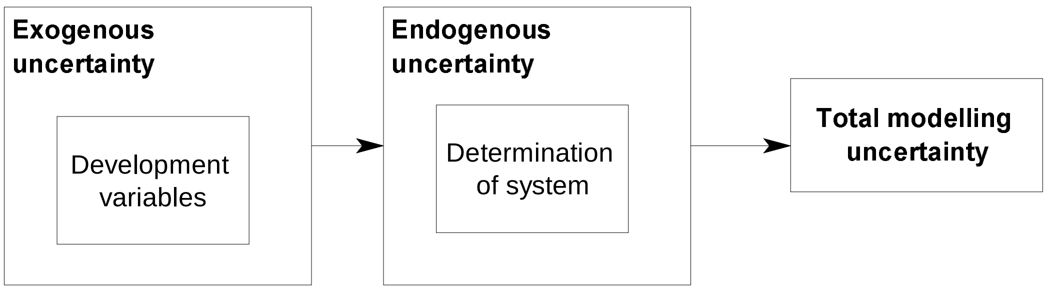
The ambition of the scenario approach is to treat the future uncertainty concerning value judgement and the 'structure of the world' collectively. In the scenario definition applied here (see chapter 2) a scenario study comprises a set of consistent and plausible futures that address the issue of future uncertainty.

3.3.1 A DEFINITION OF MODEL UNCERTAINTY

The issue that has not been dealt with concerns what influence changes in the 'structure of the world' has on modelling. From a perception theoretic point of view everything is a model, from the pictures we develop of the world we live in (mind maps) to the assumptions on descriptive variables for travel behaviour (car ownership, preference sets). With respect to transport planning, mathematical models is the primary concern. Such models are ambiguous abstractions or extractions of a complex 'reality', which cannot be uniquely identified. The education, tradition, social background, etc. of the modelling professional necessarily influences the models. In this case mathematical models are attempts at reproducing reality on the basis simple relationships (see e.g. Rehfeld, C., 1995).

The influence this simplification has on the modelling uncertainty adds to the endogenous uncertainty. Traffic models and impact models make use of a range of development variables. The uncertainty that relates to the development variables in the future planning environment is termed exogenous uncertainty. For a planning system the flow of uncertainty can be illustrated as seen in Figure 11 below.

Figure 11 **Planning uncertainty is made up of external uncertainty related to the data set in a future planning environment and model internal uncertainty related to the model's ability to reproduce reality and our ability to verify that it does (Rehfeld, C., 1996).**

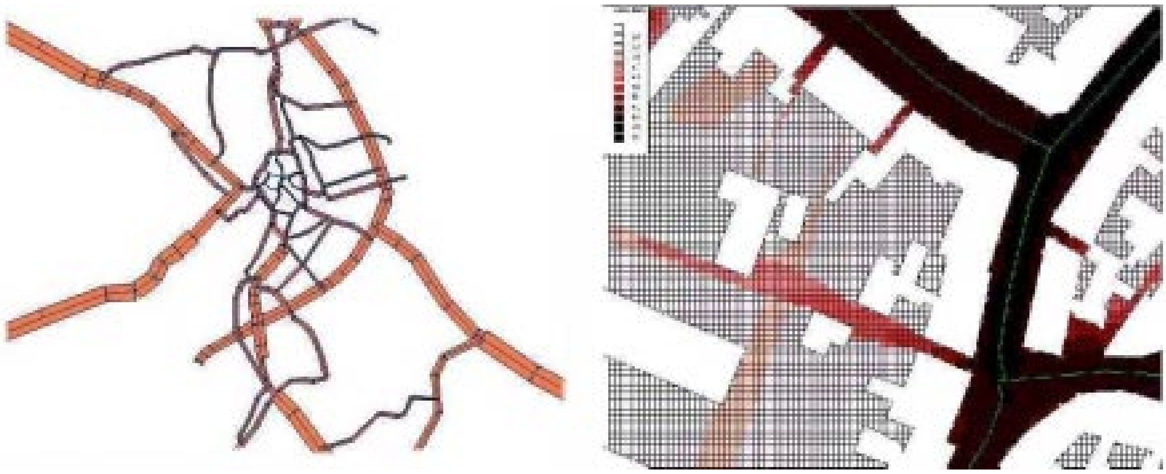


The exogenous uncertainty may also relate to the uncertainty of physical measurement (surveying), data conversion methods or other data problems etc. not affected by the scenarios.

3.3.2 TWO EXAMPLES OF ENDOGENOUS UNCERTAINTY

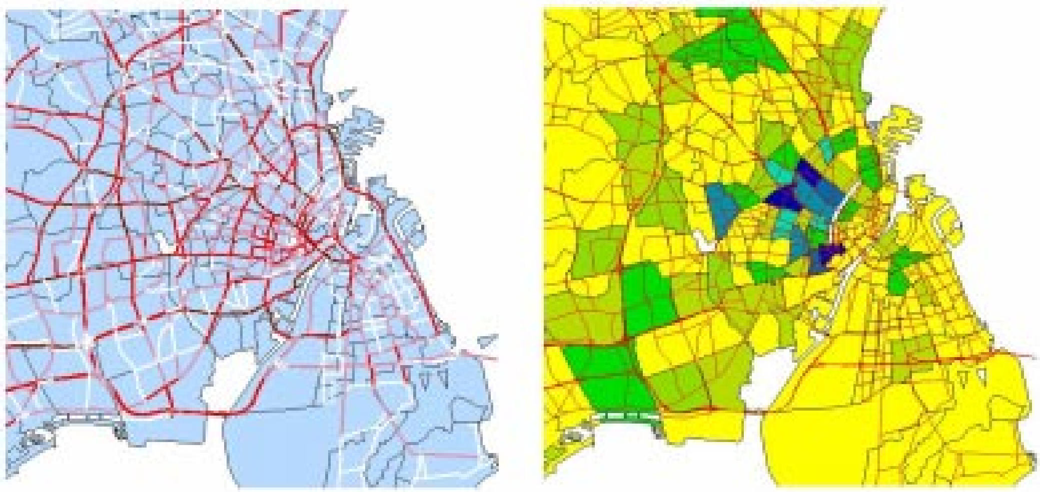
As an example of one element of the endogenous uncertainty we look at two noise models as seen in Figure 12. Both are GIS-based and apply fundamentally the same formulas for modelling noise (Namely the Common Scandinavian Noise Model – see Naturvårdsverket, 1989). On the same data set the results produced will differ (in the worst case by up to 280% - Miljøstyrelsen, 1996), and the endogenous uncertainty cannot be said to be the same.

Figure 12 Two different GIS based noise models (Rehfeld, C., 1996 & Miljøstyrelsen, 1996).



Another example of GIS-based models concerns the conversion of the same data, where the noise example concerned different applications of the same model. In Figure 13 an illustration of the conversion of link-based emission data, into zone based pollution data and further into exposure estimates is shown. The results are based on the same model results (an emission model) but the information obtained from each approach is fundamentally different.

Figure 13 Two different pollution estimates for NO_X from a GIS-based data conversion. The left image illustrates the emissions by link of in ton/km per year, whereas the right image illustrates a measure of exposure by zone in Ton Persons/km² per year. The intermediate level is the pollution measure also by zone in ton/km².



The objective is to define or describe wherein the differences between the models' uncertainty lie.

3.4 ENDOGENOUS UNCERTAINTY

Endogenous uncertainty is divided into three main groups of uncertainty:

- Objective uncertainty
  Objective uncertainty may by means of statistical methods be quantified (in theory) through comparisons with reference or control data

- Adaptive uncertainty
  Adaptive uncertainty concerns the applicability of a model to the planning problem, whether the model actually provides answers to the questions posed

- Subjective uncertainty
  Subjective uncertainty is related to the perception of model results, which is not directly quantifiable.

The subjective uncertainty is not only related to the perception of the planner or expert, but equally much to the decision-makers or publics acceptance of the model. This became very clear from the discussions following the publication of modelling results from the Great Belt Link and The Øresund Link construction consortia. The elements of the endogenous uncertainty are:

Table 8 Uncertainty elements of endogenous model uncertainty (Rehfeld, C., 1996).

UNCERTAINTY ELEMENT	DESCRIPTION
Objective uncertainty	
Precision	Degree of detail of the results
Exactness	Resemblance with reference data
Reproducibility / Reliability	The results can be reproduced without too large difference
Continuity	The model responses are consistent (without discontinuities) with changes in data, key variables or data relations.
Adaptive uncertainty	
Applicability	The degree to which the model provides answers to the questions posed
Suitability	The model suitability for the planning problem concerning the level of aggregation, the data availability and the model objective
Feasibility	Feasibility with respect to the balance the available funds and the model complexity
Subjective uncertainty	
Expert:	
Conceptual uncertainty	Uncertainty concerning cause and effect and/or logical composition of the model
Descriptive uncertainty	Qualitative uncertainty concerning data and results
Comparative uncertainty	Uncertainty with respect to whether results from two models are comparable and how
Meta-uncertainty	Uncertainty with respect to the level of uncertainty
Public / Decision-makers:	
Credibility	Does the model results reproduce an image of the reality which is recognisable.
Comprehensibility	Understandable causes and effects to non-experts. Do the model appear to be a 'black-box' model.
Familiarity	The model is recognisable or comparable to previous experiences.

The objective uncertainty represents the core test of model applicability in any context. Without useful objective verification of model results, the model becomes irrelevant. Hence, it is with good reason that the majority of the modelling effort is used at verifying the modelling system. If a reasonable level of objective uncertainty is not reached then the other elements become irrelevant. A low level of objective uncertainty is the litmus test of any model.

The adaptive uncertainty concerns the context specific applicability of the model, being if not essential then very important to the final model uncertainty. This type of uncertainty is also related to the acceptability of uncertainty. Limited time and funding must result in a corresponding acceptability of a higher level of uncertainty. In some cases the adaptive uncertainty will set the standard for the measuring rod with respect to the subjective uncertainty.

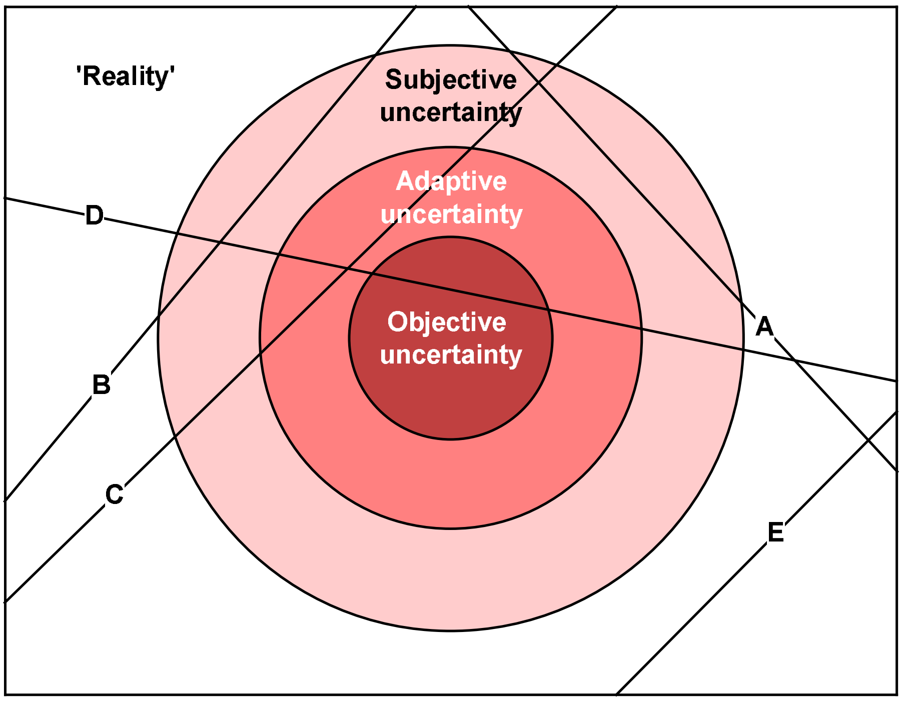
The subjective uncertainty is far more intangible than the other two. The subjective uncertainty is made up of two parts: The uncertainty of the professional with an in-depth understanding of the modelling system, and the public and the decision-makers without this insight. The latter regard the results with respect, not only on the basis of objective criteria, but equally based on overall planning objectives and credibility. The consequence of these considerations is that otherwise objectively good results are uncertain by the mere fact that they do not appear credible to the public. This is probably a well-known problem. With respect to the subjective uncertainty of the professional, there will always be a fundamental uncertainty about exactly how uncertain the results are. This has been termed meta-uncertainty. This may be asserted to the fact that the more in-depth knowledge one acquires the more obvious the limitations become - I know only that I know nothing.

The categorisation shows that modelling uncertainty cannot be assessed simply through our ability to perform suitable tests to verify the performance of a model, but equally much with 'soft' intangible elements. Since models only are elements in a political decision-making process, it becomes evident that the uncertainty that is associated with model results not only stems from measurable or quantitative uncertainty but, equally much or even more so by these intangibles. The following section discusses the interaction between the future uncertainty and the endogenous model uncertainty.

3.5 ENDOGENOUS MODEL UNCERTAINTY AND SCENARIOS

The interaction between scenarios and the endogenous model uncertainty is illustrated by way of Figure 14. Assume that the frame of the figure represents an abstraction of reality, and that the five lines within it represent different scenarios. The circles within the frame are the elements of endogenous uncertainty concerning a specific modelling system. The circles do not touch the frame to show that the model only describes a part of the abstraction made. Which in it implies that no modelling system can exist without some degree of uncertainty. The scenarios represented by the straight lines cut through the abstraction with varying depth and intensity. The inclination of the lines indicates the theme of the scenario.

Figure 14 **Illustration of the influence future uncertainty has on the different elements of endogenous uncertainty. The influence is illustrated by five scenarios, denounced A – E (Rehfeld, C., 1996).**



The figure should aid understanding the way in which scenarios influence at increasing levels a models endogenous uncertainty. Not all models or modelling approaches are influenced equally by all scenarios.

The lines A and B represent scenarios that describe societies that are not fundamentally different from what we know today. The further into the future we get, the uncertainty elements concerning e.g. acceptability or meta-uncertainty is likely to change. One such change in acceptability could the reduced confidence in e.g. computer models as the political system to a larger degree relies on and develops e.g. other forms of consensus building tools. In such a case the adaptive and objective domains remain untouched whereas the subjective domains is influenced. The difference in inclination between the lines A and B could illustrate a difference in preferences concerning the environmental and economic objectives.

Line C on the other hand symbolises a scenario, which more or less maintains the preference sets from scenario B (parallelism). In scenario C, questions are raised concerning whether the model actually produce the required results or is applicable to the planning problem. Such concerns could be associated with traditional socio-economic analysis, which e.g. excludes strategic objectives concerning mobility, economic development or the global environment to mention a few. Assuming that such concerns are increasingly important in a scenario this would influence a models level of adaptive uncertainty over time. This may however not necessarily influence the objective uncertainty of the model.

Line D is a representation of quite fundamental changes in society, which necessitates a complete re-evaluation and adjustment of the objective elements of the model or modelling approach. Existing assumptions and understandings must be re-considered.

Such a scenario could involve changes in the social structure of our society so that e.g. the family once again becomes a central core with following changes in location patterns and job structure. This could significantly alter some of the background for modelling human behaviour. Equally, a technological jump at the turn of the millennium could completely change the modelling approach to many local environmental effects, e.g. pollution.

Finally, some models are scenario neutral in the sense that no elements of the scenario alter the overall uncertainty already inherent in the model. In many scenarios no influence will occur, as the assumptions to a large degree remain fixed. Models that will most often remain unaffected by scenarios are models for physical effects such as noise. If the car technology does not develop, neither will our modelling approach to noise or our understanding of noise change.

3.6 CONCLUDING REMARKS

The modelling conditions surrounding infrastructure appraisal was analysed and the framework for an integrative approach was laid down. The uncertainty in the modelling system was divided into exogenous and endogenous uncertainty. An analysis showed that the endogenous uncertainty can be divided into objective, adaptive and subjective uncertainty. Combined with the previous definition of scenarios applied in this study (chapter 2) the influence scenarios have on model uncertainty was described and graphically illustrated in Figure 14. The next chapter will discuss the question of evaluation in a scenario-based planning context. The following second part of this report will present a methodology for the envelopment of future uncertainty.

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4 APPRAISAL METHODS IN PERSPECTIVE

The following sections are concerned with the development in decision theory as found in long range transport planning over the last thirty to forty years. This will illustrate scenario-based planning as a logical further development of the existing decision theory. In the 1930s when the first actual manual on socio-economic appraisal was laid down in The United States Flood Control Act in 1936 to the late 1960s, social cost-benefit analysis (SCBA) was seen as the 'true' rational tool for decision makers (Leleur, S., 1995). The rational planning approaches experienced a continuous development over the years and in the beginning of the 1970s reached a point were the rational approach became increasingly comprehensive.

During the 1970s a number of 'softer' impacts were added to most infrastructure evaluation frameworks. The frameworks were extended from concerning solely transport economic impacts to including external environmental impacts as well as other planning impacts, and the scope changed. In this period extensive research was concerned with multi-criteria evaluation approaches. The research was fairly early divided into approaches that disregarded the basis of welfare theory as applied in the social cost-benefit analysis and those that are based on it. The intention was the inclusion of decision maker preferences in the evaluation process, to promote either satisficing or optimising project selection. The use of scenarios in appraisal seems in the light of the development in transport related decision theory over the last 30 years to be logical continuation of the previous appraisal trends.

- Rational comprehensive planning
- Sensitivity testing
- Multi-criteria analysis
    - Scenario painting

This line of rationing where decision theory has developed from rational comprehensive planning across sensitivity analysis and multi-criteria analysis, forms the basis for suggesting a scenario based approach which aims at extracting some of the elements of the existing methods and bringing them together in a scenario-based appraisal methodology (SEAM).

4.1 RATIONAL COMPREHENSIVE PLANNING

Socio-cultural systems, which include the transport system, are highly complex. Systems theory being the ultimate expression of the rational comprehensive planning tradition is based on the conception that even though the planning environment is complex, system behaviour is predictable even in the long term. Essentially, the idea is that systems prediction is possible provided that a sufficiently sophisticated mathematical model is developed relying on a sufficient amount of system variables.

Systems theory was introduced in transport planning in the late 1960s. For a review and presentation of systems theory refer to e.g. Leleur (1984) or de Neufville & Marks (1974). The introduction of systems theory in transport planning coincided with the development of the computer and the development of operations research as an independent research field. Buckley (1967) defined three (simple) system types or in this case planning environments.

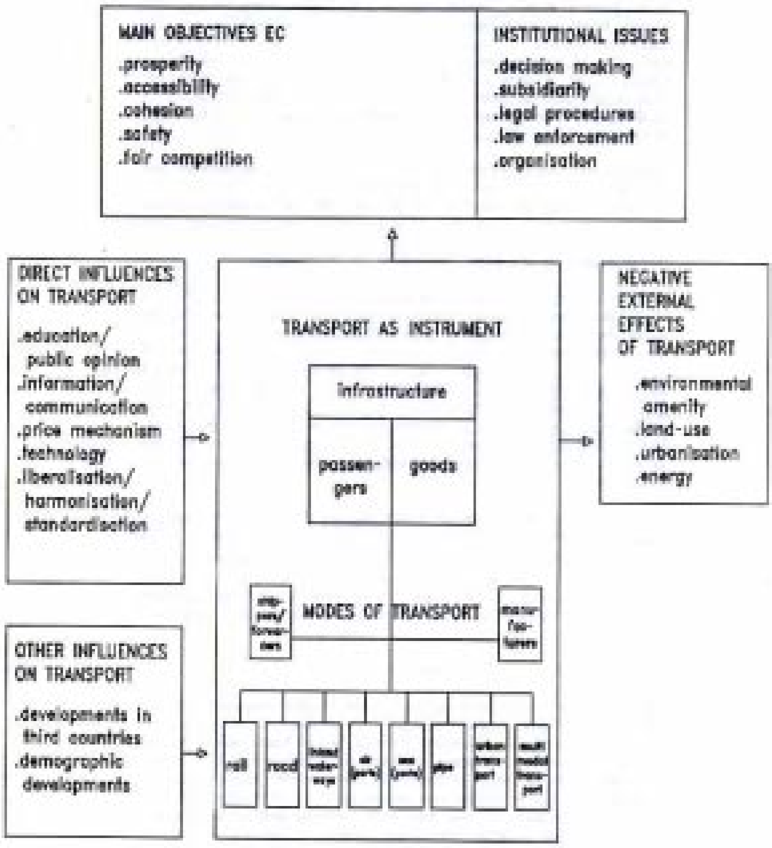
- The equilibrial system
  This is a planning environment that is "*affected only by external 'disturbances' and have no internal or endogenous sources of change…and since they are relatively closed they have no feedback or other systematic self-regulating or adaptive capabilities*".

- The homeostatic system
  This planning environment is compared to a single cell organism. In this case "*the system's main characteristics is its functioning to maintain the given structure of the system within pre-established limits. It involves feedback loops with its environment, and possibly information…but these are geared principally selfregulation (structure maintenance) rather than adaption (change of system structure)*".

- The complex adaptive system
  A complex adaptive system or planning environment is "*open 'internally' as well as 'externally' in that the interchanges between their components may result in significant changes in the nature of the components themselves with important consequences for the system as a whole… True feedback control loops make possible not only self-regulation, but also self-direction or at least adaptation to a changing environment. …the socio-cultural system is fundamentally of the latter type, and requires for analysis a theoretical model or perspective built on the kinds of characteristics mentioned*".

Based on this classification the transport system is clearly a part of a complex adaptive planning environment, as illustrated by the discussions found in chapter 2 and 3. A systems approach illustrating of the complexities of transport planning is found in Figure 15 below.

Figure 15 A systems approach to the transport planning environment (Group Transport 2000 Plus, 1990).



In transport planning systems theory led to the application of operations research techniques in computer models. One of the best known applications of systems theory to large transport planning problems is the Mexico City Airport study by De Neufville, R. & Keeney, R.L., 1974). The developed model consisted of a static (strategy screening) model and a dynamic (policy) model concerned with the project phasing.

Even though the model analysed slightly less than 4000 strategy alternatives with respect to 6 impacts (8 in all since two were time specific) the authors conclude that the planning environment surrounding such large public investments is far too complex to deal with in a relatively simple mathematical model. A systems model is efficient for the analysis of the huge number of alternatives, even though it does not necessarily lead to decision-making, as this is part of the political process (De Neufville, R. & Keeney, R.L., 1974, p.368).

Despite the very important emphasis that the systems analysis approach put on the changing nature of socio-cultural systems, fundamental variables have often been left unchanged for the entire planning period even in long range planning applications. Sometimes sensitivity analyses have been performed on key variables, but the approach has fundamentally been a single planning environment approach.

The Traffic 2000 study (ATV, 1977) presented in chapter 2, is one of few thorough applications of systems theory found in Danish transport studies. It applies a systematic view of the planning environment attempting at describing future transport demand

and transport patterns. The study did sensibly include scenarios as part of the approach for assessing the span of the expected future demand.

4.1.1 THE FRAMEWORK EVALUATION APPROACH

In rational comprehensive planning evaluation frameworks are often used for the determination of costs and benefits. In a historic perspective these evaluation frameworks have equally developed over time from being traffic economic and uni-modal (mainly road transport see e.g. VD, 1992) to being very broad and multi-modal. Looking at the development in evaluation frameworks from the Danish and German Highway Priority Manuals (VD, 1992; PLANCO, 1993) to the European EURET, APAS/Road3 (CEC, 1996a; 1996b-f) and now EUNET (Leleur et al., 1998) one can ascertain that there has been an interesting development (see also appendix A). The traditional evaluation frameworks are mainly concerned with operation and maintenance issues, user benefits (in the broadest sense) and local environmental effects such as noise, air pollution and severance. The European frameworks have expanded the scope. The attempt has been to cover what Pearce has termed the 'Total economic value' (Pearce et al., 1989; Pearce, D.W. & Turner, R.K., 1990). This comprises:

- Actual use value
- Option value
    - Existence value

The actual use value is what traditional social cost-benefit analysis and some specific environmental impacts assess. The use value relates to the specific trip, the use of the local forest, the expenditure on road maintenance etc. The use value covers a wide range of benefits that accrue from <u>utilisation or use</u>. The option value is the benefit that we place on the <u>potential</u> of doing something. Simply having a car entails a benefit as it offers its owner the potential for immediate travel even though this potential is not used. This also goes for forests that we are willing to pay for, in order to have the potential to use it at some later stage. Finally the <u>existence</u> value relates to the willingness to pay for future generations supply of an unpolluted environment even though it has neither use nor a potential use value to us. This equally involves sympathy for animals such as whales. We have never seen one and probably never will, but the thought of their existence is comforting.

From the point of view of the EUNET transport evaluation frameworks, the option values are attempted included through e.g. measures of strategic mobility (see Kronbak, J., 1998) and the existence value through the strategic environment. The problem relating to these benefits is that they are difficult to assess from a modelling point of view. But it seems obvious that a concept similar to that of the 'Total economic value' will be guiding for future developments in evaluation frameworks.

In the EUNET transport evaluation frameworks impacts are classified by mode into four main groups (see Leleur et al., 1998 and appendix A):

- Core impacts (A-impacts)
  Basic impacts comprising transport economic and local environmental impacts.

- Non-core, non-strategic impacts (B-impacts)
  'Soft' mode specific impacts relating to the transport quality and the visual environment.

- Strategic, territorial impacts (C-impacts)
  Impacts with territorial affiliation such as mobility considerations, economic growth and global environment.

- Strategic, non-territorial impacts (D-impacts)
  Other strategic impacts with no territorial affiliation such technology development and other policy and planning issues.

The EUNET framework for inter-urban road infrastructure projects is seen below:

Table 9 EUNET framework for inter-urban road infrastructure projects: Variables (Leleur et al., 1998).

FV 11-I LMS IMPACTS		ROAD INFRASTRUCTURE PROJECT TYPES Variables INTER-URBAN
Core impacts		
A1	Investment costs	Materials, labour, land and property acquisition (including compensation)
A2	System operating and maintenance costs	Structural repairs, carriageway delineation, signing, enforcement of traffic regulations
A3	Vehicle operating costs	Fuel and oil consumption, tyre wear, vehicle maintenance, depreciation
A4	Travel time benefits	Working time, home-work time and leisure time
A5	Safety	Fatalities, severe and slight injuries, damage only accidents
A6	Local environment	Noise and air pollution, severance
Non-core, non-strategic impacts		
B1	Driver convenience	Comfort, stress, smoothness
B2	Urban quality & landscape	Visual environment
Strategic, territorial impacts		
C1	Strategic mobility	Accessibility and networks
C2	Strategic environment	Greenhouse effect, strategic atmospheric pollution, loss and damage of ecological, historical, archaeological and scientific sites, energy consumption, natural resources
C3	Strategic economic development	Land use, economic development, employment impact
Strategic, non-territorial impacts		
D1	Private financial attractiveness	Financial internal rate of return, net present value or equal
D2	Other strategic policy and planning impacts	Conformity to other strategic policy and planning concerns

Some of the impacts are well defined and monetised and may be used directly in a cost-benefit analysis as is the case for the A-impacts. The other impacts are however not easily monetised and are often not well defined from a modelling point of view.

4.2 SENSITIVITY TESTING

Sensitivity testing refers in this context to a systematic variation of variables within the context of one set of preconditions. Simple sensitivity testing normally involves the variation of a few of the uncertain and central key variables. These uncertain variables are set at a more extreme value (higher and lower) and the influence on the project score is reviewed. Extensive analyses of this kind are rarely performed due to the number of possible combinations. Consequently only a few key variables are put into the sensitivity analysis for projects that are already singled out as an optimal solution in order to get a picture of the influence of each variable on the outcome. One problem with simple sensitivity testing of this kind is the lack of recognition of the correlation between variables (Allport et al., 1986). The influence of scenarios on model uncertainty and the modelling structure as discussed in chapter 3 is normally neglected.

Over the last decade Denmark has experienced an increasing demand for socio-economic viability of publicly financed infrastructure investments. A requirement that include sensitivity tests. Flyvbjerg et al. (1995) emphasised this necessity of sensitivity testing by illustrating the flaw of single-minded application of SCBA through a review of a number of national and international ex-post project appraisals. These showed a general tendency to underestimate uncertainty in socio-economic evaluations. Flyvbjerg et al. (1995) suggested a relatively simple method of sensitivity testing involving Most-Likely-Development (MLD) scenarios. A MLD scenario is, as opposed to an EGAP (Everything-Goes-According-to-Plan) scenario, an estimation of project costs and benefits based on what has been found in similar projects elsewhere. This reduces the number of computations, but on the other hand requires access to data from similar projects. A risk associated with the MLD approach is the unwarranted emphasis on one single development trend. It may prove a better than being too optimistic but the approach does not provide any information on project robustness.

4.2.1 SUBJECTIVE PROBABILITIES

Systematic variations may also be based on the assumption that some or all variables are stochastic (See e.g. Dasgupta, A.K & Pearce, D.W., 1972; Pearce, D.W. & Nash, C.A., 1981; Adams, J., 1995). On the basis of expert judgement the range of each variable is estimated (subjective probability distributions) and optimally all possible combinations and correlations are included in the analysis. Each variable will have to be described by at least three values. Such as the median, the first and last deciles (Pearman, A.D., 1988). A full analysis of this kind involving 8 variables will results in 3^8=6561 scenarios. A great deal of which may be disregarded due to lacking consistency. Still, an analysis may only rationally be performed through Monte-Carlo simulation (Allport et al., 1986). Even with today's substantial computer power, the implementation of this approach to an entire transport planning system would be a rather extensive exercise. Once each project alternative has been analysed for each scenario, the optimal strategy can be selected as the one with the highest expected utility, by way of stochastic dominance (see e.g. Copeland, T.E. & Weston, J.F., 1988 or von Winterfeldt, D. & Edwards, W., 1986).

Using subjective probability distributions as the basis for evaluation is not without problems. With respect to the setting up of the model, studies have revealed problems, even for experts, in assessing the correct confidence intervals of the variables (Pearman, A.D., 1988). Within the modelling system the interdependencies between development variables may not be fully integrated nor fully perceived. Also the degree of correlation between variables may well vary over time and thus compromise the model results.

From the point of view of the decision-maker, the concept of probabilistic results may also be a difficult concept to appreciate. The simulation approach involving extensive correlations may prove so difficult to explain that it unintentionally renders the results less certain in the eyes of the decision-makers (Allport et al., 1986). For a more thorough discussion on subjective probability distributions, which is beyond the scope of this study, please refer to e.g. von Winterfeldt & Edwards (1986).

A less comprehensive approach involves the weighting of scenarios according to their likelihood of occurrence (Pearman, A.D., 1988)(see also chapter 2). Likelihood considerations may be regarded as less strict than probabilities, but may merely be general reflections of the likelihood. By way of such an approach projects in a pool may be ranked. This approach may however give an unwarranted sense of certainty in the evaluation results.

4.3 MULTI-CRITERIA DECISION MAKING

During the 1970s it was recognised that the systems theory from a theoretic point of view is interesting but that our understanding of the processes in socio-cultural systems is very limited. The transport system and the decision processes are far too complex to use optimising mathematical models alone and other solutions were investigated. This was accentuated by the fact that no models had foreseen the economic recession and the long period with low economic growth that followed the 1973 oil-crisis.

At the same time an increasing emphasis was put on environmental issues that were found to be difficult to valuate for the use in traditional social cost-benefit analysis. Also society was getting increasingly polarised with conflicting objectives. The question was which preferences to apply in optimising modelling. Decision research started focusing on methods for dealing with conflicting planning objectives. The multi-criteria methods developed in two main directions (CEC, 1996a):

- Outranking methods
  - Utility based methods

In this context only the utility-based methods are of concern. In a United Nations seminar on International Transport Investments as cited by CEC (1996a) the following distinction is made between utility-based multi-criteria methods and traditional social cost-benefit analysis (taken from CEC, 1996a, appendix 4):

"The primary difference between the two methods is that in cost-benefit analysis, the analyst attributes the weights to the various objectives and is responsible for the aggregation of the project's effect, whereas in multi-criteria analysis the decision-maker gives the weights to the objectives and is involved in the final evaluation phase."

The point being that sometimes there tends to be limited differences between the practical application of either methodology. This is a very general consideration as some methods are clearly optimising, whereas others are satisficing and flexible.

4.3.1 A UTILITY-BASED MULTI-CRITERIA METHOD

WARP is one utility-based multi-criteria method used for assessing shadow prices on the basis of weight profiles and a price base (Leleur, S., 1984). The price base may be arbitrary or e.g. relate to the level of benefit estimated from the valuated impacts (such as travel time savings, vehicle operating costs etc.). The unit price estimation technique is seen in Eq. 2:

Eq. 2
$$UP_i = \frac{Weight_i \cdot PriceBase}{\sum_{n=1}^{N} Effect_{in}}$$

By using multiple weight profiles project performance can be assessed through several scores. Consequently, this approach does not necessarily provide a definite ranking of project alternatives. The late inclusion of the multi-criteria method in the appraisal process results in the collapse of the time dimension as e.g. the monetised impacts are discounted into a net present value in order to constitute the price base.

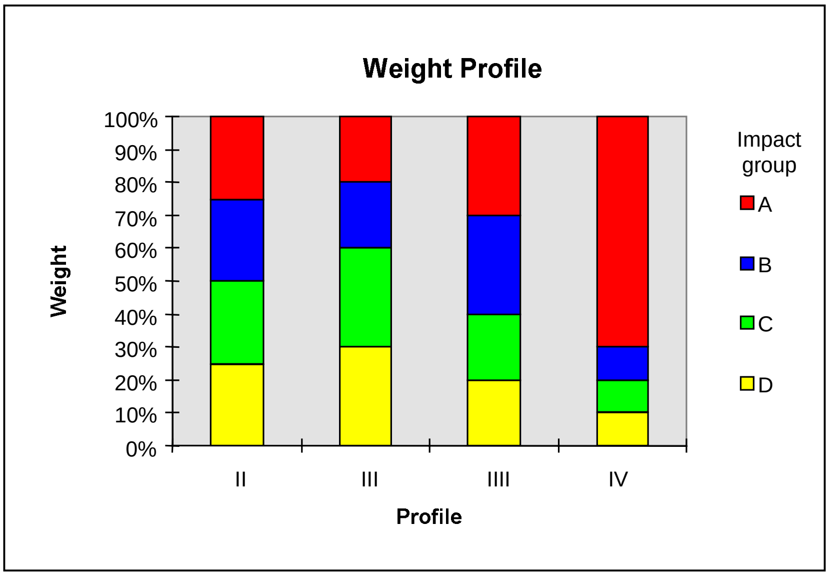
Weight profiles applied to the EUNET transport evaluation frameworks could in this case be adjusted through a two step procedure; a set of weights for the A, B, C and D impact groups and a mode specific set of weights within each group. The A, B, C and D weights (level 1 weights) are equal for all modes and basically reflect the overall planning objective. The weights within each impact group will however have to be mode specific. Both level 1 weights and level 2 weights could be defined either directly or through a pairwise comparison procedure. To illustrate the above considerations the following weight examples can be given (Leleur et al., 1998):

Table 10 **Level one weight profiles. I is a Base profile. II is a profile with emphasis on strategic issues, III mainly concerns local issues, whereas IV is a strategy with emphasis on CBA.**

	WEIGHT PROFILE			
IMPACT GROUP	I	II	III	IV
A – Core impacts	0.25	0.20	0.30	0.70
B – Non-core, non-strategic impacts	0.25	0.20	0.30	0.10
C – Strategic, territorial impacts	0.25	0.30	0.20	0.10
D – Strategic, non-territorial impacts	0.25	0.30	0.20	0.10
Sum:	1.00	1.00	1.00	1.00

Graphically the level one weight profile has the following appearance (Leleur et al, 1998):

Figure 16 **Level one weight profile, where the impacts groups refer to the EUNET transport evaluation frameworks, A - Core Impacts, B – Non-core, non-strategic impacts, C – Strategic, territorial impacts and D – Strategic, non-territorial impacts (Leleur et al, 1998).**

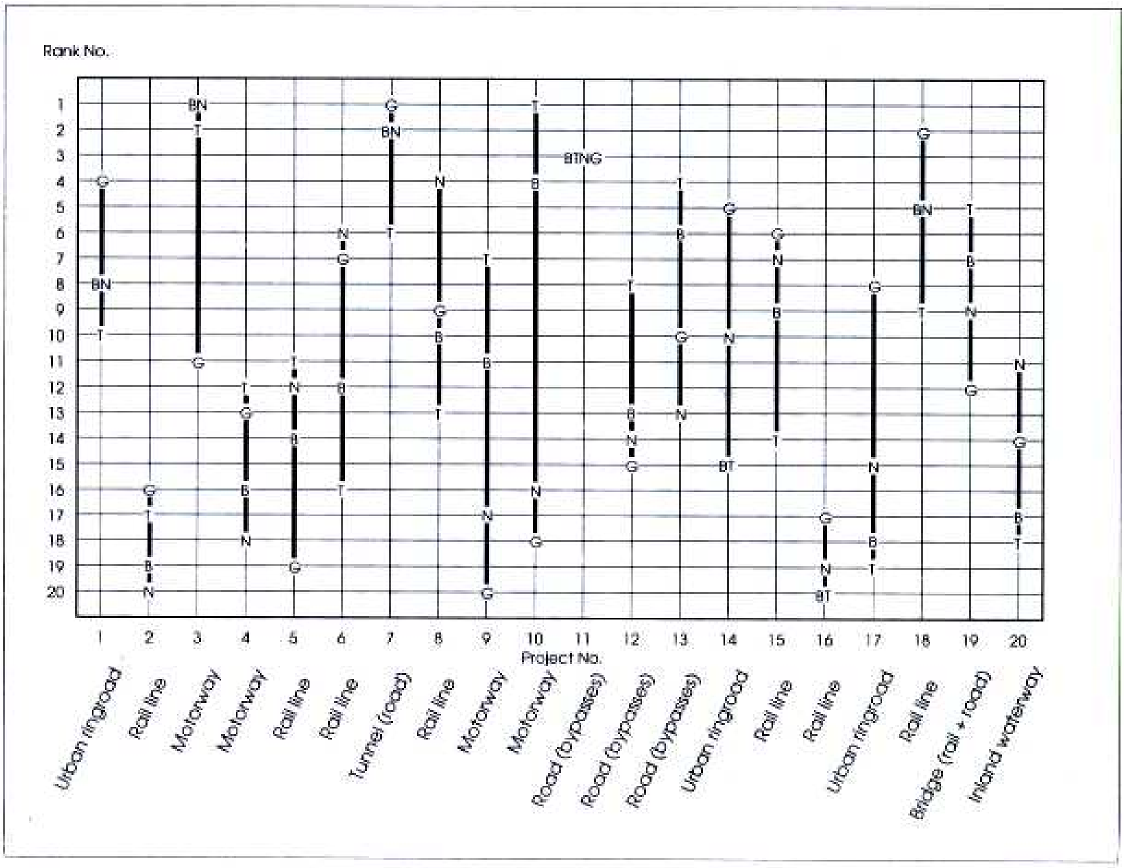


The Level 2 default weights are as mentioned mode specific and should be worked out systematically according to certain suitable strategies so that they are consistent across modes. Such strategies comprise:

B: Base case strategy
T: Traffic economy strategy
N: Network strategy
G: Green strategy

The combination of four level one weight profiles with four level two weight profiles (I to IV) one for each strategy adds up to 16 weight profiles altogether. This type of multi-criteria analysis is in a sense a consistent way of performing sensitivity analysis. The weight profiles represent varying preference sets and hereby extent a space for possible outcomes. The preference sets are fixed in time in the sense that variation in present preference sets is used for performing preference-based robustness tests of project alternatives. The project robustness can e.g. be illustrated by way of a rank-variation graph (see Figure 17).

Figure 17 Rank variation graph for a number of projects in a project pool (Leleur, S., 1995).



A rank variation graph illustrates the rank a project achieves under different weight profiles in a project pool.

4.4 SCENARIO PAINTING

In the beginning of the 1980s the scenario technique was to a larger extent adopted in transport planning. The application of scenario techniques was partly associated with the problems related to project sensitivity testing. As has been illustrated previously that the scenario analysis covers a very broad and inhomogeneous group. In most scenario-based approaches, as in utility-based multi-criteria analysis, the scenario painting of the preference sets are assessed for the discounting year only.

In a complete scenario-based planning approach as is suggested in this study, both the assessment of preferences as well as the modelling systems development variables should be painted as well as cross-sectional. A cross-sectional assessment of the development variables involves a step by step scenario assessment for each calculation year in accordance with the development profile of the scenario. The difference between a cross-sectional scenario-approach compared to the traditional e.g. multi-criteria approach to the assessment of development variables is seen below:

Figure 18 **Different principles for the application of scenario-based methods for the assessment of shadow prices: A cross-sectional scenario-based approach compared to a traditional scenario-based multi-criteria approach. The abbreviations such as EXP refer to different impact model types: EXP – Exposure, SEV – Severance, GLO – Global environment, MOB – Mobility, ECO – Economic development and OTH – Other strategic policy and planning objectives.**

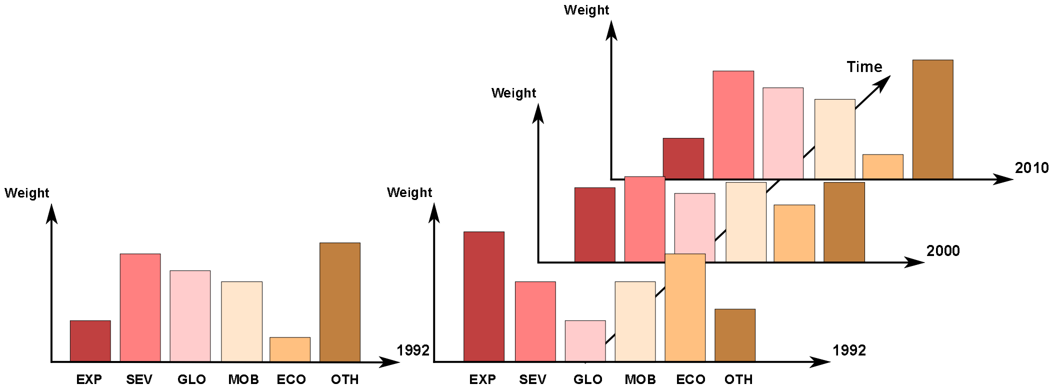


Figure 18 outlines the difference between a true scenario-based approach and a scenario-based multi-criteria approach. In the scenario-based multi-criteria analysis the preference set of the scenario is used in the present and there is often no scenario painting of other development variables. Conversely, in the true scenario-based approach the development profile of the scenarios is used for a consistent and plausible painting of all development variables.

Chapter 1 described the need for a broader planning framework, which explicitly dealt with planning uncertainty. The activities of such a framework based on robustness were listed. The concept of robustness seems an applicable approach to evaluation in a scenario-based planning context since "*robustness is based on satisficing*…" (Rosenhead, J., 1980b). Robustness may well be assessed in a manner comparable to the rank variation graphs seen in Figure 17. Such variation graphs can be based on multiple evaluation criteria such as a net benefit measure (Pearman, A.D., 1988). Some possible options are (Dasgupta, A.K & Pearce, D.W., 1972; Leleur, S., 1995):

- The net present value (NPV)
- The benefit-cost ratio (B/C-Ratio)
  - The internal rate of return (IRR)

Any of these measures are applicable for robustness analysis in a scenario-based context. One scenario ranking method for assessing project robustness has been suggested by Allport et al. (1986). It involves the development of a trend or base scenario in addition to the 'true' ones. Such a base scenario could resemble the Most-Likely-Development (MLD) scenario or simply reflect a prolongation of present day preference sets. Preferably this base scenario should be a 'best knowledge scenario' based on present trends as known from traditional prognoses. It should be noted that this trend scenario is quite different in intention from traditional trend analysis. The base scenario merely serves as a fixing point useful for comparison and analysis of the 'true' scenarios.

How decisions should be taken on the basis of a robustness measure will depend on the planning context. There are two main possibilities (Pearman, A.D., 1988):

- Threshold screening with a secondary selection of highest scoring project alternative within this group. The decision-maker will have to decide on the level of the threshold for each criterion.
- Choice on the basis of the rank variation graph. The choice is then based on a selection of those alternatives that generally score well in a visual inspection. This however requires that all projects be tested using the same scale.

This basis for decision helps to promote those projects or initiatives that appear robust with respect to future development. The project may not be optimal in the future that does arise but will most likely prove a satisficing solution to the planning problem.

4.5 CONCLUDING REMARKS

The review of the appraisal methodologies as applied for transport infrastructure evaluation indicated a four-stage development that comprised rational comprehensive planning, sensitivity testing, multi-criteria analysis and scenario painting. As has been shown the scenario painting approach combines elements of the other appraisal methodologies in a scenario-based context. In section two of this report the scenario painting approach will be combined with the conceptual model for the understanding of future uncertainty in order to form the basis for the development of a fully fletched scenario-based appraisal methodology (SEAM). The object being to incorporate or sew together the existing project appraisal methodologies in a scenario-based planning context. The approach is discussed in detail in chapter 5. Elements of the approach are illustrated on a case study in chapter 7 using the scenarios developed by Palludan et al. (1996) as described in chapter 2. Chapter 6 is about the practical issues of developing a decision support system (DSS) adaptable for dealing with such a wide set of modelling options as SEAM involves.

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5 A METHODOLOGY FOR SCENARIO-BASED APPRAISAL (SEAM)

Part I of this report formed the conceptual basis concerning uncertainty and scenario based thinking. Chapter 1 presented the planning problems relating to transport prediction and furthermore drew attention to the need for a new broader planning framework which has led to the conceptualisation of a combined robustness and scenario-based planning framework. On this basis scenarios were defined in chapter 2 for application in this study. In chapter 3 the traditional modelling approach to project appraisal was investigated in the context of scenario-based planning. The overall modelling uncertainty was divided into exogenous and endogenous uncertainty and a classification was made of the elements of endogenous uncertainty. Finally in chapter 4 the issue of evaluation in a scenario-based planning context was discussed. This led to the indication of a four-stage development of appraisal methodologies comprising:

- Rational comprehensive planning
- Sensitivity testing
- Multi-criteria analysis
  - Scenario Painting

On the basis of the collective findings and conclusions in the previous chapters this chapter develops the foundation for a scenario-based appraisal methodology (SEAM). SEAM involves elements from each of the existing appraisal methodologies but makes use of them within a scenario-based planning context. The following sections are concerned with the different elements of a full scenario-based appraisal. This will illustrate scenario painting as a logical further development of the existing methodologies.

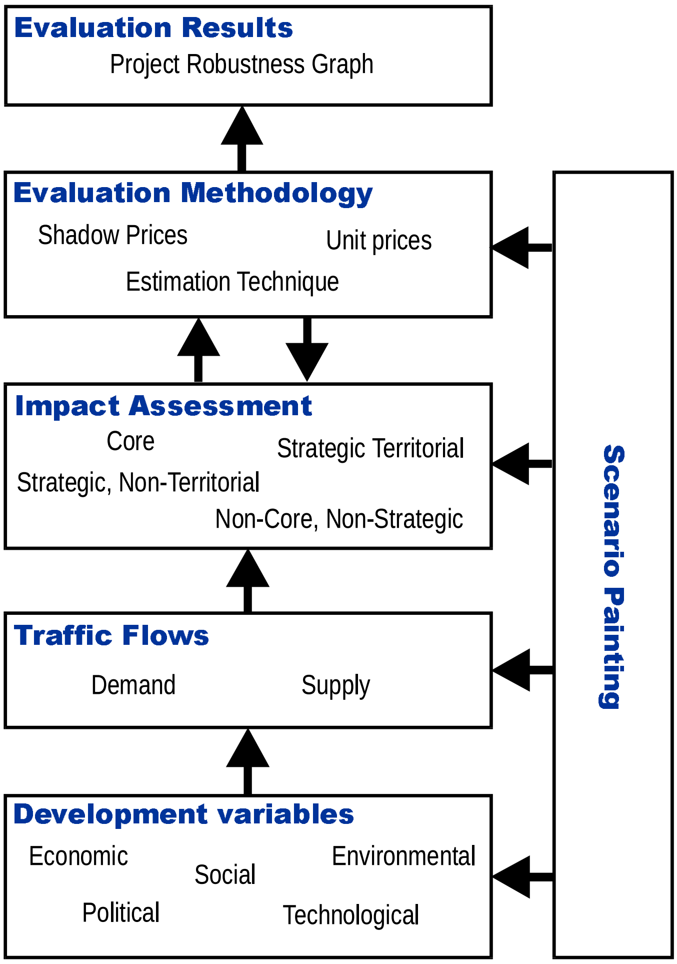
5.1 THE STRUCTURE OF THE SEAM METHODOLOGY

Chapter 3 showed that project uncertainty can be assessed only to a limited extent through simple variation of single variables. The influence of scenarios on model behaviour and uncertainty is far more fundamental. The future uncertainty is better assessed through scenarios determining the planning environment and its development over time. The scenario is as such exogenous to the appraisal system but influences the endogenous uncertainty of each model within it. The endogenous uncertainty was divided into three elements:

- Objective uncertainty
- Adaptive uncertainty
  - Subjective uncertainty

It was shown that for some scenarios model uncertainty might be affected only marginally (e.g. through changes in the subjective uncertainty), whereas other scenarios substantially affect the model uncertainty (e.g. through changes in both the subjective as well as the adaptive and objective uncertainty – See Figure 14). Consequently, a scenario-based appraisal methodology should be capable of dealing with the influence of scenarios on model behaviour. A rigorous assessment of probabilities does not seem feasible due to the problems associated with this approach and the structure of the endogenous uncertainty. Instead a scenario-based appraisal methodology (SEAM) is suggested that attempt to envelop the planning uncertainties from the interdependencies between models and scenarios. The methodology elaborates on the scenario and modelling interrelationship in the context of transport planning by painting the appraisal system according to each scenario. SEAM aims at embracing these complexities through the collective evaluation of the project within multiple scenarios. The scenario painting of the appraisal methodology relates to multiple levels within it. The structure of the SEAM methodology is seen in Figure 19.

Figure 19 The scenario-based appraisal methodology (SEAM).



The SEAM methodology includes and utilises existing project appraisal techniques as part of the developed scenario-based approach. It draws on the systems theory through the description of a comprehensive modelling structure in order to describe the interdependencies in the planning system. It applies the argumental basis of the sensitivity analysis, but promotes a wider understanding of project uncertainty. Finally, it applies estimation techniques found in multi-criteria analysis for the assessment of cross-sectional shadow prices. The methodology involves several separate layers of which three elements will be discussed in detail:

- Scenario painting of development variables
- Impact assessment (Unit prices, shadow prices and estimation techniques)
  - Evaluation results

The elements of the methodology that are not specifically discussed in the following are dealt with elsewhere in this report.

5.2 SCENARIO PAINTING OF DEVELOPMENT VARIABLES

Development variables refer to variables of the planning environment (see chapter 2). Some variables influence travel behaviour directly whereas others have a more indirect influence. The level of income, the car ownership, legislation and taxation are variables that have a direct influence. Other development variables influence indirectly through e.g. increases in the efficiency of the transport system. Then again other variables influence the intensity of the external impacts of the transport system. The exogenous assumptions may however also affect the internal relationship between models in the modelling system. Assuming for example that cars become far quieter than we know them today, this will positively affect the noise impact. Conversely it may also have a negative impact on the expected number of accidents, as e.g. pedestrians are not forewarned by the noise of approaching vehicles.

This interconnectedness of the planning environment and the attempt to describe it forms the basis of rational comprehensive planning. The systems analysis attempts to embrace the interaction between the model system and the planning environment. The difference between systems theory and SEAM is that system theory is used for systems prediction whereas SEAM aims at assessing the logical structure within each scenario to envelop planning uncertainty in project robustness. Systems logic is only sought within the boundaries of each scenario, since the type and degree of interaction may change depending on the scenario in question.

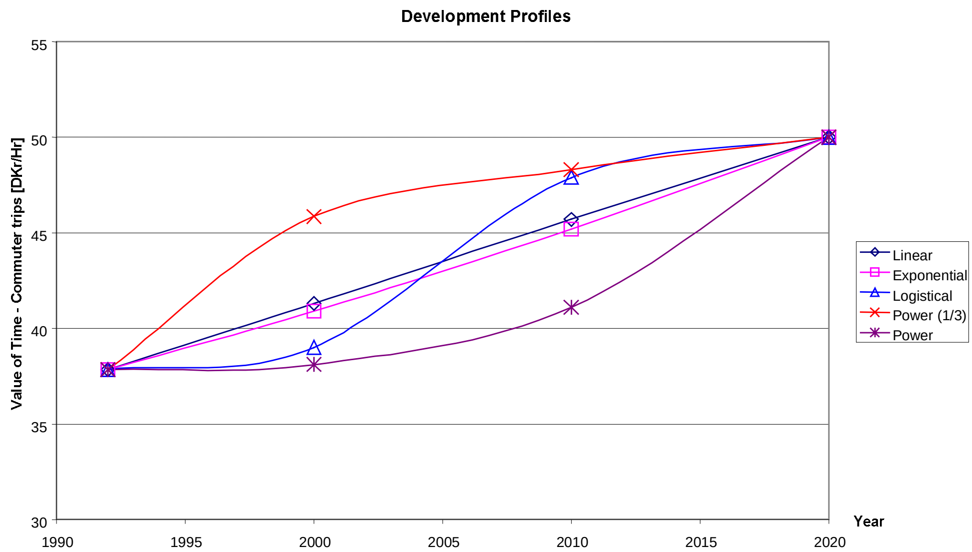
The determination of cause and effect in socio-cultural systems is highly complex and may involve several feedback loops. The feedback between development variables in the planning environment also involves a certain level of inertia. Some development variables make swift responses whereas others are rather slow. Especially if the response involves a chain of variables or changes in attitudes the time gap may be substantial (see chapter 3). Scenarios often are constructed with a specific year in mind and are rarely concerned with the development profile: In the scenario year 20xx the behavioural patterns will be this or that.

Some of the elements of a scenario do from the present point of view seem more or less obvious. Obvious in the sense that elements of the scenario are imaginable in the near future (this should not be confused with the likelihood of a scenario which relates to the scenario year). Other scenarios appear more obscure and will presumably take longer to mature before being fully fledged. Yet again other scenarios involve changes that seem vague and evenly distributed over time. Also a trend may prevail in the point of departure but the scenario will determine the finishing-point. To accommodate different development profiles a range of functions are applicable:

- Linear (Evenly distributed)
- Exponential / Percentual (Slow development at first whereafter it accelerates)
- Logistical (Very large and quick/revolutionary change in the medium term)
- Power (Very slow/fast development at first then it becomes very fast/slow depending on the power)
  - Polynomial / Customised (Development profile specifically adjusted to the planning context)

Any more development profiles seem unnecessary as the above mentioned cover a satisfactory range of options. The assessment of the development profile will necessarily be based on professional judgement in a dialog with decision-makers. Different examples of development profiles for the value of commuter time between 1992 and 2020 are illustrated in Figure 20.

Figure 20 **Example of development profiles for the value of time for commuter trips. The examples are taken from the market-oriented scenario (MKT) where the value of commuting time increases from 37.86 to 50 DKr/Hour. The Logistical curve was developed using an approximation based on two power functions (power 3), The exponential function had a growth rate of approximately 1% p.a. The one power function curve is based on a power of 1/3 and the other on a power of 3.**



The development profile should be assessed with great care as to avoid significant inconsistencies in-between calculation years. Not all variables evolve along the same profile in each scenario. This may in the medium term lead to inconsistencies. Special care should also be taken in assessing whether such inconsistencies are too severe. In that case certain variables will need a customised development profile.

A possible composition of development profiles within a number of scenarios will be illustrated through a practical example. The development variables involve model variables, unit prices as well as weights. The scenarios used for this example are the four scenarios constructed by Palludan et al. (1996) described in section 2.3.3. The four scenarios developed in that study as they are interpreted here are:

- The Market-oriented scenario (MKT)
  A 'liberal' scenario involving de-regulation in all sectors and high economic growth.

- The Intimate scenario (INT)
  A 'social' scenario in which attitudes changes towards the local values and local environment.

- The Supra-national scenario (SUP)
  A 'political' scenario where the global environment is a global concern and the European Union and the United Nations play a central role.

- The Technological scenario (TEC)
  The 'technological' scenario in which a technological jump occurs and a technology friendly society evolves.

The example is limited to the analysis of the impact assessment for road transport since it has been beyond the available resources of this Ph.D.-study to consider all model aspects. A full scenario painting would also involve behavioural variables for the traffic model. Specifically since e.g. the social share of the vehicle operating cost is relatively scenario neutral, the behavioural cost is not. Presumably an energy taxation in both the Intimate (INT) and the Supra-national (SUP) scenarios would be far higher than in the other two scenarios. In the full application of SEAM such elements should be considered.

It should also be emphasised that such development profiles and the terminal level of the development variables should be assessed in close interaction and collaboration with decision-makers. This is a critical success factor for the implementation of and utilisation of SEAM. Otherwise the final results are at risk of acquiring a black-box character. In this case scenario profiles have been developed as a suggestion of a possible range and interpretation of the scenarios by Palludan et al. (1996).

The scenario painting of the development variables is structured in accordance with the EUNET transport evaluation framework for road infrastructure (see Leleur et al., 1998 or appendix A). In Table 11 the result, model and assessment variables are listed according to this evaluation framework. The evaluation variables comprise the model results, which enter the evaluation. The model variables are specific impact model development variables (See appendix B). The valuation variables are either monetary unit prices or shadow prices that are assessed using an estimation technique.

Table 11 **Overview of the modelling approach used for each of the impacts, listing the assessment variable, model variables and valuation variables (For details on each modelling approach refer to appendix B).**

FV 11-I		**Road infrastructure**		
Impacts		**Evaluation Variables**	**Model Variables**	**Assessment Variables**
A - Core impacts				
A1	Investment costs (INV)	Monetary Value	None	-
A2	System operating and maintenance costs (OMC)	Monetary Value	Assumed scenario neutral due to low impact and high complexity	-
A3	Vehicle operating costs (VOC)	Vehicle kilometres	None	Cost per vehicle km.
A4	Travel time benefits (TTB)	Working time, home-work time and leisure time	Vehicle occupancy rate, trip purpose,	Cost per passenger hour by trip purpose
A5	Safety (SAF)	Expected number of casualties	Parameters a and p	Cost per accident
A6	Local environment			
	Noise (NOI)	Noise Load Number (SBT)	Noise severity (A, B, K), Reference noise level L_{AEq}	Cost per SBT
	Air pollution (EMI/POL/EXP)	Exposure to NOX, CO and HC	Emission factors, percentage catalytic converters, technology	Shadow price
	Severance (SEV)	Project specific point score	-	Shadow price
B - Non-core, non-strategic impacts				
B1	Driver convenience (DCO)	Not assessed	-	-
B2	Urban quality & landscape (UQL)	Not assessed	-	-
C – Strategic, territorial impacts				
C1	Strategic mobility (MOB)	Project point score	-	Shadow price
C2	Strategic environment (GLO)	Energy consumption (GJ)	Energy factors, technology	Shadow price
C3	Strategic economic development (ECO)	Not assessed	-	-
D – Strategic, non-territorial impacts				
D1	Private financial attractiveness (PFA)	Project point score	-	Shadow price
D2	Other strategic policy and planning impacts (OTH)	Project point score	-	Shadow price

As seen in Table 11 it has not been possible neither to valuate nor to model all impacts directly. Instead it is necessary to apply an estimation technique for the assessment of shadow prices and introduce point scores. There are a variety of multi-criteria methods available for this purpose (see e.g. CEC, 1996f). In this study the WARP method has been found useful (see chapter 4 and Leleur, S., 1995). WARP may either be used in two manners: To derive shadow prices for each impact for each calculation year, or to derive a base shadow price value for the first calculation year. The base shadow price may subsequently be developed across all calculation years. This latter approach should be used in the case of an inhomogeneous project pool.

For this study it has been necessary to develop a set of base weights in order to provide a point of departure for the scenario painting of the non-valuated impacts. In a full-scale study these base weights should be assessed in correspondence with decision-makers e.g. through a stated preference survey. The base weight profile that has been applied is seen in Table 12 below.

Table 12 The base weight profile developed and applied in this study.

IMPACTS	BASE WEIGHT PROFILE
A – Core impacts	
Benefit from valuated impacts	78.3%
Severance (SEV)	12.8%
Air pollution (EMI)	2.0%
B – Non-core, non-strategic impacts	
Urban quality and landscape (UQL)	1.0%
Driver convenience (DCO)	1.0%
C – Strategic, territorial impacts	
Strategic mobility (MOB)	2.0%
Strategic economic development (ECO)	0.0%
Global environment (GLO)	0.9%
D – Strategic, non-territorial impacts	
Private financial attractiveness (PFA)	0.0%
Other policy and planning impacts (OTH)	2.0%

For the scenario painting the following structure has been applied:

- The analysis operates with four calculation years: 1992, 2000, 2010 and 2020. 1992 is the point of departure of the development variables, even though it could be any year.
- For the evaluation and the robustness examination, a base scenario is helpful. A base scenario is in this case a scenario where the development variables remain fixed in time (except for land-use development etc.). This base scenario provides a platform for the assessment of scenario sensitivity as discussed in chapter 4.
- The development variables that are not influenced by e.g. the technological development, the political system, the development in the global environment or any other part of the current scenario is said to be scenario neutral.

In the following a series of double pages will exemplify the development profiles applied for the four scenarios constructed by Palludan et al. (1996). The examples are based on the following template to ease the comparison between the scenarios:

1. Determination of prevailing development profile
2. Graphical interpretation of the scenario painting
3. Table for the development profile for monetised impacts
4. Table for the development profile for weights for non-monetised impacts
1. Table for the development profile for derived shadow prices

The three tables are all followed by a brief discussion to emphasise main points concerning the interpretation and translation of the qualitative scenarios into the quantitative measures. The interpretation of the scenario painting is indicated on the left hand side by simple graphics. On a scale from zero to five the intensity of the painting is indicated by way of + and ÷. This can be directly compared to the other scenarios. On the right hand side the specifics are listed along with the short description. Following these double pages the scenario painting of model variables is discussed.

5.2.1 THE MARKET ORIENTED SOCIETY (MKT)

Prevailing development profile: **Linear**

Table 13 Graphical interpretation of the changes stemming from the scenario painting from the Market-oriented scenario (MKT) compared to the base scenario.

IMPACTS		MARKET (MKT)	INTIMATE (INT)	SUPRA-NATIONAL (SUP)	TECHNOLOGICAL (TEC)
A – Core impacts					
A1	Investment costs (INV)				
A2	System operating and maintenance costs (OMC)				
A3	Vehicle operating costs (VOC)			+++	÷ ÷ ÷
A4	**Travel time benefits (TTB)**	+++	÷ ÷ ÷		+++
A5	Safety (SAF)		++++	++	÷ ÷ ÷
A6	Local environment				
	Noise (NOI)		++++	++	÷
	Air pollution (EMI/POL/EXP)		++++	++++	÷ ÷ ÷ ÷
	Severance (SEV)	÷÷÷	+++	++	
B – Non-core, non-strategic impacts					
B1	**Driver convenience (DCO)**	++			
B2	Urban quality & landscape (UQL)		++	++	
C – Strategic, territorial impacts					
C1	**Strategic mobility (MOB)**	++++	÷ ÷ ÷ ÷		
C2	Strategic environment (GLO)		++++	++++	
C3	**Strategic economic development (ECO)**	+++			
D – Strategic, non-territorial impacts					
D1	**Private financial attractiveness (PFA)**	++++			
D2	Other strategic policy and planning impacts (OTH)			+++	

Table 14 The Market-oriented scenario (MKT) development profile for the socio-economic unit prices.

SCENARIO: MKT	UNIT PRICES (VALUATED IMPACTS) – LINEAR DEVELOPMENT					
IMPACT	VOC	TTB			SAF	NOI
		WORK	COMMUTE	OTHER		
YEAR \ UNIT	DKR/KM		DKR/HR		DKR/ACC.	DKR/SBT
1992	0.88	145.13	37.86	22.72	1181000	12650.40
2000	0.88	155.09	41.33	24.80	1181000	12650.40
2010	0.88	167.54	45.66	27.40	1181000	12650.40
2020	0.88	180	50	30	1181000	12650.40

Table 15 The Market-oriented scenario (MKT) development profile for the weights.

SCENARIO: MKT	WEIGHTS (NON-VALUATED IMPACTS) – LINEAR DEVELOPMENT					
YEAR \ IMPACT	SEV	EXP	GLO	MOB	PFA	OTH
1992	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2000	11.0%	2.0%	0.9%	4.3%	1.4%	2.0%
2010	8.7%	2.0%	0.9%	7.1%	3.2%	2.0%
2020	6.4%	2.0%	0.9%	10%	5.0%	2.0%

Table 16 The Market-oriented scenario (MKT) development profile for the shadow prices.

SCENARIO: MKT	SHADOW PRICES (NON-VALUATED IMPACTS) – LINEAR DEVELOPMENT						
YEAR \ IMPACT [DKR/UNIT]	SEV	EXP [NO_X]	EXP [CO]	EXP [HC]	GLO	MOB	PFA	OTH
1992	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2000	9689176	0.0134	0.00064	0.00971	6.45	1134853	571428	883191
2010	7669588	0.0134	0.00064	0.00971	6.45	1817426	1285714	883191
2020	5650000	0.0134	0.00064	0.00971	6.45	2500000	2000000	883191

The market-oriented scenario is assumed to be a continuation of a liberal and market economic trend found in our present society. The development is assumed to be linear, as no rapid changes are expected in connection with this type of development. The vehicle operating cost remains unchanged but the taxation will increase (not shown). The value of time increases by approximately 25%, as the real income is expected to increase. The value of leisure time increase relatively more than the value of working time because of the increasing importance of being put on the limited spare time available. The importance of the local environment stays unchanged except for the severance, which is halved on behalf of mobility issues that get significantly higher attention. The importance of public and private partnerships is also of high importance to this scenario.

5.2.2 THE INTIMATE SCENARIO (INT)

Prevailing development profile: **Exponential**

Table 17 **Graphical interpretation of the changes stemming from the scenario painting from the Intimate scenario (INT) compared to the base scenario.**

IMPACTS		MARKET (MKT)	INTIMATE (INT)	SUPRA-NATIONAL (SUP)	TECHNOLOGICAL (TEC)
A – Core impacts					
A1	Investment costs (INV)				
A2	System operating and maintenance costs (OMC)				
A3	Vehicle operating costs (VOC)			+++	÷ ÷ ÷
A4	**Travel time benefits (TTB)**	+++	÷ ÷ ÷		+++
A5	**Safety (SAF)**		++++	++	÷ ÷ ÷
A6	**Local environment**				
	Noise (NOI)		++++	++	÷
	Air pollution (EMI/POL/EXP)		++++	++++	÷ ÷ ÷ ÷
	Severance (SEV)	÷÷÷	+++	++	
B - Non-core, non-strategic impacts					
B1	Driver convenience (DCO)	++			
B2	**Urban quality & landscape (UQL)**		++	++	
C – Strategic, territorial impacts					
C1	**Strategic mobility (MOB)**	++++	÷ ÷ ÷ ÷		
C2	**Strategic environment (GLO)**		++++	++++	
C3	Strategic economic development (ECO)	+++			
D – Strategic, non-territorial impacts					
D1	Private financial attractiveness (PFA)	++++			
D2	Other strategic policy and planning impacts (OTH)			+++	

Table 18 The Intimate scenario (INT) development profile for the socio-economic unit prices

SCENARIO: INT	UNIT PRICES (VALUATED IMPACTS) – EXPONENTIAL DEVELOPMENT					
IMPACT	VOC	TTB			SAF	NOI
		WORK	COMMUTE	OTHER		
YEAR \ UNIT	DKR/KM		DKR/HR		DKR/ACC.	DKR/SBT
1992	0.88	145.13	37.86	22.72	1181000	12650.40
2000	0.88	143.07	37.21	22.09	1247857	15368.40
2010	0.88	134.74	34.61	19.52	1519464	19601.28
2020	0.88	120	30	15	2000000	25000

Table 19 The Intimate scenario (INT) development profile for the weights

SCENARIO: INT	WEIGHTS (NON-VALUATED IMPACTS) – EXPONENTIAL DEVELOPMENT					
YEAR \ IMPACT	SEV	EXP	GLO	MOB	PFA	OTH
1992	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2000	14.5%	3.3%	1.5%	0.9%	0.0%	2.0%
2010	17.1%	5.7%	2.7%	0.3%	0.0%	2.0%
2020	20%	10%	5%	0.1%	0.0%	2.0%

Table 20 The Intimate scenario (INT) development profile for the shadow prices

SCENARIO: INT	SHADOW PRICES (NON-VALUATED IMPACTS)- EXPONENTIAL DEVELOPMENT							
YEAR \ IMPACT [DKR/UNIT]	SEV	EXP [NOX]	EXP [CO]	EXP [HC]	GLO	MOB	PFA	OTH
1992	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2000	12256260	0.020	0.0010	0.014	9.5	6849	0	883191
2010	13558910	0.035	0.0017	0.024	15.4	26	0	883191
2020	15000000	0.06	0.003	0.04	25	0	0	883191

The Intimate society involves significant changes in the way we have arranged our present society. We focus to a greater extent on the local issues and the soft values (family, the environment etc.). This has a substantial behavioural impact. In that sense it seems reasonable to assume that a rather long period of time will pass before habits and attitudes starts changing. But the change in habits and attitudes will accelerate at the end of the period. Hence an exponential development is assumed. The value of time decreases by approximately 1/5 at the same time, as the mobility issue becomes irrelevant. The local impacts such as severance, noise, air pollution and the global environment become far more important issues. The same goes for accident costs due to a greater importance of grief and suffering.

5.2.3 THE SUPRA-NATIONAL SCENARIO (SUP)

Prevailing development profile: **Linear**

Table 21 **Graphical interpretation of the changes stemming from the scenario painting from the Supra-national scenario (SUP) compared to the base scenario.**

	IMPACTS	MARKET (MKT)	INTIMATE (INT)	SUPRA-NATIONAL (SUP)	TECHNOLOGICAL (TEC)
A - Core impacts					
A1	Investment costs (INV)				
A2	System operating and maintenance costs (OMC)				
A3	**Vehicle operating costs (VOC)**			+++	÷ ÷ ÷
A4	Travel time benefits (TTB)	+++	÷ ÷ ÷		+++
A5	**Safety (SAF)**		++++	++	÷ ÷ ÷
A6	**Local environment**				
	Noise (NOI)		++++	++	÷
	Air pollution (EMI/POL/EXP)		++++	++++	÷ ÷ ÷ ÷
	Severance (SEV)	÷÷÷	+++	++	
B - Non-core, non-strategic impacts					
B1	Driver convenience (DCO)	++			
B2	**Urban quality & landscape (UQL)**		++	++	
C – Strategic, territorial impacts					
C1	Strategic mobility (MOB)	++++	÷ ÷ ÷ ÷		
C2	**Strategic environment (GLO)**		++++	++++	
C3	Strategic economic development (ECO)	+++			
D – Strategic, non-territorial impacts					
D1	Private financial attractiveness (PFA)	++++			
D2	**Other strategic policy and planning impacts (OTH)**			+++	

Table 22 The Supra-national scenario (SUP) development profile for the socio-economic unit prices.

SCENARIO: SUP	UNIT PRICES (VALUATED IMPACTS) – LINEAR DEVELOPMENT					
IMPACT	VOC	TTB			SAF	NOI
		WORK	COMMUTE	OTHER		
YEAR \ UNIT	DKR/KM		DKR/HR		DKR/ACC.	DKR/SBT
1992	0.88	145.13	37.86	22.72	1181000	12650.40
2000	1.01	145.13	37.86	22.72	1272143	14178.86
2010	1.16	145.13	37.86	22.72	1386071	16089.43
2020	1.32	145.13	37.86	22.72	1500000	18000

Table 23 The Supra-national scenario (SUP) development profile for the weights.

SCENARIO: SUP	WEIGHTS (NON-VALUATED IMPACTS) – LINEAR DEVELOPMENT					
YEAR \ IMPACT	SEV	EXP	GLO	MOB	PFA	OTH
1992	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2000	12.8%	4.3%	3.5%	2.0%	0.0%	2.9%
2010	12.8%	7.1%	6.75%	2.0%	0.0%	3.9%
2020	12.8%	10%	10%	2.0%	0.0%	5.0%

Table 24 The Supra-national scenario (SUP) development profile for the shadow prices.

SCENARIO: SUP	SHADOW PRICES (NON-VALUATED IMPACTS) – LINEAR DEVELOPMENT							
YEAR \ IMPACT [DKR/UNIT]	SEV	EXP [NOX]	EXP [CO]	EXP [HC]	GLO	MOB	PFA	OTH
1992	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2000	11304846	0.026	0.0013	0.018	11.75	588794	0	1059422
2010	11304846	0.043	0.0021	0.029	18.375	588794	0	1279711
2020	11304846	0.06	0.003	0.04	25	588794	0	1500000

The supra-national society is slowly becoming a fact. It takes several small steps over a long period of time to adjust the political structure with a view to handing over power to supra-national bodies. Out of these changes an increasing awareness of the common environmental problems of the earth emerges. As the change will be gradual, a linear development has been chosen. The concern for the global environment causes a substantial increase in the valuation of the global environment. The valuation of noise increases as does the accident costs (mainly due to a greater importance on grief and suffering), whereas severance remains unchanged. The broader perspective in this scenario leads to an increase in the weighting of the coherence of planning initiatives. Limitations in the oil resources cause substantial increases in the vehicle operating cost.

5.2.4 THE TECHNOLOGICAL SCENARIO

Prevailing development profile: **Logistic**

Table 25 Graphical interpretation of the changes stemming from the scenario painting from the Technological scenario (TEC) compared to the base scenario.

	IMPACTS	MARKET (MKT)	INTIMATE (INT)	SUPRA-NATIONAL (SUP)	TECHNOLOGICAL (TEC)
A - Core impacts					
A1	Investment costs (INV)				
A2	System operating and maintenance costs (OMC)				
A3	**Vehicle operating costs (VOC)**			+++	÷ ÷ ÷
A4	**Travel time benefits (TTB)**	+++	÷ ÷ ÷		+++
A5	**Safety (SAF)**		++++	++	÷ ÷ ÷
A6	Local environment				
	Noise (NOI)		++++	++	÷
	Air pollution (EMI/POL/EXP)		++++	++++	÷ ÷ ÷ ÷
	Severance (SEV)	÷÷÷	+++	++	
B – Non-core, non-strategic impacts					
B1	Driver convenience (DCO)	++			
B2	Urban quality & landscape (UQL)		++	++	
C – Strategic, territorial impacts					
C1	Strategic mobility (MOB)	++++	÷ ÷ ÷ ÷		
C2	Strategic environment (GLO)		++++	++++	
C3	Strategic economic development (ECO)	+++			
D – Strategic, non-territorial impacts					
D1	Private financial attractiveness (PFA)	++++			
D2	Other strategic policy and planning impacts (OTH)			+++	

Table 26 The Technological scenario (TEC) development profile for the socio-economic unit prices.

SCENARIO: TEC	UNIT PRICES (VALUATED IMPACTS) – LOGISTIC DEVELOPMENT					
IMPACT	VOC	TTB			SAF	NOI
		WORK	COMMUTE	OTHER		
YEAR \ UNIT	DKR/KM		DKR/HR		DKR/ACC.	DKR/SBT
1992	0.88	145.13	37.86	22.72	1181000	12650.40
2000	0.86	150.84	39.82	23.86	1181000	12650.40
2010	0.74	171.88	47.17	28.30	1181000	12650.40
2020	0.70	180	50	30	1181000	12650.40

Table 27 The Technological scenario (TEC) development profile for the weights.

SCENARIO: TEC	WEIGHTS (NON-VALUATED IMPACTS) – NEUTRAL DEVELOPMENT					
YEAR \ IMPACT	SEV	EXP	GLO	MOB	PFA	OTH
1992	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2000	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2010	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%
2020	12.8%	2.0%	0.9%	2.0%	0.0%	2.0%

Table 28 The Technological scenario (TEC) development profile for the shadow prices.

SCENARIO: TEC	SHADOW PRICES (NON-VALUATED IMPACTS) – LINEAR DEVELOPMENT							
YEAR \ IMPACT [DKR/UNIT]	SEV	EXP [NOX]	EXP [CO]	EXP [HC]	GLO	MOB	PFA	OTH
1992	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2000	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2010	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191
2020	11304846	0.0134	0.00064	0.00971	6.45	588794	0	883191

Essentially, the preferences are assumed stable in the Technological society. Consequently, all socio-economic unit prices and weights remain the same whereas the value of time increases due to an increase in the real income. The new technology reduces the vehicle operating cost. The changes in this scenario mainly relate to the technology performance and not to behaviour. Technology developments are often revolutionary and consequently the significant improvements are assumed in between the first year and the scenario year. This is around the year 2005. Accordingly the development profile is logistic.

5.3 SCENARIO PAINTED MODEL VARIABLES

The main focus of this section is the relation between the model variables for different model types and the four scenarios. The interrelation between models and scenarios is described both qualitatively and quantitatively in order to obtain a consistent modelling system for each scenario. The models considered are those with model variables listed in Table 11.

5.3.1 SYSTEM OPERATION AND MAINTENANCE COST (OMC)

System operation and maintenance is very labour intensive and is consequently influenced mainly by the change in real income and to some extent the oil prices. The interdependence between each of these elements is however unclear. Furthermore, the influence that system operation and maintenance costs have on project performance is often marginal, even though this need not necessarily be the case for specific large infrastructure investments such as bridges or tunnels.

On this basis the approach selected here is to acknowledge that the scenarios do influence the assessment of the system operation and maintenance costs, but due to the complexities associated with the estimation the influence is neglected. It is at the same time acknowledged that a fault arises from this negligence, but this is considered acceptable due to the generally low influence on project performance. In case of a potentially large influence a more in-depth analysis of the impact is required in order to 'fan out' the model results.

5.3.2 TRAFFIC SAFETY (SAF)

The total number of casualties has decreased in Denmark by approximately 30% over the last 10 years (Lahrman, H. & Leleur, S., 1994; Danmarks Statistik, 1996). The development in *a*- and *p*-values for the periods 1967 - 1971, 1978 - 1982 and 1984 - 1988 for a two-lane rural road is illustrated in Table 29 and Figure 21 below.

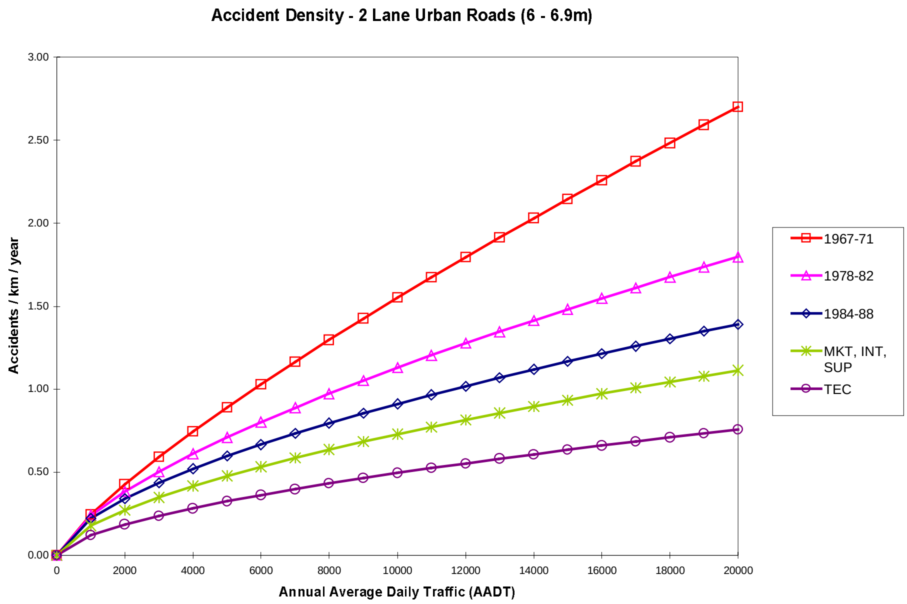
Table 29 **The development in a and p values for a urban 2-lane road and for motorway respectively over a 20 year period (Jørgensen, N.O. & Jørgensen, E., 1996).**

	RURAL TWO-LANE ROAD		MOTORWAYS	
YEAR	$a \cdot 10^6$	P	$a \cdot 10^6$	p
1967 – 71	97.87	0.8	-	-
1978 – 82	2360	0.67	10.5	1.07
1984 – 88	3311	0.61	69	0.94

It seems reasonable to assume that the total number of casualties will continue to decrease due to increasingly safer cars and the continued effort towards altering or removing dangerous road designs. The *a* and *p* parameters are re-estimated for each new analysis. This makes the fixation of either the *a* or the *p* parameter impossible due to the strong interrelationship between the parameters (Greibe, P. & Kronbak, J., 1994). Another complication is the influence of the technological development. Technological innovations that increase traffic safety could e.g. include auto-detection systems responsive to moving objects or breaking vehicles in front as found in intelligent vehicle highway systems (IVHS). Such systems are presumably not equally efficient on all road types, in all speed ranges and for all flow densities.

Consequently, the assessment of future *a* and *p* parameters is not a simple matter. A simplifying approach (which is used here) assumes that the expected improvement in safety will be equally large for all traffic flows through a scaling of the *a* parameter alone whereas *p* remains fixed.

Figure 21 **Accident density for the periods 1967 - 71, 1978 - 82 and 1984 - 88, including the terminal value (2020) for all scenarios (MKT – Market-oriented, INT – Intimate, SUP – Supra-national) except for the Technological scenario (TEC) (based on Jørgensen, N.O. & Jørgensen, E., 1996).**



It has been assessed accident rates are relatively scenario neutral and that only the technology scenario (TEC) will be adjusted beyond what is otherwise expected.

Table 30 **The change in the accident density is assumed equal for all scenarios (MKT – Market-oriented, INT – Intimate, SUP – Supra-national) except for the Technological scenario (TEC).**

Accidents	Change in accident density	
Scenario	All other	Technological (TEC)
Development	Linear	Logistic
1992	0 %	0 %
2000	-5.7 %	-7.3 %
2010	-12.8 %	-34.5 %
2020	-20 %	-45 %

5.3.3 Noise (NOI)

The influence from scenarios on noise modelling is twofold:

- The perception of the severity of noise
  - The equivalent noise level at 10 meters

The perceived severity of noise is expressed through the nuisance factor:

Eq. 3 $$NF = A \cdot B^{0.1(L_{Aeq}-K)}$$

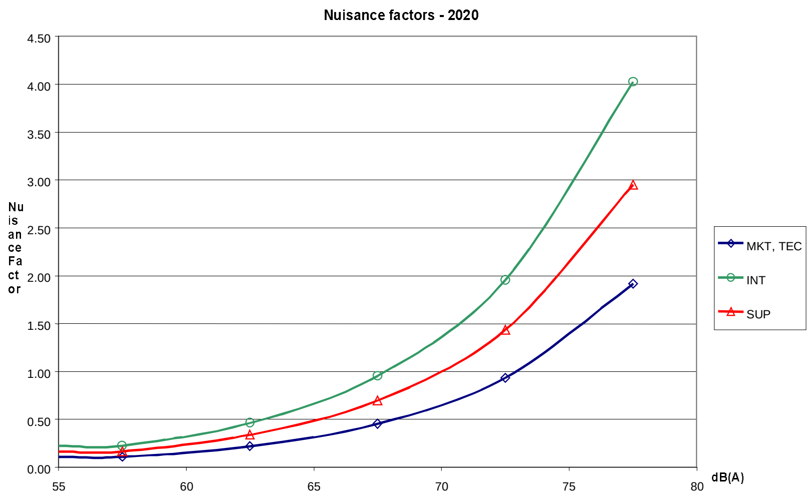
Each of the three variables, *A*, *B* and *K* may be used for scaling the nuisance factor. The scaling can either be based on an equally large percentual change for all noise levels through *A* or through a change in shape of the nuisance factor by way of *B* or *K*. In the Technological (TEC) and Market-oriented (MKT) scenarios no increase in the nuisance factor is assumed, whereas the Intimate scenario (INT) involves an increase in *A* as this provides the largest increase in the nuisance factor for the lowest noise levels. In the Supra-national scenario (SUP) an increase in the perception of noise is made through a decrease in *K*. The development variables are seen below:

Table 31 **The nuisance factor variables for each of the four scenarios.**

NOISE	SEVERITY								
SCENARIO	MARKET-ORIENTED (MKT)/TECHNOLOGICAL (TEC)			INTIMATE (INT)			SUPRA-NATIONAL (SUP)		
DEVELOPMENT	NEUTRAL			EXPONENTIAL			LINEAR		
YEAR	A	B	K	A	B	K	A	B	K
1992	0.01	4.22	41	0.01	4.22	41	0.01	4.22	41
2000	0.01	4.22	41	0.012	4.22	41	0.01	4.22	40.1
2010	0.01	4.22	41	0.016	4.22	41	0.01	4.22	39.1
2020	0.01	4.22	41	0.021	4.22	41	0.01	4.22	38

The development in the nuisance factor over time for the Intimate (INT) and the Supra-national (SUP) scenarios is illustrated in Figure 22 below. The lower most line for 1992 is equal to the present nuisance factor. In the Intimate scenario (INT) the nuisance factor is more than a twice as high after 30-years. In the Supra-national scenario (SUP) the increase is approximately 50%. The scaling is easiest to interpret if it is based on the *A*-variable alone, as the link to the nuisance factor will be linear. The interpretation of the *K* or *B* variables is slightly more uncertain.

Figure 22 **The nuisance factor for the intimate (INT) and the supra-national (SUP) scenarios compared to the present nuisance factor which is equal to the Market-oriented (MKT) and the Technological (TEC) scenarios.**



Road traffic noise is composed of three main elements (VD, 1990a):

- Engine noise
- Wheel noise
- Wind noise

All three elements may be affected by technological development. Assuming that electric vehicles become a feasible alternative to the traditional combustion engine, engine noise will decrease. Wind noise has probably been reduced slightly over the last 15 years, as cars have become increasingly aerodynamic. As concerns wheel noise, technological innovation may reduce the noise created in the contact between the road surface and the wheel. These elements all add to the reduction of the reference equivalent noise level ($L_{aeq,10m}$). As these reductions are difficult to assess, a reduction is assumed only in the Technological scenario (TEC).

Table 32 **Development variables for the reference equivalent noise level for all scenarios.**

NOISE	REFERENCE EQUIVALENT NOISE LEVEL ($L_{AEQ,10M}$)	
SCENARIO	ALL OTHER	TEC
DEVELOPMENT	NEUTRAL	LOGISTIC
1992	68	68
2000	68	66.7
2010	68	61.9
2020	68	60

5.3.4 SCENARIO INFLUENCE ON EMISSIONS

Scenarios may influence the energy consumption and the emissions differently. As an example, catalytic converters have a negative impact on the energy efficiency, whereas the toxic emissions decline. In this case however the energy consumption and the emissions are assumed positively correlated in the sense that a 20 % improvement in fuel efficiency entails a 20 % reduction in emissions, even though this may underestimate the reduction in emissions. The amount of emitted pollutants is furthermore influenced by the percentage of cars with functioning catalytic converters.

The change in energy efficiency can be assessed either through an equal scaling for all speeds or through a re-estimation of energy consumption factors. In this case the energy efficiency is scaled with an equal percentage for all travel speeds. This is probably not very realistic since this has a tendency of 'flattening' the emission factor profile. It is however a very simple and operational approach. No change has been assumed in the percentage of diesel cars. A 20% improvement in energy efficiency seems reasonable as a base assumption. Only with respect to the Supra-national (SUP) and the Technological (TEC) scenarios are the improvements higher. The changes are listed below.

Table 33 Change in emission and energy consumption factors in the four scenarios. The abbreviations used are Lin. for linear, Exp. for exponential and Log. for logistical development.

	Market (MKT)			Intimate (INT)			Supra-national (SUP)			Technological (TEC)		
Change in %	Energy	Emission	Catalytic Converter	Energy	Emission	Catalytic Converter	Energy	Emission	Catalytic Converter	Energy	Emission	Catalytic Converter
	Lin.	Lin.	Lin.	Exp.	Exp.	Lin.	Lin.	Lin.	Lin.	Log.	Log.	Lin.
1992	0	0	40	0	0	40	0	0	40	0	0	40
2000	5.7	5.7	57.1	3	3	57.1	7	7	57.1	12	12	57.1
2010	12.8	12.8	78.5	12	12	78.5	16	16	78.5	58	58	78.5
2020	20	20	100	20	20	100	25	25	100	75	75	100

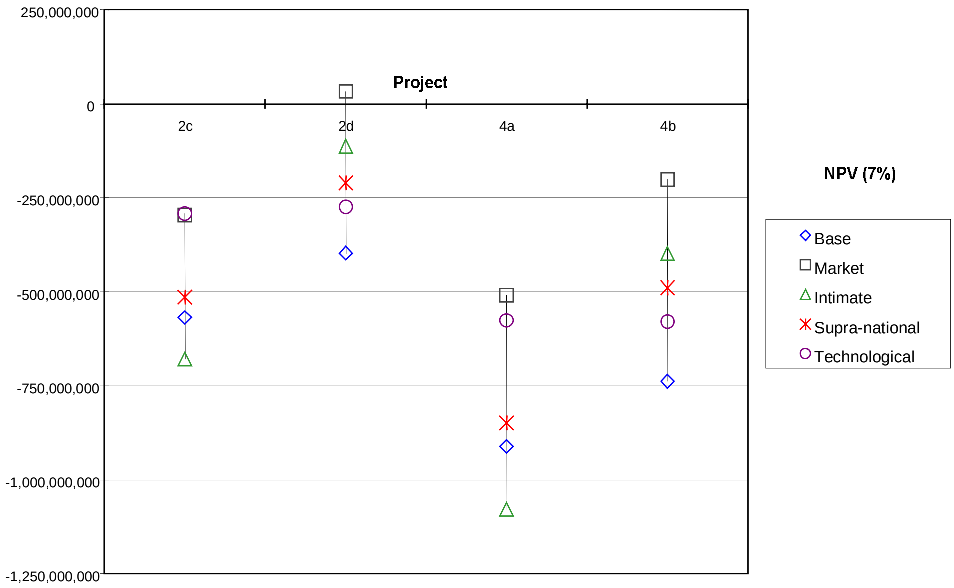
The percentage of cars with operating catalytic converters equals 100 in the year 2000, which is not a reasonable assumption for the entire car park. This does however make up for the fact that the expected technological innovation has not been included specifically as concerns pollutants.

5.4 Robustness examination

Following the scenario painting of the development variables each infrastructure project can be evaluated with respect to its net benefit for each scenario. The SEAM methodology involves the painting of multiple variables throughout the modelling system. Assuming that a planning problem involves the evaluation of six projects that have been assessed by a traffic model for four calculation years. Assume also that the projects are assessed by 10 different impact models for four different scenarios and a base scenario. This will lead to $6 \cdot 4 \cdot 10 \cdot 5 = 1200$ impact assessments. As the planning process is well known not to be a linear process, but far more searching and learning (see Leleur, S., 1995) the impact assessment may have to be repeated several times. A structured and efficient approach to the management of such a system is required (see chapter 6).

Due to the efficiency of the speed of present computers and their visualisation tools it becomes possible to undertake a scenario-based appraisal and perform a graphical inspection of the project robustness. In this manner SEAM performs a scenario-based envelopment of the planning uncertainty. The SEAM methodology does not aim at making an analytical assessment of robustness as originally suggested by Gupta & Rosenhead (1968), nor does it aim at presenting the planning uncertainty by way of probabilities. Robustness is in this study an interpretation of project scores in the specific planning context. This is illustrated by a graphical presentation of robustness as seen below in Figure 23.

Figure 23 **An example of a graphical presentation of project robustness (Scenario robustness graph). It can be seen that none of the project performs well.**

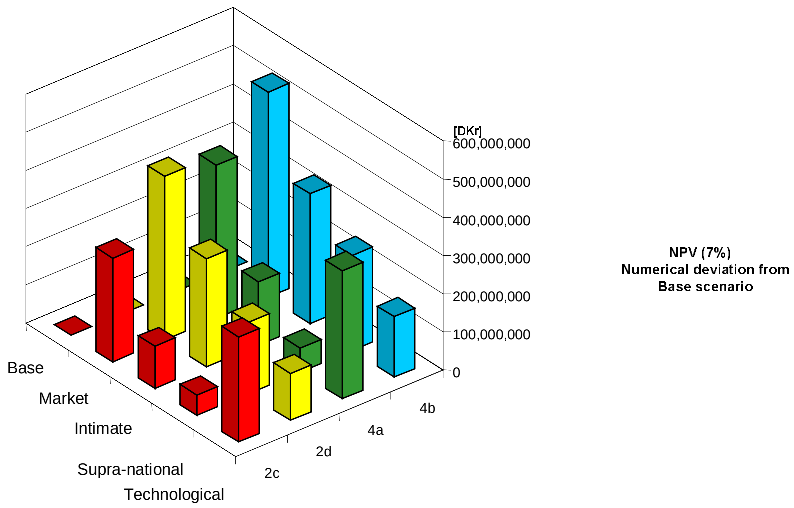


The graphical presentation of the project scores by scenario illustrates (a) the difference between robustness and project performance and (b) the result of the envelopment of project uncertainty. The analysis of robustness is based on a comparable analysis between projects in a specific pool and is not based on some definite measure. No single score for project performance is provided, only a range expressing its robustness. The determination of threshold values for minimum project performance (minimum score value) could be part of the decision making process.

The planning uncertainty has been enveloped on the basis of the painting of the planning environment. This envelopment of planning uncertainty underlines the importance of the applied scenarios and their interpretation into consistent sets of development variables. The effect the different uncertainty elements have on the final project outcome is embedded in the robustness measure as a range rather than an explicit expression.

Another type of graphical inspection that illustrates project sensitivity towards the different scenarios is seen in Figure 24 below.

Figure 24 An example of a graphical presentation of scenario sensitivity (Scenario sensitivity graph).



The type of presentation shown above in Figure 24 illustrates the scenario sensitivity of different projects. The graph is based on a comparison between the base scenario and each of the applied scenarios. The graph does not show whether a project performs better or worse than it does in the base scenario, since the graph is based on the numerical deviation from the Base scenario. What it does depict, is the sensitivity of each project with respect to each scenario. As seen the projects denoted 2c and 4a are obviously more sensitive towards the Technological scenario (TEC) than the projects 2d and 4b, whereas all projects appear sensitive towards the Market-oriented scenario. The scenario sensitivity graph illustrates qualities of the benefit distribution and reveals the influence this has on project uncertainty.

The basis for the graphical presentations of project robustness and scenario sensitivity seen in Figure 23 and Figure 24 is discussed in more detail in chapter 7.

5.5 CONCLUDING REMARKS

This chapter has presented a methodological formulation for a scenario-based appraisal methodology – SEAM. This new methodology incorporates the interdependencies between models and scenarios in a context of transport planning. Through a consistent painting of development variables the methodology involves an envelopment of planning uncertainty which leads to a graphical examination of project robustness and project scenario sensitivity. The envelopment of planning uncertainty underline the importance of the applied scenarios and their interpretation into a consistent set of development variables.

As outlined in chapter 3 the level of integration between the stages in the modelling processes is relatively limited. The scenario-based appraisal methodology (SEAM) accentuates the need for a closer integration between impact and transport models and a better understanding of the interdependencies of each model stage. This integrative modelling approach may be obtained through a painting of the entire planning system. Through further research and the application of SEAM to full-scale studies it is expected that this will provide a better understanding and insight into model and project uncertainty. In chapter 6 a computer model developed for scenario-based appraisal is presented, and in chapter 7 some case study results are presented as application examples of the SEAM methodology.

5.6 LITERATURE

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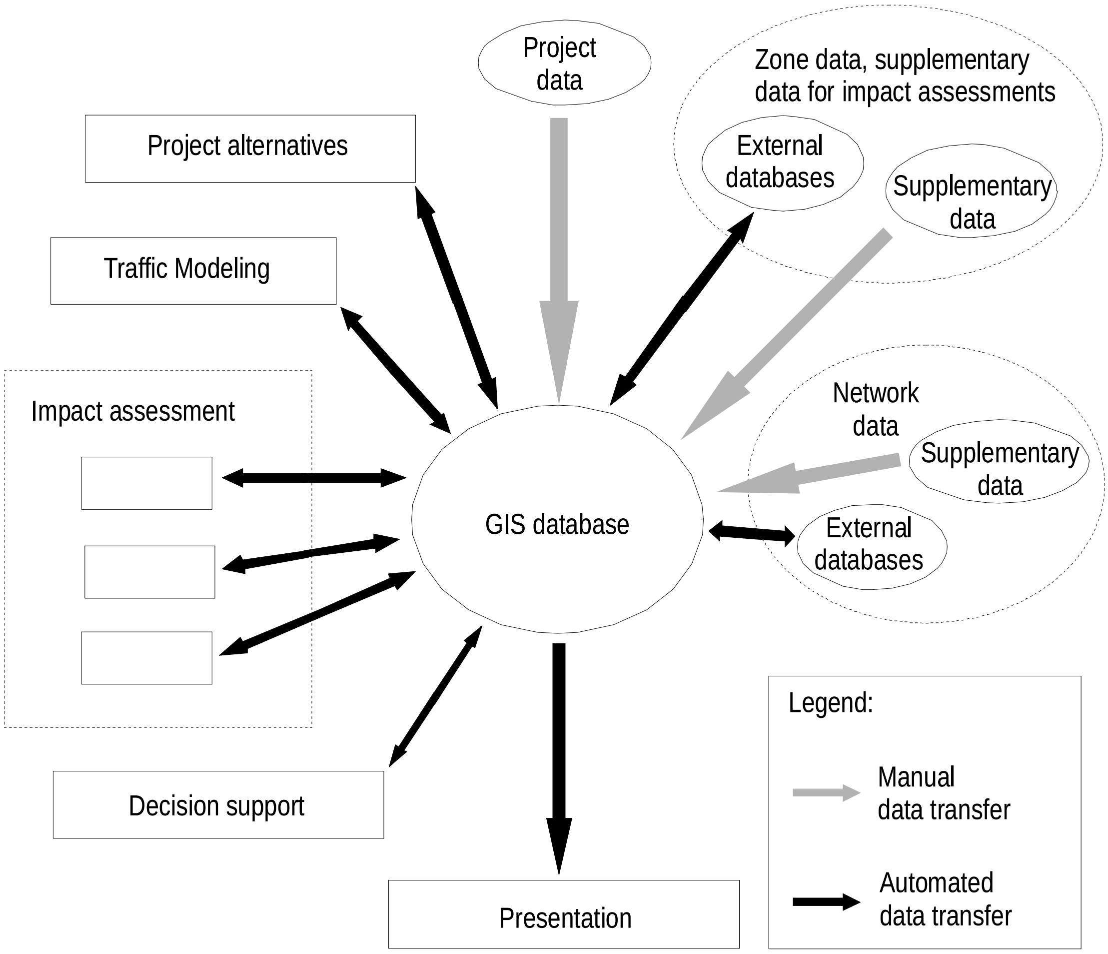
6 THE SYSTEM DESIGN FOR SEAM

In chapter five the structure of a scenario-based appraisal methodology (SEAM) was presented. The methodology was developed on the basis of the findings in chapters one to four. This chapter is concerned with the practical issues of developing a decision support system (DSS) for the application of SEAM to transport planning. A structural model for a SEAM DSS is presented along with a presentation of a comprehensive software developed for the illustration of the issues discussed.

One main concern for the development of a SEAM DSS has been to obtain a close integration with a geographical information system (GIS). This will enable the utilisation of the data storage and maintenance facilities and the graphical presentation tools available in GIS. The advantages of such integration for transport planning have been obvious for many years. Multiple papers have advocated this closer integration of GIS in traffic planning (GIS-T): Meyer & Sarasua, 1992; Batty, 1993; Vonderohe et al., 1994; Nielsen, O.A., 1995; Rehfeld, C., 1995 to name but a few. One integration concept is (Nielsen, O.A., 1995):

Figure 25 Outline of a suggested system for the integration of GIS in traffic planning (Nielsen, O.A., 1995).



Batty (1993) addressed the issue of embedding impact assessment models in GIS and Heikkila (1998) discusses the future closer integration of GIS and planning support systems. These papers deal with the conceptual issues of such an approach from a theoretic point of view. Little progress in terms of an actual integration of all levels of the planning process has actually been made. This illustrates that such integration is by no means a simple endeavour.

The remainder of this chapter is concerned with the determination of details and practicalities of developing such an integrated GIS-T tool-box applicable to scenario-based transport modelling. In the following the term 'project' will be used interchangeably with 'initiative'.

6.1 CONCEPTUAL REQUIREMENTS

The development of a SEAM decision support system, or any other computer software, involves the determination of clear principles for the objective, design and development strategy. The fundamental question is first and foremost the identification of the active user and what support the system should provide to the decision process. The decision process surrounding the planning of public transport infrastructure may be categorised as unstructured (see Carlson, E.D., 1983). A decision process is unstructured when "objectives are ambiguous and non-operational…numerous and conflicting" and when the effect of a decision is difficult to predict (Bennett, J.L., 1983, p.2). Consequently, the role of such a decision support system is to support the decision-making and not to make the decisions. The system should support the "decision maker in being efficient in the pursuit of a goal that is itself effective". In this case there has been four main objectives concerning the systems design of the decision support system for transport projects:

- The Disaggregate structure for data presentation and analysis
- The embedding of models in a GIS
- The systematic implementation of SEAM
  - The level of model flexibility

The last point concerning model flexibility has been an underlying theme throughout the development and will continue to be so through this chapter. As concerns the flexibility of the approach it should be possible to apply the SEAM DSS to as wide a variety of appraisal methodologies and impact models as possible. Additionally, it should be possible to perform comparisons between any combination of models and appraisal methodologies. The main objective has been to accommodate a freedom of choice for the user. The degree of freedom will naturally be based on choices made by the developer. But the aim has been to develop a foundation for such a freedom of choice. The freedom of choice in software development does however entail a cost. There will be an increase in complexity and it may involve some degree of data redundancy. The other three objectives listed will be discussed specifically in the following paragraphs.

It has not been possible within the resources available to a Ph.D.-study to develop all areas of such a complex modelling system. Consequently, the development process involved early decisions on the level of implementation required for a satisfactory illustration of the advantages of SEAM. The implementation and application of the SEAM model relates only to the impact assessment and evaluation, whereas the painting and structuring of transport models are excluded.

6.1.1 DISAGGREGATE STRUCTURE FOR DATA PRESENTATION AND ANALYSIS

Geographical maps are an efficient way of communicating complex information (see e.g. Hearnshaw, H., 1994 & MacEachren et al., 1994). The close integration with GIS offer options for making visual analysis of detailed results. Most impact models are based on information on links, nodes, zonal information or a combination of these data sources. Consequently the data may be visualised most efficiently if they are stored at the same aggregation level as the source data. Also, aggregation always entails a loss of information (Kronbak, J. & Rehfeld, C., 1998).

Results are accordingly stored at the lowest level of aggregation by e.g. link, node or zone. Through simple relation the data may subsequently be visualised in e.g. ArcView (ESRI, 1995). Examples of these presentations are found in chapter 7 and appendix C.

6.1.2 EMBEDDING MODELS IN GIS

Not all impact models gain from a GIS implementation, but as virtually all transport impacts can be related to a geographic object, it should still be possible to visualise these impacts even though the model is non-spatial. At least the visualisation can aid in the model quality control. The models available in the SEAM DSS have been implemented in a number of ways:

- Internal model
- External model
- GIS model
    - Combinations

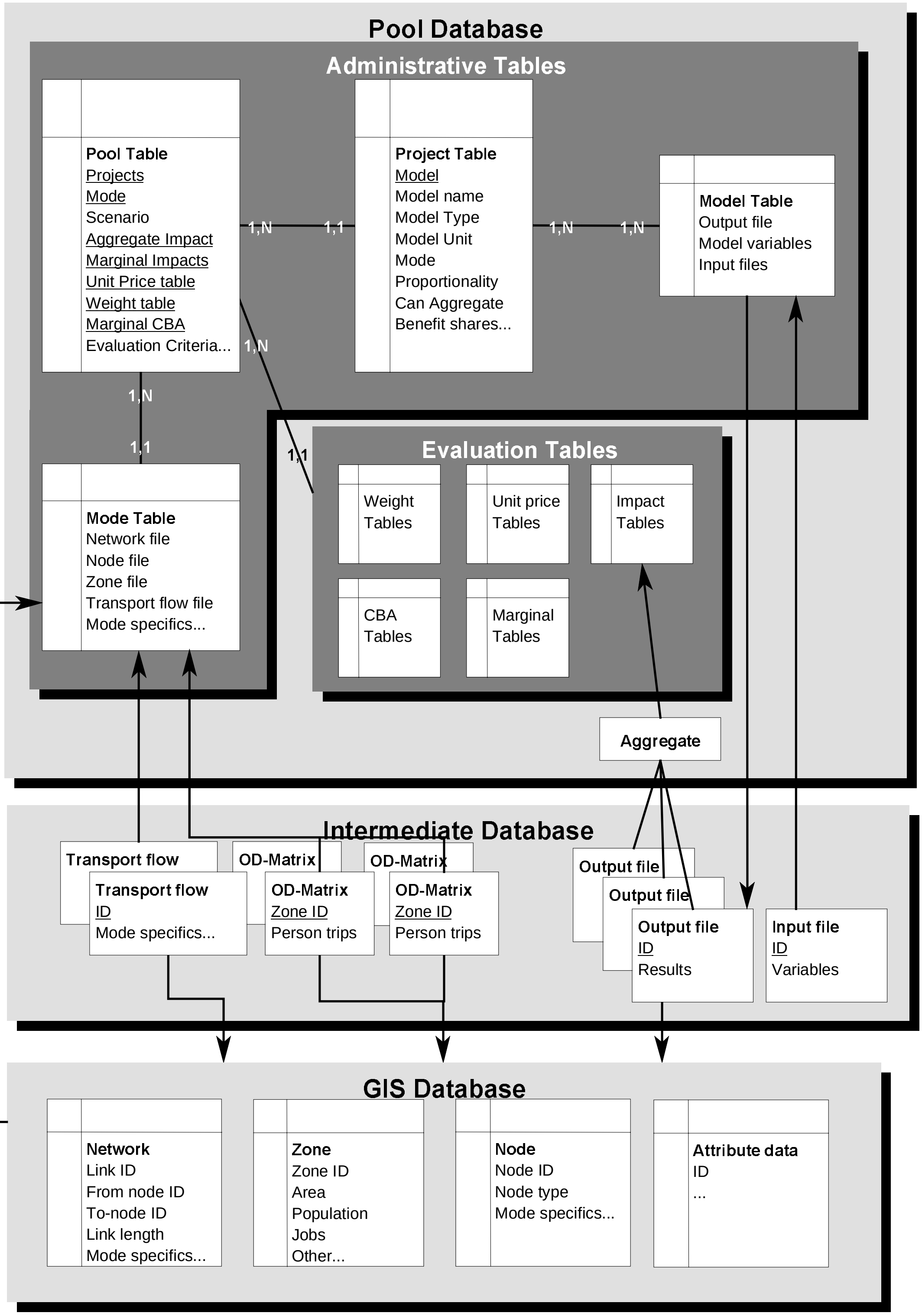
This implies that the impact assessment structure should be able to handle multiple modelling approaches and schemes and combinations hereof. Such approaches need often be customised for the specific task but common procedures can be implemented to secure the applicability of the DSS.

6.1.3 THE SYSTEMATIC IMPLEMENTATION OF SEAM

In chapter 5 it was illustrated that the extensive modelling requirements involved in SEAM calls for a structured and efficient approach to the management of such a system. This has led to the database structure seen in Figure 26.

The system is built around two main databases: A geographical database storing the network, node, zone and some attribute data and a so-called pool database maintaining the structure of the SEAM DSS. The intermediate database stores the transport flows and the result files that as such are external to the GIS database, but can be visualised graphically by way of simple relations using identifiers (ID) common to the geographically related data and the results files.

Figure 26 **Database structure of the SEAM DSS. The numbers describe the relations between the tables. 1,N should be read: At least one table, but possibly several.**



The database structure is as follows. The projects are defined in the Pool database. The Pool database is made up of two main table types: (I) the administrative tables and (II) the evaluation tables. The administrative tables define the pool set-up. A project inside the pool is composed of a project table and one or several mode tables. The mode specific table maintains the relation to the spatial data in the GIS. As each project is assessed by a range of models there are one or several model tables associated with each project which indicates the development variables and where to create the output files for the GIS to access. Some models may equally use external set-up files. The dis-aggregate impact model results are aggregated onto a number of impact tables used for the project evaluation. The underlined items in each table are identifiers either to a table or if the identifier is ID it refers to an item in another table.

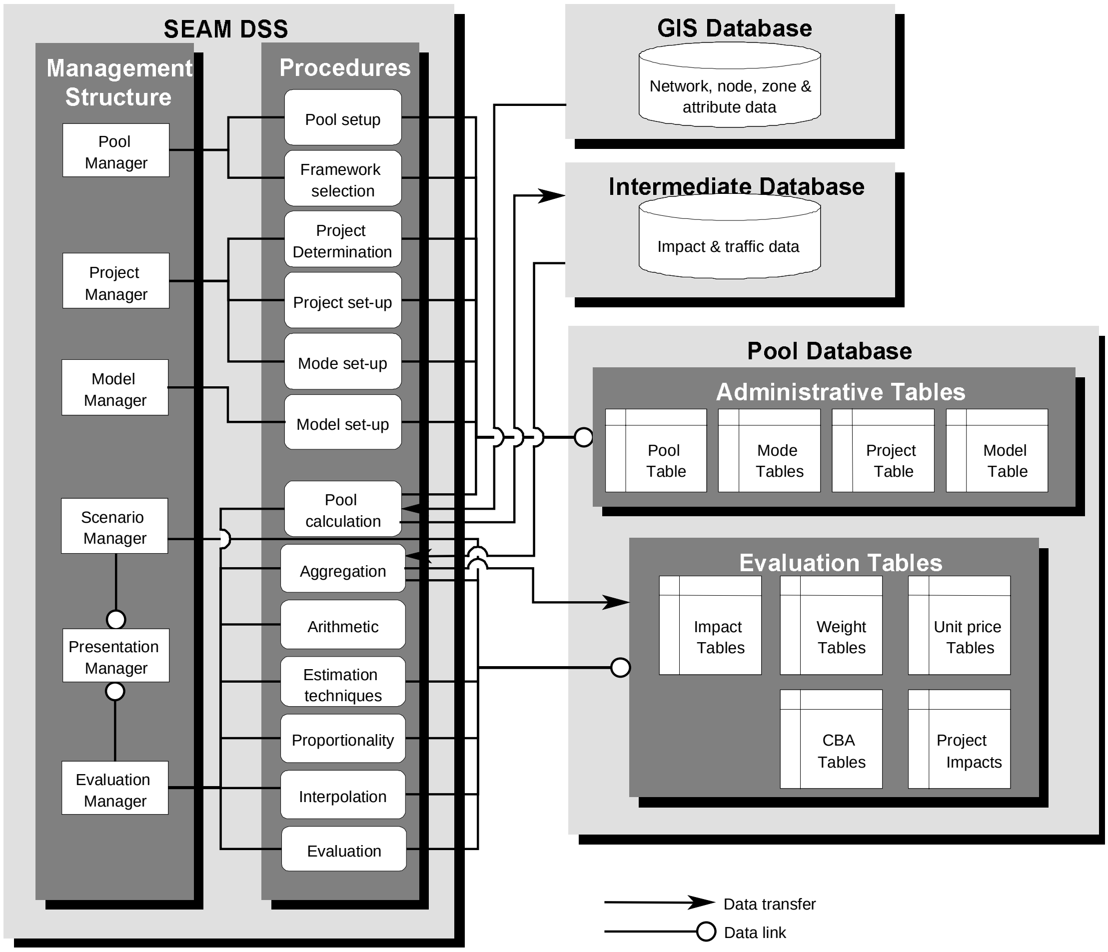
This very brief description covers the general structure of the SEAM DSS database structure. In the subsequent sections this database structure will be discussed in more detail.

The data requirements of the SEAM DSS is based on a number of assumptions concerning the format of the data used for storing the traffic flows, networks, zones etc. The functional and structural information of the networks should be stored in one table with an item for the column in which data is stored. The traffic flows should equally be stored in a table following the same principle. If this is the case SEAM DSS will read most comma separated files and dBase files. The polygon data must be in a format handled by ESRI software (INFO files or shape files) (ESRI, 1995).

6.2 THE SYSTEMS STRUCTURE

The DSS functions lie on top of the database structure as an umbrella with respect to the administrative database structure as well as providing model links, tools and procedures to the user. The structure of the SEAM DSS with relation to the databases presented above is seen in Figure 27.

Figure 27 **The system structure of the SEAM DSS. For simplicity the internal structure of the database system has been left out. The details on the databases are seen in Figure 26 above.**



The SEAM DSS is divided vertically into an overall management structure and a set of procedures that the user will pass through during a full SEAM modelling process. Horizontally the system may be divided into two collective groups of managers and procedures, where one is mainly concerned with structural database maintenance whereas the other is mainly concerned with the evaluation process. There is generally very little overlapping between the two collective groups. The links between them are the procedures termed 'Pool calculation' and 'Aggregation', which is apparent in both Figure 26 and Figure 27. These two procedures are mainly concerned with data transfer, which implies modelling or aggregation (creation of new data on the basis of existing). These operations are indicated with arrows. The other procedures mainly operate on or manipulate data within the boundaries of the DSS (the data links).

6.2.1 THE MANAGEMENT STRUCTURE

The management structure has six layers, each of which is made up of several procedures. This structure is helpful for the conceptualisation of the SEAM methodology, but requires more specific descriptions for practical implementation. Since the evaluation process including the impact assessment is a multi-layered process the steps in the procedure has been structured and associated with five of the managers. For the sake of simplicity the management structure and the project appraisal process is presented as linear. In practice the process is by no means linear.

Pool Manager
1. Pool set-up
2. Selection of evaluation framework

Project Manager
3. Determination of project alternatives & scenarios
4. Project set-up
5. Determination of variables by mode

Model Manager
6. Model Specification
7. Model set-up

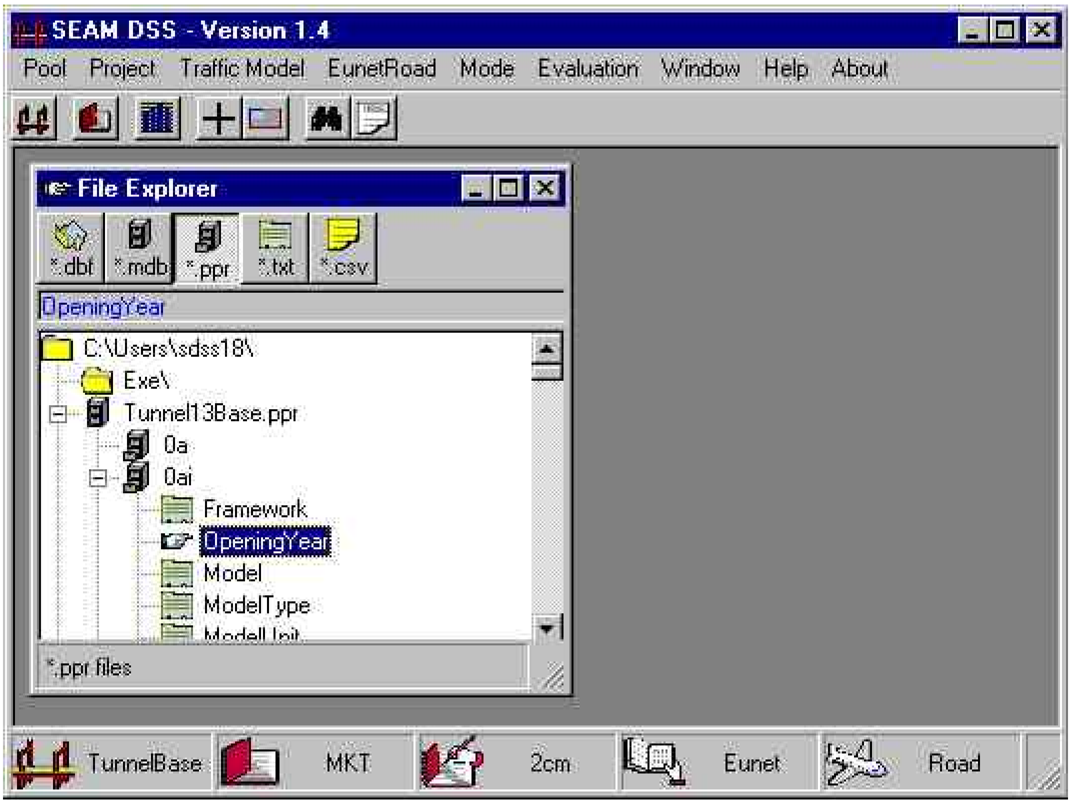
Scenario Manager
8. Scenario painting of development variables

Evaluation Manager
9. Impact assessment
10. Aggregation of impacts
11. Calculation of project impacts (Arithmetic)
12. Determination of unit prices and estimation of shadow prices
13. Calculation of cross-sectional benefits (Arithmetic)
14. Correction of signs
15. Interpolation
16. Evaluation

Besides these process-oriented managers, a utility has been developed for the graphical presentation and analysis of results and tables denoted the Presentation Manager. As seen in Figure 27 the Presentation Manager is closely integrated with both the Scenario and the Evaluation Manager. The Presentation Manager is a utility in the sense that it is available as a resource to any of the other managers. Other utilities not directly accessible to the user (such as data transfer objects etc.) are not shown for the sake of simplicity.

Each accessible Manager is represented by one or several user interfaces aiming at being as self explaining and flexible as possible. The graphical interface of the SEAM DSS is seen below:

Figure 28 The graphical interface of the SEAM DSS.



At the bottom of the DSS interface a range of information is provided for the user. The DSS always operates on the current pool (TunnelBase), current scenario (MKT), current project (2cm), current evaluation framework (EUNET), current mode (Road) and a default database (not shown). All operations concerned with structural database maintenance will be performed on the current mode, current project or current scenario. The File Explorer is a utility customised for exploring the Pool and Intermediate databases used by the SEAM DSS. It is applied in combination with many other user interfaces for drag-drop procedures. For the databases listed it will open the database and list the tables within the database. In the next level it lists the items in each table. In this way different files, databases, tables and items are easily accessible and may then quickly be entered into the Pool database.

6.3 The Pool Manager

The Pool Manager provides the backbone of the SEAM DSS. It is at first glance the most disparate of the managers as it manages the fundamentals of the system. It is made up of two main groups:

1. Pool set-up
2. Selection of evaluation framework

Each will be discussed in detail below:

6.3.1 Pool set-up

The pool set-up consists of a mainly technical part about the establishment of the link to external geographical information systems (GIS) and external databases. In this case it operates with links to both ARC/INFO and ArcView and ensures that these external software packages are accessible to the models that involve spatial modelling and analysis. This also involves the reference to the model default database. This database contains default variables for all models in the software. The inclusion of the default database is optional, as is the use of GIS.

The second part is concerned with Pool variables. These variables are common to all projects in the pool. They may be changed at any stage of the process. Most of these variables are not essential to neither the Project, Model or Scenario Manager but are essential to the Evaluation Manager. The variables are:

- The discount year
- The current evaluation framework
- The price level

Other general information is included such as a pool description and the monetary unit.

6.3.2 SELECTION OF EVALUATION FRAMEWORK

The evaluation framework required will depend on the planning context. A minor rural by-pass road involves only one mode and a limited set of impacts (see e.g. VD, 1992). In other cases the project may be very large and involve long-term impacts, which calls for an advanced multi-modal evaluation framework. A framework essentially outlines the relevant set of impacts for the available modes that should be accessible to the user as a means of securing consistency across projects. The frameworks available are (see also appendix A):

- The Danish National Trunk Road Evaluation Framework (VD, 1992)
- The EURET multi-modal frameworks (CEC, 1996a-e)
- The APAS/Road3 framework (CEC, 1996f)
- The EUNET multi-modal frameworks (Leleur et al., 1998)

Many of the modelling approaches are common to each framework, but the range and classification is not. The SEAM DSS can handle any number of modes but at the moment six alternative modes or types of infrastructure are available:

- Road
- Rail
- Inter-modal
- Air
- Short Sea Shipping
- Waterway

These can be combined as one sees fit.

6.4 THE PROJECT MANAGER

The Project Manager forms the core of the software. This part of the software concerns the determination of the projects. The process has been subdivided into three elements:

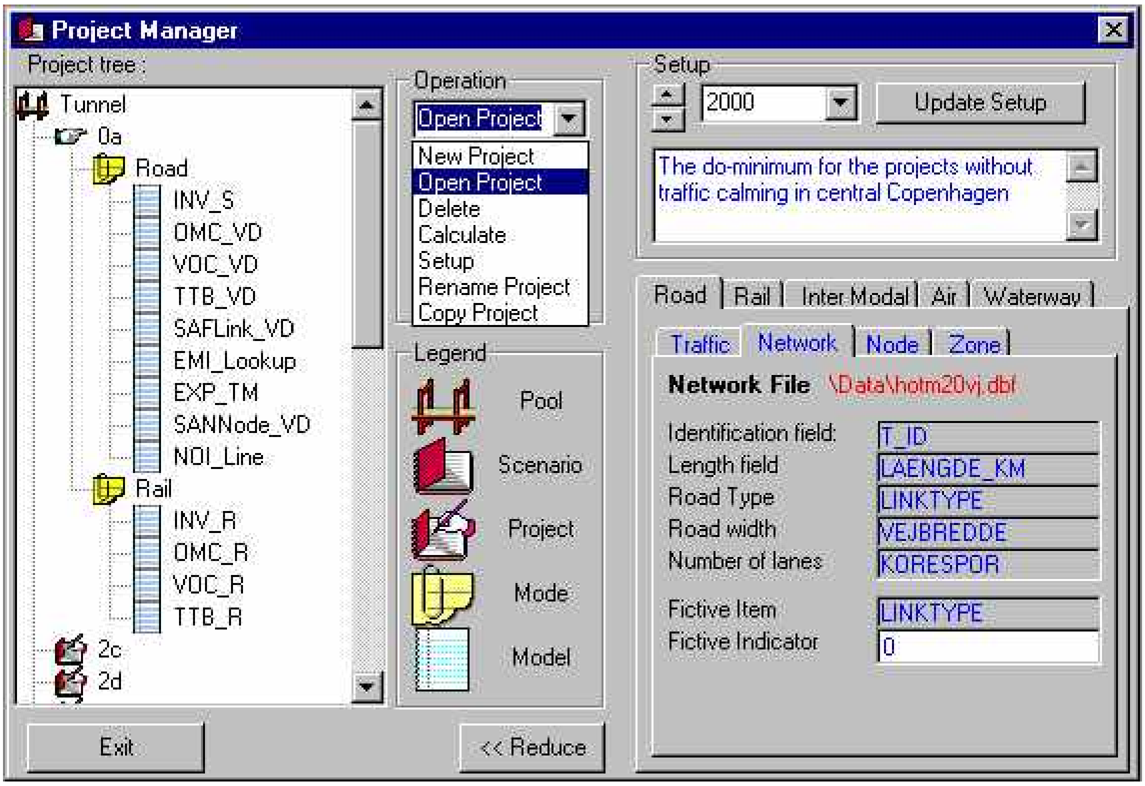
3. Determination of project alternatives & scenarios
4. Project set-up
5. Determination of variables by mode

Each will be discussed in detail below:

6.4.1 Determination of project alternatives & scenarios

Projects are defined in connection with the scenarios in such a way that a project can be evaluated both across scenarios as well as within one scenario. Following the determination of each scenario the appropriate modes relevant to the planning problem are determined. The interface for the Project Manager is seen below:

Figure 29 The Project Manager interface. To the left the projects are listed by project pool. The models are divided by mode.



The data is entered for each calculation year. In the right side of the interface data may be entered using the drag-drop option from the File Explorer. The information entered is either files (from the Intermediate database – see Figure 26), items, or specific variables in a table column. Only the leaves relevant to the current evaluation framework are accessible to the user.

6.4.2 Determination of project variables

In order to perform sensitivity analyses a number of variables otherwise common to all projects in the pool have been made project specific. This entails some redundancy but on the other hand it secures the flexibility of the DSS. The project specific variables are:

- Opening year
- Discount rate
  - Project period

This makes it possible to perform analysis for a projects optimal time phasing for different scenarios, to perform sensitivity tests on the discount rate, tests regarding the project period etc.

6.4.3 DETERMINATION OF VARIABLES BY MODE

To secure consistency in the software, model variables have been divided into two groups:

- Common variables and data
- Model specific variables and data

The common variables and the common data concern information used by virtually all models for each mode in the project assessment. To ease the model set-up and to secure model consistency across each project, this information is stored centrally. The common data are furthermore divided into four main groups according to their territorial affiliation (see the right side of Figure 29):

- Link flow data
- Network data
- Node data
- Zone data

All model data are stored according to a calculation year. The structure of the common data can be generalised to apply to all modes, however only the structure of the common data relevant to road transport is discussed here.

6.4.3.1 Link flow data

The link flows describe the flow pattern in the transport network. The common road link flow data and relevant variables are stored in the Mode table as seen in Figure 26:

Table 34 Common traffic related variables and data.

COMMON ROAD LINK FLOW INFORMATION	
DATA & VARIABLES	DESCRIPTION
Traffic file	Path to the traffic file containing the link flows and speeds
Link Id	Link ID item in the traffic file
Forward flow	Forward flow item in the traffic file
Backward flow	Backward flow item in the traffic file
Total flow	Total flow item in the traffic file (optional)
Forward speed	Forward speed item in the traffic file
Backward speed	Backward speed item in the traffic file
Average speed	Average speed item in the traffic file (optional)
Lorry percentage	Item indicating the percentage of lorries in the traffic file (optional)

The total flow and average speed items are optional and are relevant only if the traffic model results are aggregated. Models have however been included for this type of link data. The lorry item is equally optional. The effect of lorries is included in the calculations if the percentage of lorries in the traffic flow is available. Alternatively the flow of lorries can be assessed separately.

6.4.3.2 Network data

As concerns the network data the information is mainly structural. However, the functional link classification is often more important. The common road network data and variables comprise:

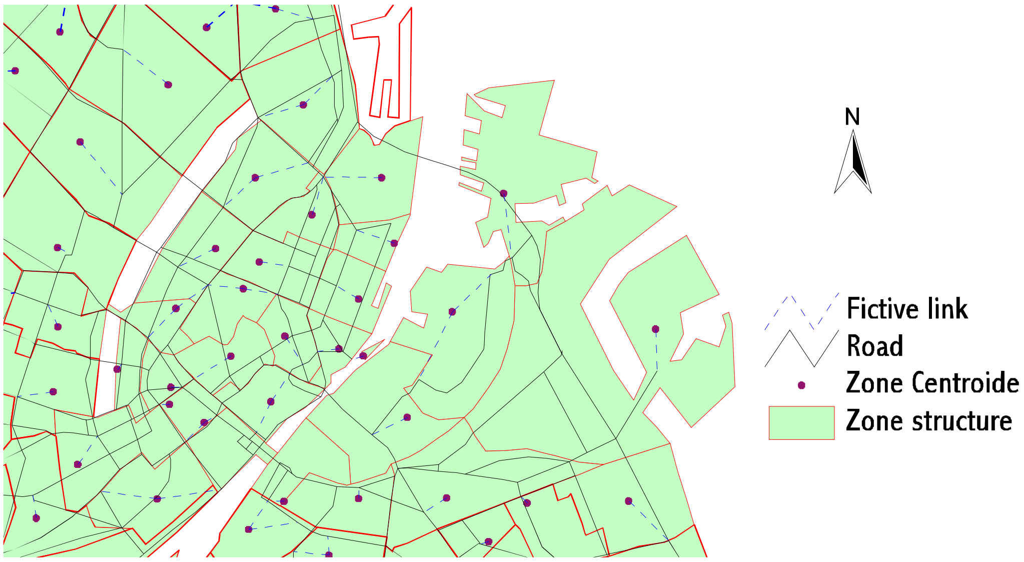
Table 35 Common network related variables and data.

	Common road network information
Data & variables	**Description**
Network file	Path to the network file containing the link data
Link ID	Link ID item in the network file
Link length	Length item in the network file
Functional road type	Road classification item in the network file
Road width	Road width item in the network file (in meters)
Number of lanes	Total number of lanes item in the network file
Fictive item	Fictive (zone internal link) item in the network file
Fictive indicator	The indicator of the fictive item on the zone internal links

The traffic model data traditionally comprises a zonal structure based on homogenous socio-economic data and a functional transport network. The traffic flow on the network is assumed to originate from a zone centroide located at the centre of activity of the zone. As the zone centroide represents a simplification of where traffic actually originates from a fictional internal distance from the centroide to the functional transport network is included in order to model the travel resistance correctly. This is seen in Figure 30.

The impact of the flows on the fictional links (representing real flows) is difficult to model. Consequently, they are disregarded in the impact assessment. A specific indicator should indicate fictional links. For a discussion on the assessment of zone internal links and zone internal traffic see e.g. Nielsen, O.A., 1995 or Israelsen, T. & Nielsen, E.R., 1996.

Figure 30 **The zone structure of the Ørestad Traffic Model (OTM). The dotted lines indicate the zone internal links.**



6.4.3.3 Node data

Node data is required not only in relation to the traffic model but also in relation to the accident assessment. The node data comprises:

Table 36 **Common node related variables and data.**

COMMON NODE INFORMATION	
DATA & VARIABLES	DESCRIPTION
Node file	Path to the node file containing the node data
Node ID	Node ID item in the node file
Functional node type	Intersection classification item in the node file
Signalised	Signalised item in the node file (0 – no, 1 – yes)
Flared	Flared item in the node file (0 – no, 1 – yes)
Delay	Delay item in the node file

The inclusion of delays and turn limitations requires a more detailed description of the node. How this is obtained depends on the network description and several solutions may apply. No definite choice as to the representation of turn limitations in the SEAM DSS has been selected.

6.4.3.4 Zone data

Zone data covers a very inhomogeneous collection of information. Such information may relate to a wide range of socio-economic data as well as matrices describing the flow between zones. The common zone data included here are:

Table 37 Common node related variables and data.

COMMON ZONE INFORMATION	
DATA & VARIABLES	**DESCRIPTION**
Zone file	Path to the zone file containing the zonal data
Zone ID	Zone ID item in the zone file
Population	Population item in the zone file
Jobs	Number of jobs item in the zone file
OD-matrix	Path to the OD-matrix containing the number of trips between zone pairs
OD From-zone	From zone item in the OD-matrix
OD To-zone	To zone item in the OD-matrix
Person trips	Person trips item in the OD-matrix
Cost matrix	Path to the Cost matrix containing the average cost of travel between zone pairs
Cost From-zone	From zone item in the Cost matrix
Cost To-zone	To zone item in the Cost matrix
Distance	Distance item in the Cost matrix
Travel time	Travel time item in the Cost matrix

The OD and Cost matrices are used for assessing the changes in generalised traveller benefits consisting of vehicle operating cost and travel time benefit under variable demand (see chapter 3). The socio-economic data have been limited to the population and the number of jobs. Socio-economic data may be far more detailed and are often tailored to each specific transport model.

6.4.3.5 Some final remarks on the common data

At the most reduced level of information most impact models run on the base of only two data sets:

- The annual average daily traffic (AADT) by link
  - The average speed by link

The amount of data to be transferred and stored increases proportionally to the complexity of the planning problem as does the traffic model and impact model interconnectivity as discussed in section 3.2.

6.5 THE MODEL MANAGER

The Model Manager provides the interface determining which models to include by mode in each project. For each impact type a mode specific model interface is available. The interface is based on a common template. The Model Manager provides the opportunity for the:

6. Model specification
7. Model set-up

These will be discussed in the following.

6.5.1 MODEL SPECIFICATION

In chapter 3, model adaptability with respect to the planning context was discussed. Model adaptability was defined as consisting of (Rehfeld, C., 1996):

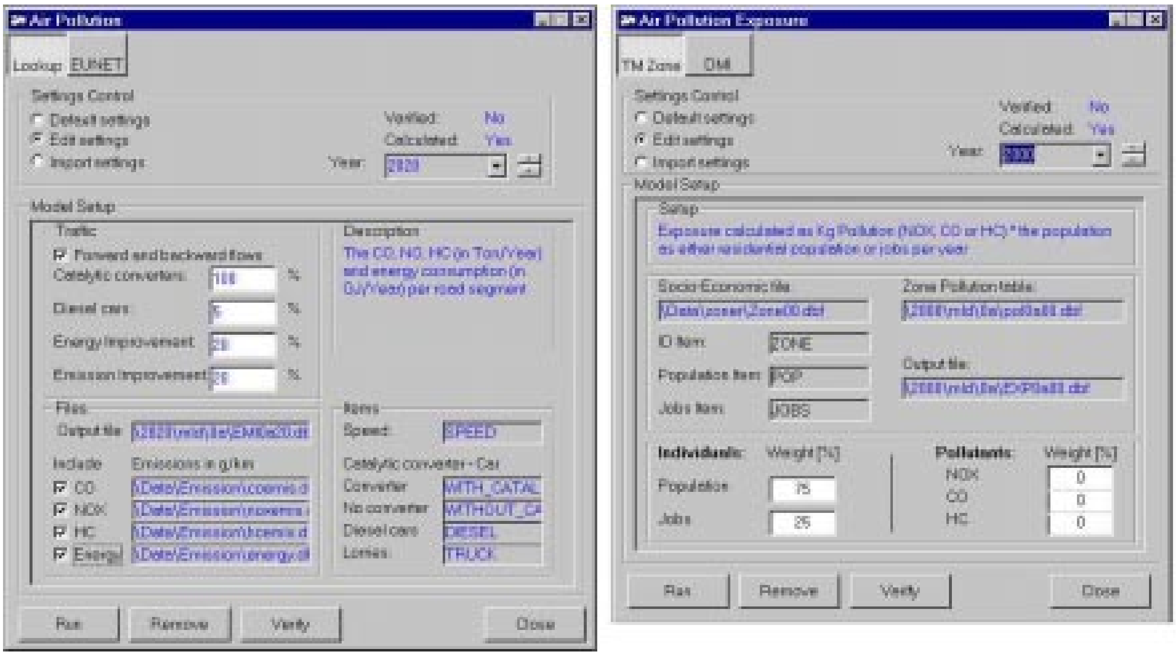
- Applicability
  The degree to which the model gives answers to the questions posed.

- Suitability
  The model suitability for the planning problem concerning the level of aggregation, the data available and the objective of the model.

- Feasibility
  The feasibility of the approach with respect to the balance between the available funds and the proper model application.

What the adaptability involves is that for a given planning context a multiplicity of models may be available for the estimation of the same impact with varying degree of applicability, suitability and feasibility. In practical planning the model choice will often be governed by the resources available as the data requirements for some models exceed what is reasonable in the given context. Optimally, the modelling approach can be selected from a collection of parallel impact models. An example of an impact model interface is seen below.

Figure 31 The Model Manager interfaces of the emission and the exposure model. At the top of the interface a choice can be made between parallel models. Just beneath the model selector two controls are available: the Settings Control and the Model Set-up Control.



At the top of the interface a number of choices concerning parallel models are available.

6.5.2 DETERMINATION OF MODEL SPECIFIC VARIABLES

Two examples of a Model Manager interface are seen in Figure 1.1 which, is made up of the model choice and two model specific controls:

- The Settings Control
  - The Model Set-up Control

The Settings Control is common to all models and indicates the data source used for the model set-up. There are three possible sources for the set-up of each model: (I) the set-up is available only from a default database (which cannot be edited), (II) the model has project specific settings (which are editable) or (III) the settings used are available from another project. The Settings Control furthermore establishes the current and the available calculation year(s). The options available and the current model set-up are maintained automatically.

The Model Set-up Control is specific to each parallel model. The data listed in this control are the model specific data. Each model equally refers to the common data when and if required. This will most often be the network flow description, the network descriptions etc. as stored by the Project Manager.

The Model Set-up Control is made up of three panels: (I) A very brief model overview is provided by the Description Panel, (II) the output table is seen in the Files Panel and (III) the model specific variables and files are set in one or more Variable Panels. All files and variables relate to the modelling year as defined in the Settings Control. By way of this interface all elements of a model may be customised for each calculation year. A specific calculation year set-up is chosen for each project by way of the Verify button. An overview of some modelling approaches and their variables are found in appendix B.

6.6 THE SCENARIO MANAGER

The Scenario Manager is highly intertwined with the Presentation Manager as seen in Figure 1.1, so they will be discussed as a unit. The Scenario Manager is used for the calculation of development profiles as discussed in section 5.2:

8. Scenario painting of development variables

Besides the painting of development variables the SEAM methodology involves, as mentioned above, the generation of multiple output files. Consequently a scenario painting must include some sort of structure of the data outputs. Also painting of groups of variables may be restricted by dependencies. The Scenario Manager makes this possible:

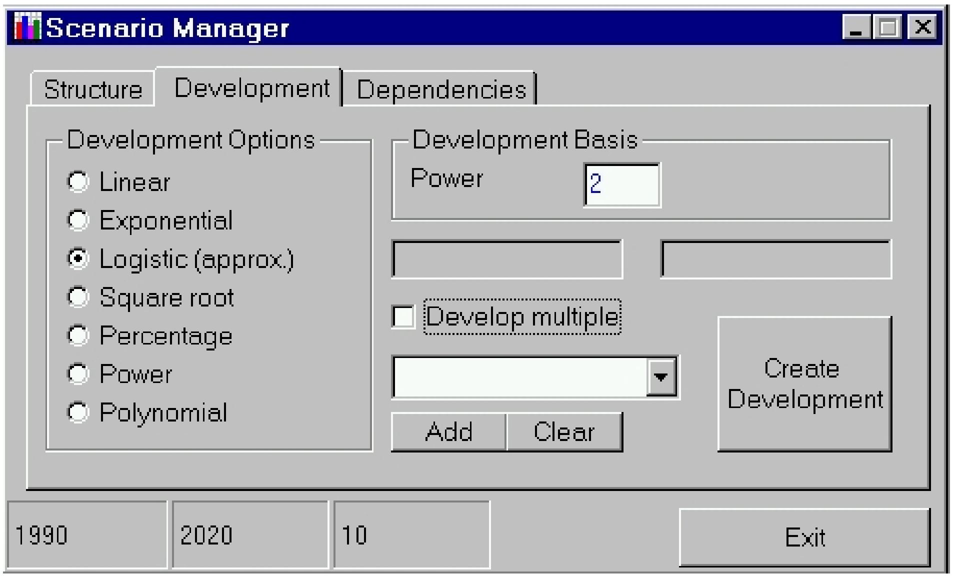
- Painting development profiles
- Maintenance of dependencies
  - Structuring of output files

Each of these will be discussed in the following.

6.6.1 PAINTING DEVELOPMENT PROFILES

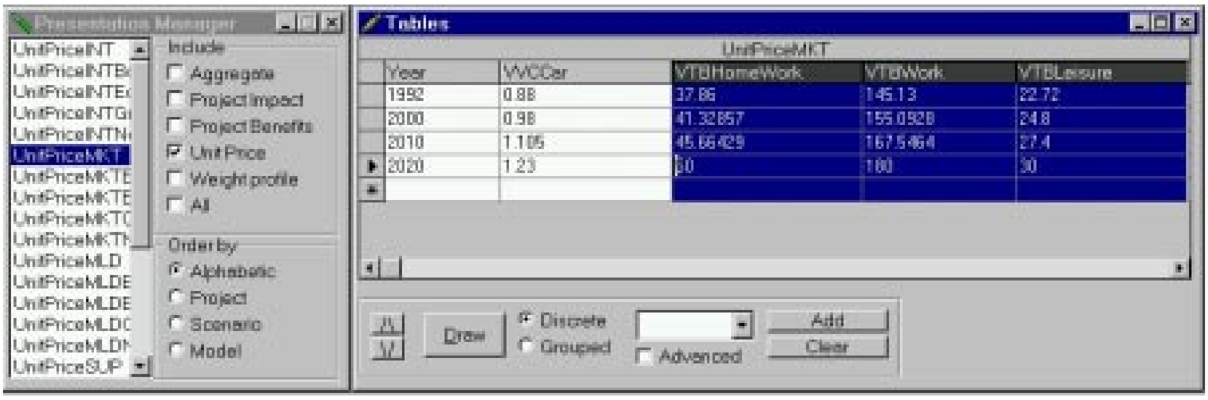
Development variables can be painted according to the development profiles listed in section 5.2. If more than one development variable follows the same development profile these can be calculated simultaneously. The Scenario Manager is seen in Figure 1.1.

Figure 32 The Scenario Manager.



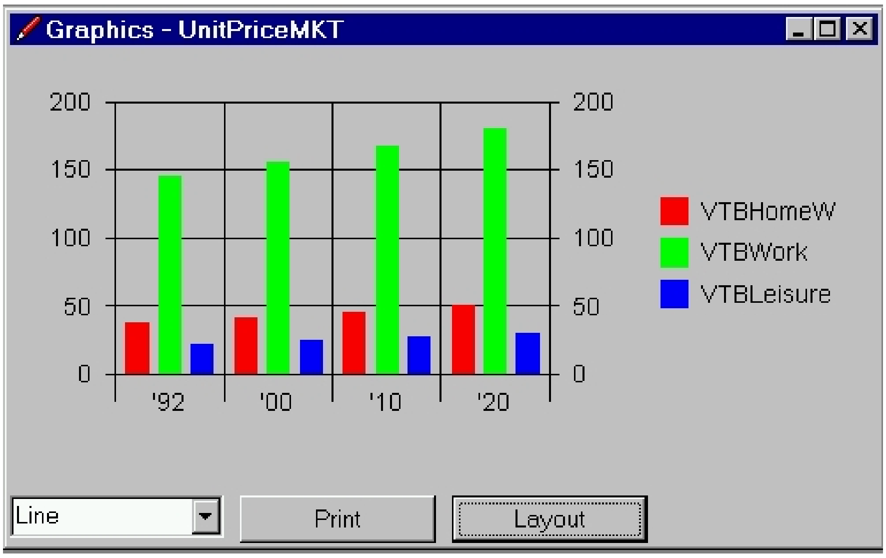
The development profile is calculated on the basis of the selected item(s) in the Tables interface of the Presentation Manager. The Tables interface is seen below:

Figure 33 The Tables interface. The table shown is the unit prices for the Market-oriented scenario (MKT). The Tables interface can be used to illustrate the entire or selected parts of the data set in the Graphics interface.



To aid the development and review of the development profiles, a graphical presentation of the development profile is generated immediately in the Graphics interface. The Graphics interface is equally part of the Presentation Manager. An example of a development profile for the value of time in the Market-oriented scenario (MKT) generated on the basis of the Table interface in Figure 33 above is seen in Figure 34.

Figure 34 **The Graphics interface. The Graphics interface can illustrate data in multiple different ways by selection of the appropriate alternative in the list. The data shown are the unit prices for the Market-oriented scenario (MKT).**

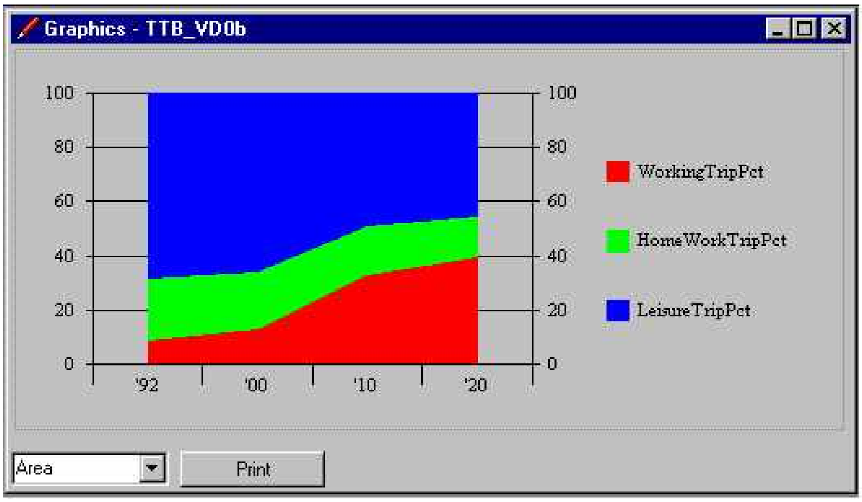


As seen the Tables and Graphics interfaces are closely related.

6.6.2 MAINTENANCE OF DEPENDENCIES

Some development variables are restricted. One such restriction concerns percentage distributions between variables. An example is the trip distribution between different trip purposes, which must amount to 100%. To accommodate this a tool for the specific treatment of these changes has been developed. Most often the scenario development will concern only one or two of these variables. The remaining variable(s) will have to be adjusted accordingly. An example of such an adjustment is seen in Figure 35 on the distribution between commuting, working and leisure trips.

Figure 35 **An illustration of the effect of the dependencies tool on a imagined trip purpose pattern.**



The share of leisure trips (LeisureTripPct) decreases by one third following a logistical trend, whereas the share of commuting trips (HomeWorkPct) decrease by 25% following a linear trend. Such a profile could be imaginable in a highly technological society with a high degree of tele commuting and automated goods delivery.

6.6.3 STRUCTURING OF OUTPUT FILES

Due to the vast amount of data files produced using the SEAM methodology, a system for automated denomination of output files is required. The convention used for the denomination of output files is:

Impact type & Project name & Year

Such a denomination practice is very useful provided that the name does not become too long. Throughout this report impacts have been classified according to a three-letter combination. Some examples are EXP for exposure, VOC for vehicle operating cost, MOB for mobility etc. The project name must equally be limited to three letters. Two letters to indicate the project name and one to indicate the scenario. In this way the full name of all output files is limited to 8 letters (a limitation relating to the 8.3 limit for naming dBase IV files). The name of the output file for a run of a noise model for project 4a in the Intimate scenario (INT) for the year 2010 would be noi4ai10.dbf. To further secure the structure and accessibility of the output data, the data is stored in a hierarchical directory structure. The structure is listed below:

%HomeDir%\Year\Scenario\Project\Mode\

%HomeDir% is a variable with the path to the directory of the software program.

6.7 THE EVALUATION MANAGER

The Evaluation Manager is the most comprehensive of the managers.

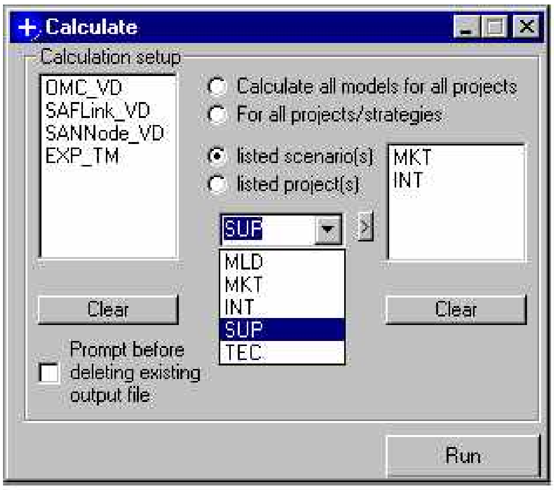
9. Impact assessment
10. Aggregation of impacts
11. Calculation of project impacts (Arithmetic)
12. Determination of unit prices and estimation of shadow prices
13. Calculation of cross-sectional benefits (Arithmetic)
14. Correction of signs
15. Interpolation
16. Evaluation

The Evaluation Manager is made up of a variety of minor interfaces that perform special tasks as part of the analysis. These interfaces are used consecutively as the basis for making the project evaluation.

6.7.1 IMPACT ASSESSMENT

It is possible, but not very efficient, to perform the impact assessment at different levels of the process. The calculations are, as described above, based on a combination of common and model specific data managed by the Project and Model Managers respectively. Calculations of any combination of projects, scenarios, years, models are performed most efficiently using the Calculation interface.

Figure 36 The Calculation interface. Using drag-drop procedures from the Project Manager and the File Explorer sets up the Calculation interface.



By way of the data concerning each model, the necessary calls are made to external programs, internal routines or whichever set-up the model requires to run. Possible problems are registered in a log-file.

6.7.2 AGGREGATION OF IMPACTS

As mentioned the results calculated are stored as disaggregated as possible to ensure their visualisation in a GIS. For the sake of the evaluation these results must be aggregated. The aggregation interface offers different options for special types of aggregation. However the main use of the aggregation interface concerns the development of the impact tables.

Figure 37 The Aggregation interface. Using drag-drop procedures from the File Explorer sets up the Aggregation interface.

An impact aggregation table is a matrix with all the impacts aggregated by year in the calculation unit. An example of an aggregated table is found below:

Table 38 **The aggregate results of the project 2d (Amager Strandvej – Traffic calming in central Copenhagen). OMC – Operation and maintenance cost, VOC – Vehicle operating cost (in vehicle km.), TTB – Travel time benefit, SAF – Safety (Number of casualties), GLO – Strategic environment, EXP – Exposure, NOI – Noise (Noise load number-SBT). For modelling details please refer to appendix B.**

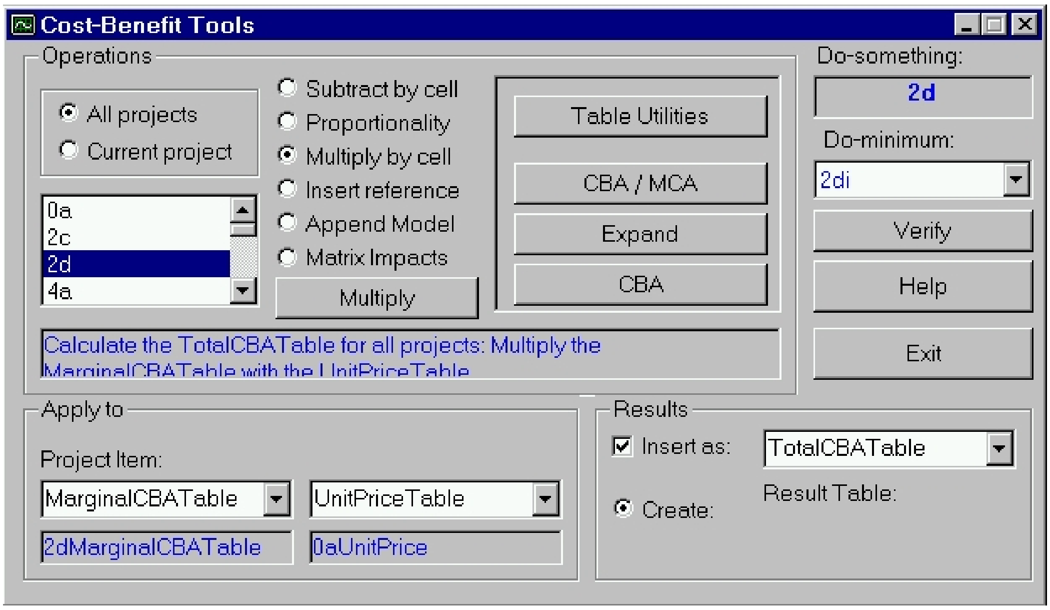
	OMC	VOC	TTB			SAF		GLO	EXP			NOI
	-	Car	Work	Com.	Leisure	Link	Node	Energy	NO_X	CO	HC	-
Year	DKr	Km	Hours			Number		GJ	Person·Ton/km²			SBT
1992	$415 \cdot 10^6$	$10.2 \cdot 10^9$	$26.8 \cdot 10^6$	$69.2 \cdot 10^6$	$280.9 \cdot 10^6$	1560	1885	$25.7 \cdot 10^6$	$8991 \cdot 10^6$	$106 \cdot 10^9$	$7322 \cdot 10^6$	10384
2000	$429 \cdot 10^6$	$10.8 \cdot 10^9$	$28.1 \cdot 10^6$	$72.8 \cdot 10^6$	$295.2 \cdot 10^6$	1510	1783	$26.7 \cdot 10^6$	$7501 \cdot 10^6$	$95 \cdot 10^9$	$6168 \cdot 10^6$	10512
2010	$443 \cdot 10^6$	$11.7 \cdot 10^9$	$30.3 \cdot 10^6$	$78.5 \cdot 10^6$	$318.3 \cdot 10^6$	1447	1731	$26.7 \cdot 10^6$	$5057 \cdot 10^6$	$73 \cdot 10^9$	$4292 \cdot 10^6$	13864
2020	$445 \cdot 10^6$	$11.8 \cdot 10^9$	$30.8 \cdot 10^6$	$79.8 \cdot 10^6$	$323.5 \cdot 10^6$	1336	1619	$15.6 \cdot 10^6$	$1633 \cdot 10^6$	$31 \cdot 10^9$	$1481 \cdot 10^6$	18814

The results from 1992 show that the model covers an area wherein approximately 1/3 of the passenger car vehicle kilometres in Denmark are undertaken (Danmarks Statistik, 1995). Not all impacts require or can be aggregated. This goes e.g. for simple scores or the investment costs. These model results may be appended at later stage.

6.7.3 Calculation of project impacts

The centre for the calculation of project efficiency is the Cost-Benefit Tools interface. This interface contains functions for the most common operations on the table format used here; specialised arithmetic operations, managerial operations and the calculation of benefits under variable demand (vehicle operating cost and travel time benefits). The most important of the operations will be discussed in the following paragraphs.

Figure 38 **The Cost-Benefit Tools interface. The interface always operates on the working project (uppermost corner) and lists the do-minimum project below. For each operation a brief information on the operation is offered.**

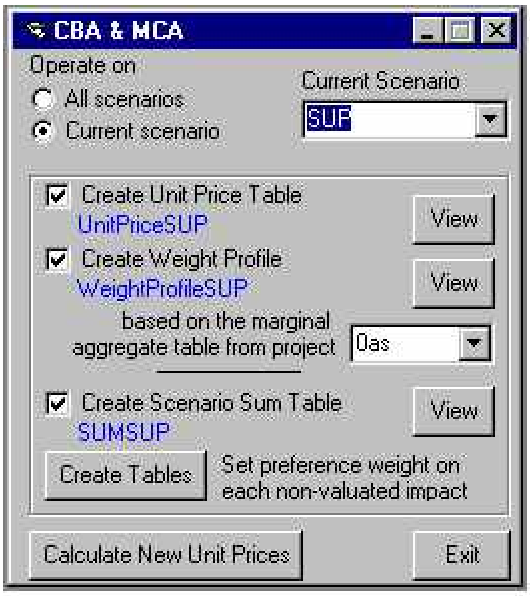


For each project a do-minimum has to be defined. This do-minimum may vary between projects. In the following the process of establishing a foundation for the evaluation is presented along with solutions selected for the SEAM DSS. The project impacts are calculated by subtracting the do-minimum from the do-something using the arithmetic procedure. In the case of variable demand the traveller impacts cannot be calculated using this simple approach (a link based approach can be used in special cases (see Buus, N., 1994)). Accordingly the marginal traveller benefits must be calculated by way of the OD and Cost matrices as described in section 3.2. These new results may be appended to the project impact table.

6.7.4 DETERMINATION OF UNIT PRICES AND ESTIMATION OF SHADOW PRICES

The unit prices and weight profiles are entered manually into a table customised for the impact composition of each scenario. The Tables interface is used for entering the data. The estimation technique for non-valuated impacts implemented in this study is the WARP procedure briefly discussed in section 4.4 (see Leleur, S., 1995 for more details). An impact Sum table is calculated across all projects for each scenario. The cross-sectional base price is subsequently calculated as the benefit of the valuated impacts. The cross sectional shadow prices are calculated for each of the weighted impacts in the Weight table. The CBA & MCA interface used to perform these operations is seen below in Figure 39:

Figure 39 **The CBA & MCA interface. The scenario listed is the Supra-national scenario (SUP).**



The shadow prices calculated on the basis of the Sum, Unit price and Weight tables are saved in the Unit price table. In the case of an inhomogeneous project pool, the estimated base shadow prices should be used as the fix point for development according to the prevailing development profile.

6.7.5 CALCULATION OF CROSS-SECTIONAL BENEFITS

As a set of combined unit and shadow prices have been established, the cross-sectional benefits are determined by multiplying the unit price table and the project impact table. This is done using the arithmetic procedure (see Figure 27).

6.7.6 CORRECTION OF SIGNS

Having calculated the benefits, these benefits should be adjusted according to their sign with respect to having a positive or negative socio-economic interpretation. As an example, a negative travel time benefit impact implies a saving and is accordingly a positive benefit. Conversely, a positive vehicle operating cost impact implies a social cost and is accordingly a dis-benefit. This change of the sign relates to most benefits but not all. An increase in train operator revenue is a benefit and hence a change of the sign is unnecessary. The same goes for the investment cost as this represents a positive cost. Accordingly all models are associated with a determination of their sign.

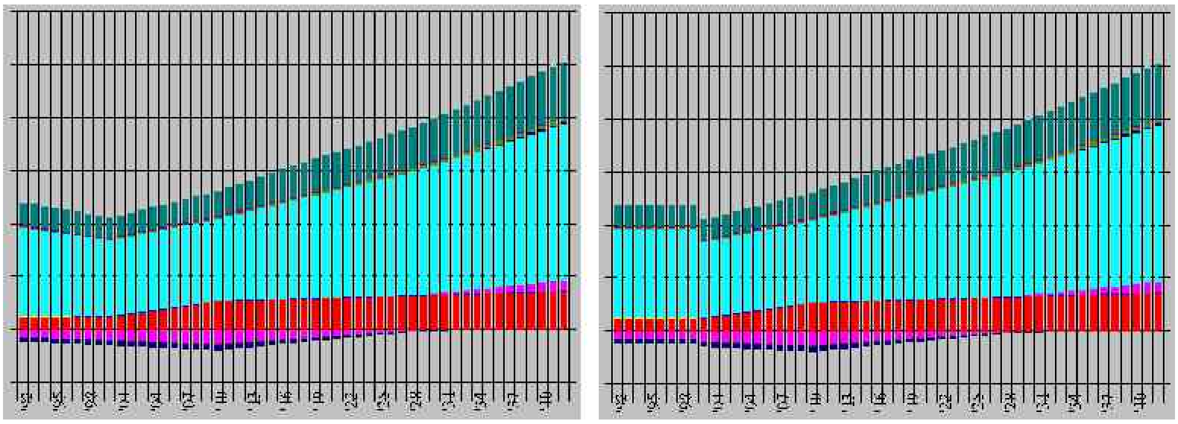
6.7.7 INTERPOLATION

So far all benefits have been discrete for each calculation year. In order to calculate the socio-economic value of a project the benefits and dis-benefits will have to be estimated for the years in between the calculation years. There are several issues to be dealt with in such an interpolation:

- The possibilities of intermediate fix years
- The prolongation from the last calculation year
- The estimation method
  - The 'cleaning' of results

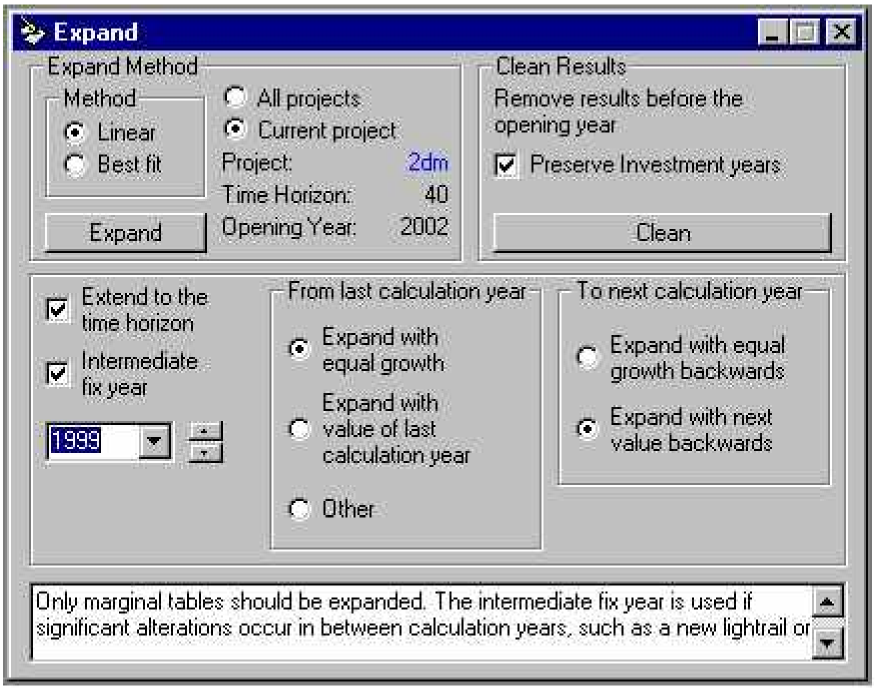
An intermediate fix year refers to important changes in the calculation preconditions in between the first and the last calculation year. In the case of Copenhagen such changes involve the opening of the Øresund Bridge and the Ørestad mini-metro. These projects are not being analysed, but they influence the score of other projects. Below the difference in benefit streams from using an intermediate fix year and not using an intermediate fix year is illustrated:

Figure 40 The difference between having an intermediate fix year and not having one.



A conscious choice must be made about the prolongation of the modelling results from the last calculation year to the end of the project period: Is it reasonable to assume a continued growth rate of the benefits stream or should a simple continuation of the last calculation year's values be selected. Still other developments are imaginable. The simplest approach is a linear approximation, but a polynomial fitting for a smoother development of benefits is equally an option. Below the Expand interface is presented:

Figure 41 **The Expand interface.**



The 'cleaning' of results refers to the final data set for evaluation. The opening year may in fact be in-between two modelling years. Accordingly all impacts should be set to zero before the opening year. The investment costs should however be maintained.

6.7.8 Evaluation

Following the data preparation as described above the least effort concerns the calculation of each projects socio-economic value. A wide range of evaluation criteria is available (see e.g. Leleur, S., 1995). A short list is:

- The first year rate of return (FYRR)
- The net present value (NPV)
- The Benefit-Cost Ratio (B/C)
  - The internal rate of return (IRR)

These evaluation criteria are calculated simultaneously. The first year rate of return has little meaning as an evaluation criterion in a SEAM context. It is however included for the sake of flexibility. The internal rate of return is less often used in socio-economic appraisal due to the well-known problem of the possibility of multiple roots and inconsistencies with the net present value in project ranking under budget constraints (PIARC, 1992).

6.8 Concluding remarks on the SEAM DSS

It has been shown that the practical issues of the SEAM methodology can be dealt with through a consistent approach to scenario painting. The staging of the approach divides the modelling into separate blocks, which eases the implementation of the methodology. It has been found that once the project and scenario structure is set the SEAM DSS is a very efficient tool to handle in an iterative process of evaluating different project alternatives.

In the next chapter some findings from a limited case study are presented. The chapter illustrates the application of the SEAM methodology in connection to a large infrastructure project.

6.9 LITERATURE

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7 APPLICATION OF THE SEAM METHODOLOGY

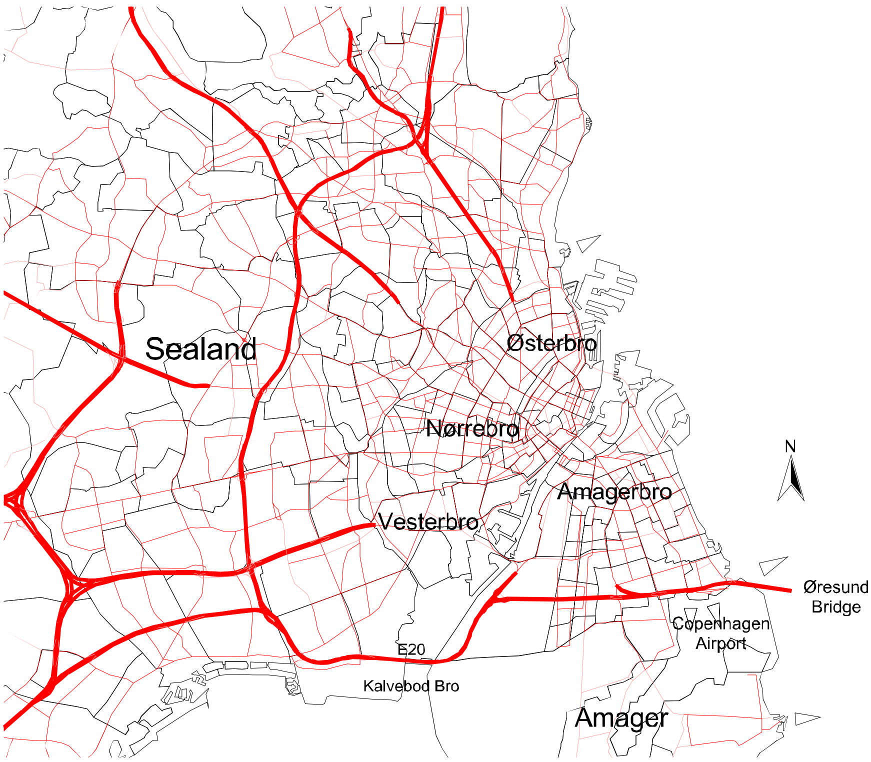
This chapter will illustrate the potential of the SEAM methodology through some case study results. The scenario painting has been limited to the impact models and evaluation development variables. The scenario painting using the Palludan et al. (1995) scenarios was described in chapter 5. The case is about a suggested fifth crossing of the Copenhagen harbour – The Harbour Tunnel. The traffic model results have been obtained from a traffic analysis of the Harbour Tunnel and used courtesy of the Danish Transport Council and the Ørestadsselskab. It has been beyond the resources of this study to undertake a full SEAM appraisal but the results will illustrate the potential of the SEAM methodology.

The traffic analysis was only concerned with passenger car transport and no scenario painting has as mentioned been made of the traffic model. It should be noted that the traffic model used for this study is being improved and applied in a full-scale study of the Harbour Tunnel.

7.1 COPENHAGEN - A BRIEF INTRODUCTION

Copenhagen, the capitol of Denmark, was founded around the turn of the first millennium. It is located around a natural harbour made up of several minor islands. The harbour divides the central areas of the city into two main conurbations. The majority of the population lives on the western side of the harbour on Sealand. Amager towards the east is an island that has a large and dense population located in the areas close to the city centre. The medieval city centre in situated on the Sealand side of the harbour.

Figure 42 Map of Copenhagen. To the East is the island Amager with Copenhagen Airport. The medieval city centre is located just opposite of Amager. Around the city centre is located four densely populated areas, Østerbro, Nørrebro, Vesterbro and Amagerbro.



Surrounding the medieval city centre are four densely populated areas. Their names reflect their geographical direction:

- Nørrebro (Northern Bridge)
- Østerbro (Eastern Bridge)
- Vesterbro (Western Bridge)
  - Amagerbro (Amager Bridge)

The bridge areas are mixes of high quality dwellings and low quality speculative development from around the turn of the century. The population of the Greater Copenhagen Region is more 1 million. The majority of the population is located along five 'fingers' stretching out from the dense city areas.

7.1.1 THE TRANSPORT SYSTEM

Four road bridges cross the Copenhagen Harbour, which represents a screen-line dividing the city. Two of these bridges cross between the medieval city centre and Amager (see Figure 43):

- Knippelsbro
  The northern most of the four bridges, connecting the parliament and medieval city centre with Amager.

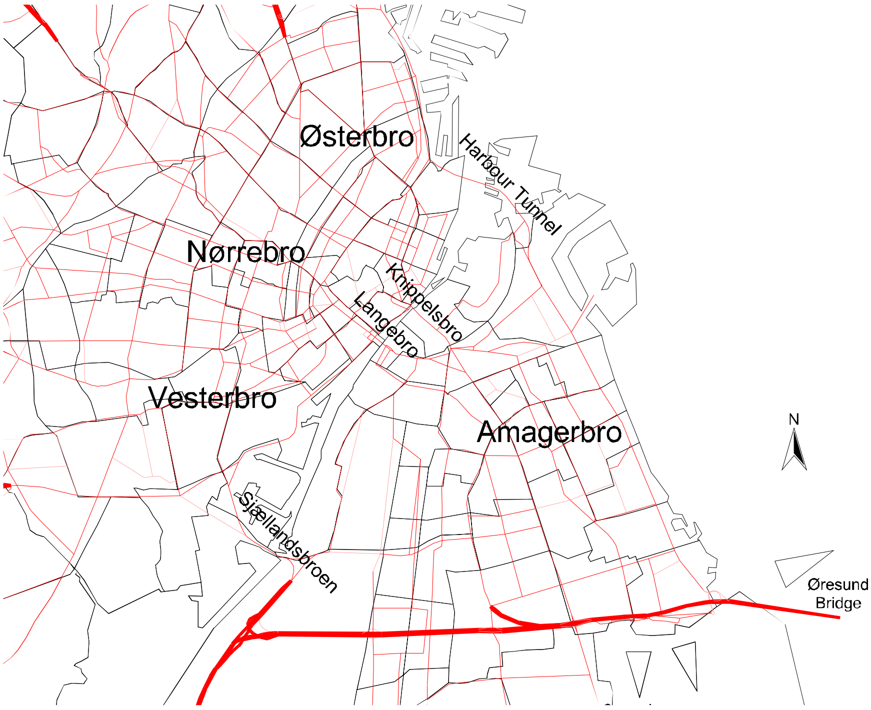
- Langebro
  Langebro located just south of Knippelsbro connects central Amager through H.C.Andersens Boulevard with central Copenhagen. H.C.Andersens Boulevard pass close by the medieval town centre.

- Sjællandsbroen
  Located slightly north of the Kalvebod Bridge connecting Amager with Copenhagen through the industrial area in the southern harbour (Sydhavnen).

- Kalvebod bro
  The motorway E20 crosses this bridge south of the Copenhagen city centre, and connects to the Danish motorway system. The E20 leads to Copenhagen airport and the Øresund Bridge.

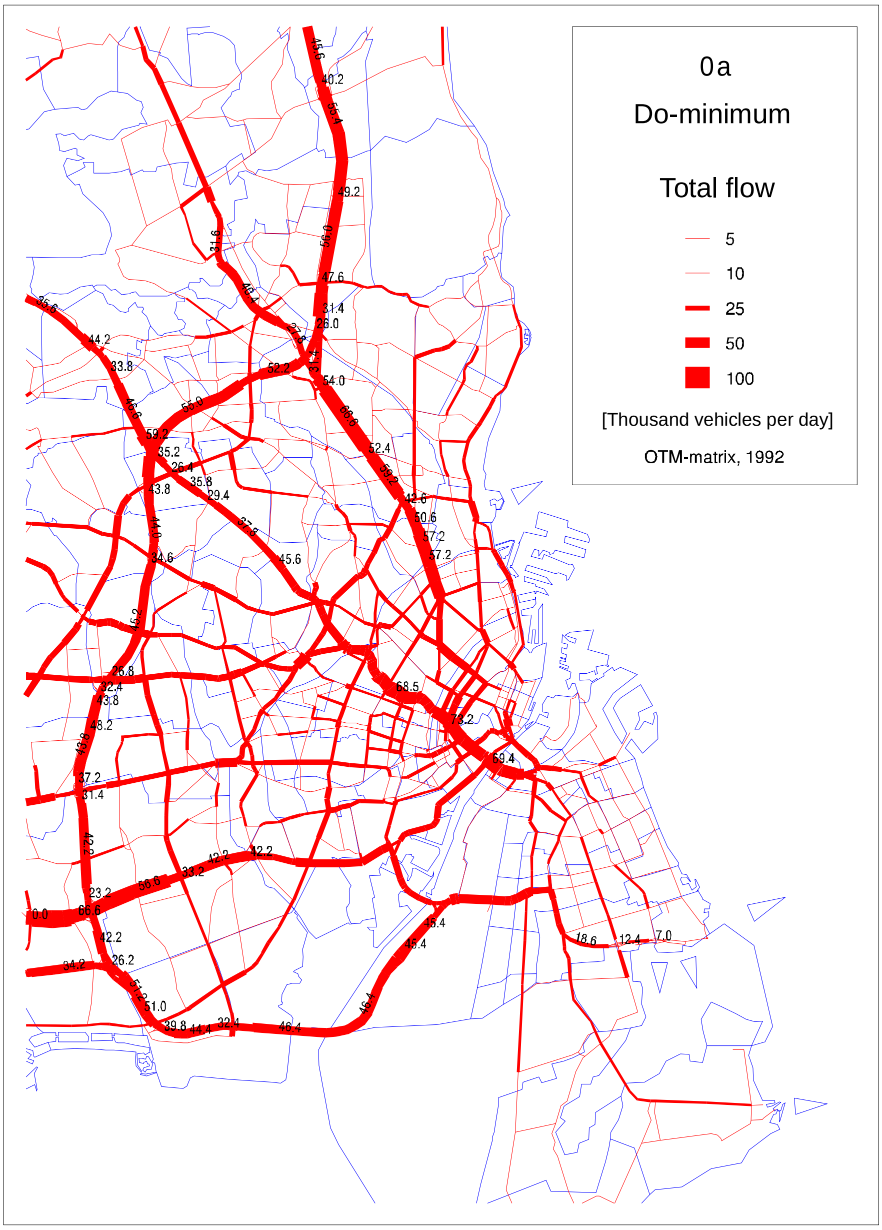
All of these bridges carry substantial traffic flows to and from the city centre, as well as some through traffic.

Figure 43 The road bridges across Copenhagen Harbour. The Kalvebod bridge is the motoerway bridge that connects to the Øresund bridge. This bridge is further south.



The traffic flow in the do-minimum case (0a) is seen below.

Figure 44 **Traffic flows on the do-minimum road network for 1992 without a Harbour Tunnel (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998).**



Besides the road network Copenhagen has a well-developed urban rail system known as the S-train system. The latest much needed development is a light rail link running perpendicular to the present direction of the S-train network, from Frederiksberg station to Amagerbro and the new Ørestad. Copenhagen also has a well-developed bus system.

7.1.2 THE ØRESTAD

The Ørestad is a new urban development project located on the western side of Amager. To avoid increasing through traffic in central Copenhagen due to the development of the Ørestad a light rail line is being constructed along the Ørestad financed by the revenue of the development whereas only a 2-lane access road is being constructed (Fich, C. & Søndergaard, M., 1997). The Ørestad, the staged mini-metro links and the S-train system is seen in Figure 45.

Figure 45 **The Ørestad with developments, and the relation between the existing S-train network and the new Ørestad mini-metro (Based on Ørestadsselsskabet, 1998).**

The mini metro is made up of three parts of which the Frederiksberg Line and the Ørestads Line are expected to open in the year 2000. The Eastern Amager Line is yet to be decided upon.

To start the development of the Ørestad, some faculties of the University of Copenhagen and the national archives are moving to the Ørestad. The modelling preconditions concerning development in the Ørestad used in the assessment is seen in Table 39 below.

Table 39 **The modelling preconditions for the development in population and the number of jobs in the future Ørestad for the each calculation year (Carl Bro, 1995 & Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998). The zone numbers refer the zones in below.**

THE ØRESTAD	POPULATION			JOBS		
ZONE	'1992	'2000	2010/2020	'1992	'2000	2010/2020
80 (North)	0	1219	3750	0	0	3575
304 (Middle)	0	0	3250	0	0	3500
305 (Vejlands Allé)	4	0	5000	494	494	12619
306 (Bella Centre, etc.)	0	375	1875	0	3907	16375
307 (Amager Motorway)	0	0	2875	0	100	6200
308 (South)	0	0	6125	0	100	5325
TOTAL	**1996**	**3594**	**22876**	**2486**	**6601**	**47595**

A fully developed Ørestad is not expected until around the year 2020 but it expected to be partly developed by the year 2000. The zone ID's listed in Table 39 are found in Figure 46 below.

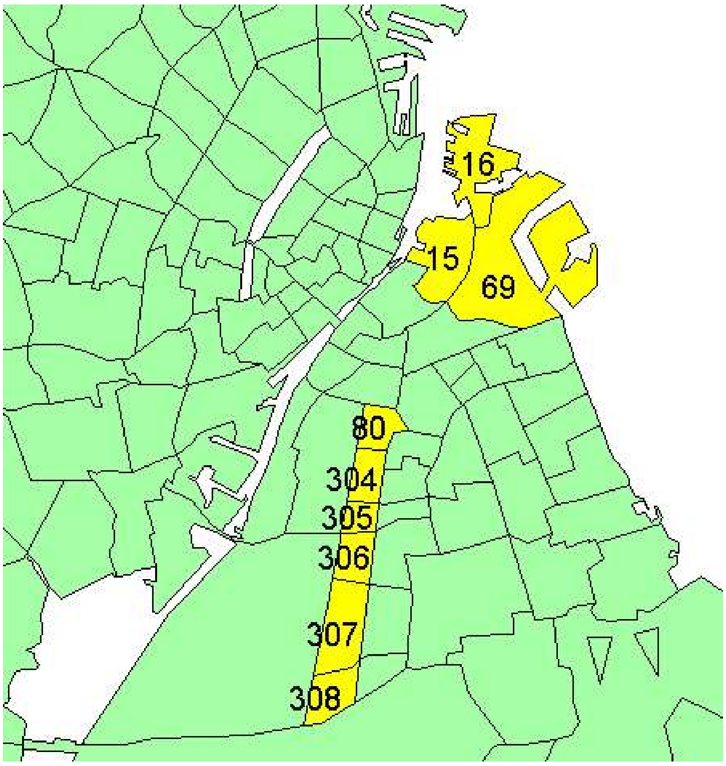
7.1.3 THE ØRESUND BRIDGE

The Øresund Bridge between Copenhagen and Malmø in Sweden aims at integrating Scania and Copenhagen and providing access from Sweden to continental Europe. The Bridge, which is a combined rail and road bridge, connects just next to Copenhagen Airport. The bridge is expected to open in the year 2001.

7.1.4 THE HOLMEN AREA

Holmen is an old navy area just opposite of medieval city centre. It was decided to move the Navy away from Holmen as the risk of having the Navy located in such a densely populated area was deemed too great. The Navy left Holmen in 1995. Soon after this the Architect Academy and the Copenhagen Acting School moved in. It is anticipated that the area will play a significant role in the future cultural life of Copenhagen.

Figure 46 **The Holmen area is made up of Holmen itself (15), Refshale Island (16) and Kløvermarken (69). The area is located towards Øresund and just across from the medieval city centre. The Ørestad is located in the zones 80 and 304-308.**



Slightly to the north of the old navy area lies two areas called Refshale Island and Kløvermarken. These areas are potentially very interesting for urban development as they face the sea and are relatively close to the city centre. Presently they are however too far from any transport infrastructure to be developed. The modelling assumptions for the entire Holmen area (including Refshale Island and Kløvermarken) is seen in Table 40.

Table 40 The modelling preconditions for the development in population and the number of jobs on in the Holmen area for each calculation year (Carl Bro, 1995 & Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998). The zone numbers refer the zones in Figure 46 above.

HOLMEN	POPULATION				JOBS			
ZONE	**'1992**	**'2000**	**'2010**	**'2020**	**'1992**	**'2000**	**'2010**	**'2020**
15 (Holmen)	910	1507	2414	2414	211	261	842	1042
16 (Refshale Island)	23	23	23	23	2413	2970	3133	18600
69 (Kløvermarken, etc.)	0	0	0	0	1902	2271	3423	8500
TOTAL	**2925**	**3530**	**4447**	**4457**	**6518**	**7502**	**9408**	**30162**

For the calculation year 2020 the population is assumed to increase substantially. The residents are furthermore assumed to have a higher average income than those living due to the attractiveness of the area.

7.2 THE HARBOUR TUNNEL

A fifth crossing of the Copenhagen Harbour, a northern tunnel, has been discussed for many years. The tunnel was part of Copenhagen's road scheme during the 1960s, but was again abandoned during the 1970s (Transportrådet, 1997). The Harbour Tunnel resurfaced in 1987 due to a report published jointly by the Port of Copenhagen and the real estate company which own the land on the Refshale Island. The argument being that the Port needed this connection in order to compete with the rail and road operators following the new Great Belt and Øresund Bridges and the possible Fehmarn Belt Bridge between Denmark and Germany. In 1988 the Port of Copenhagen published another note on the possible practical connections on either side (Transportrådet, 1997).

Later in 1988 the Tengvad Committee who were commissioned to look at transport investments in the greater Copenhagen region published their report. This report did not recommend the construction of a Harbour Tunnel. In the 1991 report from the Würtzen Committee, which also looked at transport investments in the greater Copenhagen region, the Harbour Tunnel was briefly discussed, but its construction was not suggested. The main reasons for these conclusions on the Harbour Tunnel, were the potential increase in flows on the feeder roads towards Copenhagen and the potential deterioration of the environment on the Amager side. It was, however, noted by the Würtzen Committee that a possible tunnel would reduce the traffic in the medieval city centre and Christianshavn (Transportrådet, 1997).

In a report from 1993 by the shipyard Burmeister & Wain and 1995 by the Danish Ministry of Transport (1995) user-paid solutions were suggested. Later in 1995 the Danish Road Directorate promoted the inclusion of the Harbour Tunnel as part of a regional ring road around Copenhagen, due to the expected pressure on the road network from both the Ørestad and the Øresund Bridge (VD, 1995). Later, in 1996 the Danish Road Directorate presented traffic model results which predicted a flow in the tunnel of between 50.000 - 60.000 cars per day (VD, 1996).

In 1996 the minister of transport and the mayor of Copenhagen suggested a combined solution where the ministry paid for a tunnel and the city of Copenhagen implemented traffic calming measures for the medieval city centre. Later in 1996 the city of Copenhagen presented a plan for traffic calming in Copenhagen (Københavns Kommune, 1997a). The final initiative came in 1997 when the Danish Transport Council commissioned a work on the effects on the traffic from different designs of a Harbour Tunnel (Transportrådet, 1997). The flow estimates from this traffic study are used for the calculations in the scenario based appraisal approach discussed in this chapter.

7.2.1 THE HARBOUR TUNNEL PROJECTS

Two alternative alignments of the Harbour Tunnel project are investigated here. The alternatives do not concern the tunnel itself but the different connections possible on the Amager side. The common features of the project alternatives are:

- A connection is made from the motorway Lyngbyvej through a tunnel to Gittervej.
  - From Gittervej the connection continues through the Harbour Tunnel to Amager.

The connections of the tunnel to the existing road network on the Amager side are (see Figure 47):

1. The Harbour Tunnel road continues down Amager Strandvej. Amager Strandvej connects to Copenhagen Airport and the Øresund Bridge (Amager Strandvej project alternatives 2c and 2d)

2. The Harbour Tunnel road turns right down Kløvermarksvej and continues along Lossepladsvej and connects to the motorway E20, which will form a ring road around Copenhagen. Amager strandvej will be traffic calmed (Ring road project alternatives 4a and 4b)

There are other possible solutions, but they have not been investigated here.

Figure 47 The Harbour Tunnel connection to the Lyngbyvej Motorway in the north on the Sealand side, and the possible solutions on the Amager side (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998)

The traffic model runs were used for the screening of unfeasible projects. Furthermore, not all the feasible projects were modelled for all years as required for a SEAM appraisal.

Each of the two main tunnel project alternatives investigated have been combined with a traffic calming scheme in the medieval city centre as suggested by the city of Copenhagen and the Ministry of Transport (see section 7.2). The qualities of the projects in question are listed below:

Table 41 The project alternatives included in this study with schematic description of the measures.

PROJECT	TUNNEL	CITY CENTRE	LOSSEPLADSVEJ	AMAGER STRANDVEJ	KLØVERMARKSVEJ
Do-minimum					
0a	-		2 lanes, 60 km/h	2-lanes, 60 km/h	2-lanes, 50 km/h
0b	-	Traffic calming and reducing measures	2 lanes, 60 km/h	2-lanes, 60 km/h	2-lanes, 50 km/h
Amager strandvej					
2c	4 lanes, 80 km/h	-	-	Upgraded to 4 lanes, 70 km/h	Upgraded to 4 lanes, 60 km/h
2d	4 lanes, 80 km/h	Traffic calming and reducing measures	-	Upgraded to 4 lanes, 70 km/h	Upgraded to 4 lanes, 60 km/h
Ring road					
4a	4 lanes, 80 km/h	-	Upgraded to 4 lanes, 60 km/h	Speed reducing measures, 40 km/h	Upgraded to 4 lanes, 60 km/h
4b	4 lanes, 80 km/h	Traffic calming and reducing measures	Upgraded to 4 lanes, 60 km/h	Speed reducing measures, 40 km/h	Upgraded to 4 lanes, 60 km/h

In order to assess the project alternatives involving traffic calming in central Copenhagen, it has been necessary to generate an additional do-minimum project alternative for this study. This do-minimum has been denoted 0b and is similar to the base do-minimum 0a except for the inclusion of the traffic calming of Copenhagen. Consequently, 0b is a simple redistribution of the traffic flows without a reassessment of the modal split. This involves a slight over-estimation of the traveller benefits for the project 2d and 4b.

7.2.2 THE CALCULATION YEARS

The traffic flows have been assessed for four different years for each of the project alternatives. The calculation years are 1992, 2000 along with two years denoted 20xx and 20px. 20xx originates from the OTM model and concerns the year when the Ørestad is fully developed. This is expected around the year 2010. 20px on the other hand is a maximum situation developed specifically for this traffic study (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998). In this maximum traffic scenario both the Ørestad as well as the Holmen area is fully developed, without any reductions in activity elsewhere in the region. For the sake of the evaluation, the calculation year 20xx has been set at 2010 and the calculation year 20px at 2020.

The influential changes in transport supply expected within the planning period in the Greater Copenhagen Region compared to 1992 situation are:

Table 42 **Changes in land-use and infrastructure for all project alternatives for each modelling year (Carl Bro, 1995 & Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998)**

YEAR	CHANGE
2000	• Construction of the light rail to the Ørestad from Nørreport Station (phase 1) and the extension from Nørreport Station to Frederiksberg Station (phase 2).
	• The upgrading to double track on the single track share of the S-train line to Frederikssund
	• The widening of the Helsinore Motorway from Lyngby to Vedbæk from 4 to 6 lanes
	• The Ørestad will be partly completed, without any reduction in the number of employed or population in any other parts of Copenhagen for this prognosis year (2000).
	• Opening of the Øresund Bridge
2010 (20xx)	• Extension of the Ørestad light rail from Fredeiksberg Station to Vanløse Station
	• Completion of the Ørestad, without any reduction in the number of employed or population in any other parts of Copenhagen for this prognosis year (2010).
2020 (20px)	• Complete development of Holmen, Refshale Island, without any reduction in the number of employed or population in any other parts of Copenhagen for this prognosis year (2020).

The inclusion of the maximum situation implies a maximum estimation on the future benefits.

7.2.3 THE PROJECT COST

The project costs have not been assessed in this study but are based on the rough estimates provided by the Danish Ministry of Transport (Trafikministeriet , 1995) and the Danish Road Directorate (VD, 1995). The project costs have been assessed at:

Table 43 **Rough cost estimates in billion DKr. (1995) by the Ministry of transport and the Danish Road Directorate (VD) (Trafikministeriet , 1995 & VD, 1995)**

1994 PRICES	AMAGER STRANDVEJ		RING ROAD	
COST ELEMENT [BILLION DKR]	2C	2D	4A	4B
Tunnel	1.4	1.4	1.4	1.4
Roads on Sealand	0.2	0.2	0.2	0.2
Roads on Amager	0.2	0.2	1.0	1.0
Unforeseen costs	0.5	0.5	0.5	0.5
Traffic calming	-	0.2	-	0.2
TOTAL COST	2.3	2.5	3.1	3.3

The maintenance cost associated with the tunnel was in earlier reports (1988) estimated to be between 9 and 20 million DKr. per year (Transportrådet, 1997). The costs associated with the traffic calming measures in central Copenhagen are set at 200 million DKr. The construction and planning costs used in this study are (1994 prices):

- Design cost: 20 million DKr.
    - Maintenance cost of the tunnel: 15 million DKr. per year

The tunnel is assumed to open in the year 2001. The planning cost has accordingly been distributed across the years 1999 and 2000, whereas the construction costs have been distributed across the years 2000 and 2001. The cost associated with the maintenance of the new road is considered a dis-benefit and not a cost. This share of the increased maintenance costs is calculated using the operating and maintenance cost model (OMC).

7.2.4 MODELLING PRECONDITIONS

For an appropriate assessment of costs and benefits the following elements have been used as preconditions:

Table 44 Modelling preconditions for the evaluation.

VARIABLE	VALUE
Discount rate	7 %
Project lifetime	40 years
Opening year	2001
Discount year	1998
Price level	1994
Discrete calculation years	1992/2000/2010/2020
Intermediate years	None
Interpolation method	Linear
Prolongation after last modelling year	Linear continuation of tendency

The EUNET transport evaluation frameworks have been used for the determination of impacts (see appendix A or Leleur et al., 1998). The scenario painting of model development variables, unit prices and weights is described in chapter 5. The modelling approaches for the impact models are described in appendix B. The evaluation criteria used are the net present value and the benefit-cost ratio. The shadow prices have been estimated using the WARP method (Leleur, S., 1995).

7.3 MODELLING THE HARBOUR TUNNEL TRAFFIC

This section presents the main findings of a traffic study commissioned by the Danish Transport Council. The aim of this traffic study was to provide decision-makers with an independent analysis of the expected traffic flows. The results of this study have been used as input to the SEAM impact assessment and evaluation. The main findings of the traffic study are presented in Transportrådet, 1997, and details on the modelling premises are found in Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998.

7.3.1 THE TRAFFIC MODEL SET-UP

There are presently two main traffic models for Copenhagen. One is the Greater Copenhagen Regions Traffic Model (HTM) maintained by official bodies in the region. The urban development consortium in charge of the Ørestad owns the other traffic model (OTM). OTM is a refined version of HTM in the corridor surrounding the light rail link between the Ørestad and Vanløse (see Figure 45). The OTM OD-matrices are for weekday traffic (estimates traffic flows for an average weekday – Monday to Friday), and these matrices have been used for impact the analyses carried out. That OTM is a weekday traffic model and not a annual average daily traffic model stems from the fact that this model was developed for the assessment of the service requirements of the light rail. For the same reason there is no specific goods model included. Goods transport is included through a passenger car equivalent.

Comparisons were made between the weekday traffic flows and traffic flows from a re-estimated OD-matrix for annual average daily traffic. The comparison showed that the total flow across the harbour screen line was virtually the same for the two matrices. There were however some notable differences (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998):

- The flow was 25% lower in the tunnel using the re-estimated matrix than the OTM matrix, which may be due to the slightly shorter trip distances found in the re-estimated matrix.
  - There are relatively large differences between link flows close to the screen line on both sides of the harbour.

The changes in the flows across the harbour screen-line for both the project alternatives were similar regardless of the fact that the number of trips in the daily traffic matrices is higher than that of the annual average daily traffic matrices. The consequence of the use of weekday traffic flows is <u>a slight over-assessment of the impacts</u> for all project alternatives, as most models relate to the annual average daily traffic and not the weekday traffic.

The OTM model is a multi-modal traffic model. The estimates of trip generation in OTM are based on socio-economic variables such as the population and several employment variables (Employed, number of jobs by branch, etc.) (Fich et al., 1995). The trip production is not a function of the generalised travel cost and consequently the model cannot make estimates of induced traffic. Person trip matrices have been estimated by trip purpose (work, students and other purposes) and mode (car, bicycle, walk and public transport). The specific mentioning of student trips relates to the fact that some of the faculties of the University of Copenhagen are located in the Ørestad in the vicinity of the mini metro line.

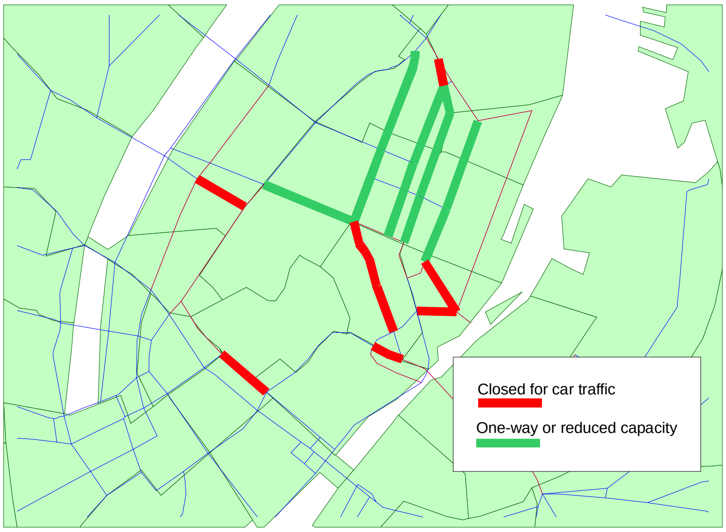
7.3.2 Traffic calming measures in Copenhagen city centre

The city of Copenhagen and the Ministry of Transport suggested a tunnel combined with traffic reducing and calming measures in the medieval city centre of Copenhagen. The traffic calming measures suggested by the city of Copenhagen involve a division of the city centre into four zones. Crossing from one zone to the next is suggested hampered by the traffic calming measures (Københavns Kommune, 1997a). The modelling of the traffic calming was obtained with four measures:

- Roads closures
- Capacity reductions
- Conversions of two-way streets into one-way streets
  - Complicating thorough fare by combining measures without reducing capacity or closing roads (e.g. by turning the direction of one-way streets)

The changes are seen below:

Figure 48 Traffic calming measures in central Copenhagen as applied in the traffic analyses (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998).



7.4 THE HARBOUR TUNNEL TRAFFIC ANALYSIS

The main result of the traffic analyses was that the Harbour Tunnel seem mainly to relocate the already existing road traffic (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998). The tunnel was found to have a limited influence on the modal split and a sketch assessment indicated that the induced traffic would be limited. The model also indicated that the traffic in the tunnel would be relatively local. The users seemed to originate mainly from the residential areas in an eastern corridor on Sealand (Østerbro/Gentofte) and the northern part of Amager. The traffic in the city centre will decline, as a part of the traffic from the aforementioned areas will select the tunnel. The findings will be presented in more detail below.

7.4.1 THE HARBOUR SCREEN LINE

The traffic flow through the tunnel in the four project alternatives for a selection of calculation years is shown in appendix C.

The central bridges Knippelsbro and Langebro experience substantial reductions in traffic flows for all projects and in all calculation years compared to the do-minimum. Not surprisingly, Knippelsbro (the closest bridge to the Harbour Tunnel) experiences the biggest reductions. Depending on the alternative up to 40% of the traffic in the tunnel stems from Langebro whereas Knippelsbro stands for at least 60%. The traffic on the other two bridges, Kalvebod bridge and Sjællandsbroen is influenced only to a minor extent, as they service traffic with origins and destinations that will experience only a limited gain from a Harbour Tunnel.

It appears that most of the trips across the Harbour Tunnel will be relatively local and of short duration. Consequently, the additional effect of the traffic calming seems to be moderate. An additional reduction is obtained for the Ring road (4a) alternative compared to the Amager Strandvej alternative (2c). This additional reduction stems from local transfers and not from a better utilisation of the Harbour Tunnel. In general there seems to be little connection between the traffic in the Tunnel and the traffic on Lossepladsvej (approximately 10% of the traffic coincides). The Ring road alternative (4a) involve ripple effects on the traffic flows on Amager towards the Ring road and generally seems to reduce traffic pressure in the western part of Amager and to be neutral with respect to the eastern part.

In the Amager Strandvej alternative (2c) the traffic seems to increase quite substantially on Amager Strandvej itself while at the same time alleviating some of the flow on the central areas of Amager slightly. The traffic mitigates towards the upgraded road. It has been found that only limited amounts of the tunnel traffic will originate either from Copenhagen Airport or from the Øresund Bridge due to the fact that the main traffic to and from these destinations will choose the southern motorway (E20). This finding underlines that the trips that go through the tunnel will be local and of short duration.

The traffic in central Copenhagen is relatively independent of which alignment is chosen on Amager. The traffic calming scheme was found to only reduce the traffic flow in central Copenhagen by an additional 10%. There is however quite some re-distribution of traffic (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998).

7.4.2 MODAL SPLIT

The results seem to imply that a Harbour Tunnel will have a relatively low impact on the modal split between cars and public transport in the region. In the analysis an improvement with respect to the public transport was found for Holmen. Consequently, the reason for the minor impact on the modal split may be explained by the previously relatively poor public transport service between the northern part of Amager and Holmen and Østerbro/Gentofte. For these zone pairs the number of trips by public transport increase quite substantially. It was estimated that an additional 900 trips per day will be made by car instead of by public transport for the Copenhagen region, which is a relatively small change (Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998).

7.5 IMPACT ASSESSMENT OF THE HARBOUR TUNNEL

This section will illustrate results based on a SEAM impact assessment and evaluation. The traffic flows, which form the basis for these results, have been presented above. The section comprises two main parts. The first part will present the general findings that will provide an overview of the results, the second part concerns the details for each of the four project alternatives.

7.5.1 ASSESSMENT OF NON-MODELLED IMPACTS

A number of impacts have been assessed purely by way of a judgmental score. This is the case for the severance (SEV), strategic mobility (MOB), Private financial attractiveness

(PFA) and other planning and policy issues (OTH) (see appendix A). These impacts have all been assessed on a point scale ranging from –5 to 5 for each of the calculation years and are common for all scenarios. The influence these impacts will have on the evaluation is governed by the weight profiles developed in chapter 5.

Table 45 **The judgmental scores applied to the project alternatives without traffic calming. The Ring road alternative (4a) weights are shown in brackets if they differ from the Amager Strandvej alternative (2c).**

2C (4A)	SEVERANCE (SEV)	PRIVATE FINANCIAL ATTRACTIVENESS (PFA)	OTHER STRATEGIC PLANNING AND POLICY ISSUES (OTH)	STRATEGIC MOBILITY (MOB)
1992	1	1 (3)	1	1 (3)
2000	1	1 (3)	1	1 (3)
2010	2	1 (3)	1	3 (5)
2020	2	1 (3)	1	3 (5)

The general scores on severance are moderate since the reduction of traffic in the city centre following the tunnel only amounted to a 10 % reduction. The scores improve over time as the traffic flow increases. The private financial attractiveness is reasonable as the real estate company of Refshale Island may wish to participate. However the private financial attractiveness improves for the Ring road alternative as the Copenhagen Harbour has an additional interest in this project. The strategic mobility improves over time and is again relatively better for the Ring road alternative (4a).

Table 46 **The judgmental scores applied to the project alternatives with traffic calming. The Ring road alternative (4b) scores are shown in brackets if they differ from the Amager Strandvej alternative (2d).**

2D (4B)	SEVERANCE (SEV)	PRIVATE FINANCIAL ATTRACTIVENESS (PFA)	OTHER STRATEGIC PLANNING AND POLICY ISSUES (OTH)	STRATEGIC MOBILITY (MOB)
1992	1	3 (5)	3	3 (5)
2000	1	3 (5)	3	3 (5)
2010	1	3 (5)	4	5 (5)
2020	1	3 (5)	4	5 (5)

The project alternatives are compared to the do-minimum without the tunnel but with traffic calming. The project alternatives have hardly any influence on the severance. As however the travel resistance is greater than before there may be an additional possibility of a toll-based tunnel. Consequently the private financial attractiveness (PFA) is increased compared to before in regard to these two alternatives. These two tunnel alternatives (2d & 4b) also comply with the suggestions from the Ministry of Transport and the City of Copenhagen. Hence a higher score on the other planning and policy issues (OTH) than was the case for the project alternatives 2c and 4b. Also the mobility gain becomes greater as the travel resistance increases following the traffic calming scheme.

7.6 SCENARIO-BASED EVALUATION

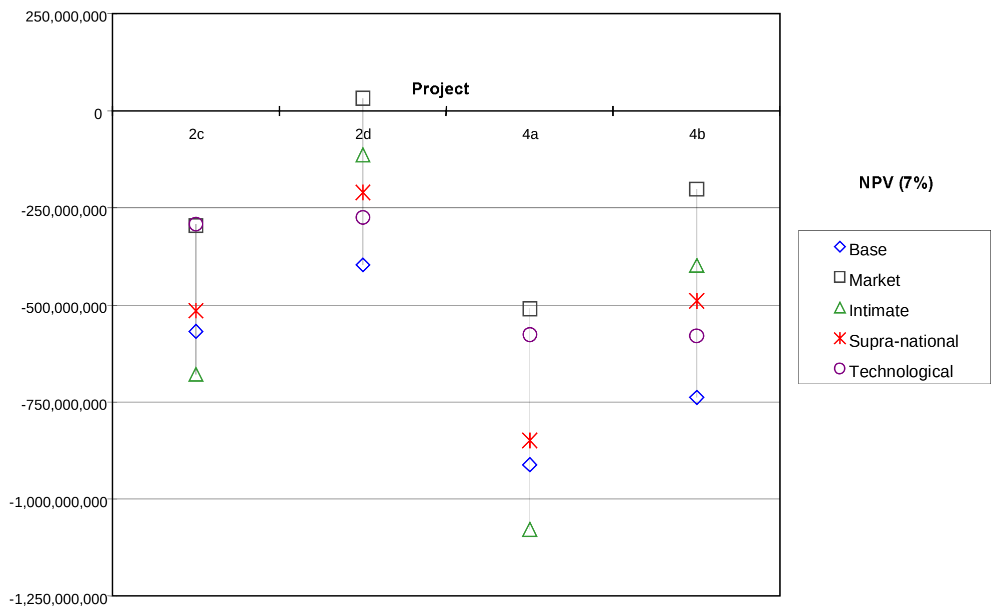
The scenario painting of the development variables of each scenario was presented in chapter 5. It should be noted that the painting from the scenarios has taken its start in the 1992 calculation and not from the present 1998. This will lead to a stronger scenario impact on each project alternative' efficiency, as the discounting will have a lesser impact. On this basis the following results were obtained:

Table 47 Efficiency of the project alternatives measured by different evaluation criteria.

	AMAGER STRANDVEJ		RING ROAD	
MEASURE	2C	2D	4A	4B
NPV				
Base	-568,174,849	-397,259,523	-911,764,781	-738,091,806
Market	-295,748,826	32,473,047	-509,604,556	-201,401,593
Intimate	-678,929,402	-113,248,923	-1,078,357,452	-398,060,087
Supra-national	-515,210,457	-210,371,200	-849,369,840	-489,777,809
Technological	-292,562,661	-274,406,819	-576,323,488	-579,664,132
Benefit Cost Ratio				
Base	0.73	0.83	0.67	0.75
Market	0.86	1.01	0.82	0.93
Intimate	0.68	0.95	0.61	0.87
Supra-national	0.76	0.91	0.70	0.83
Technological	0.86	0.88	0.79	0.80

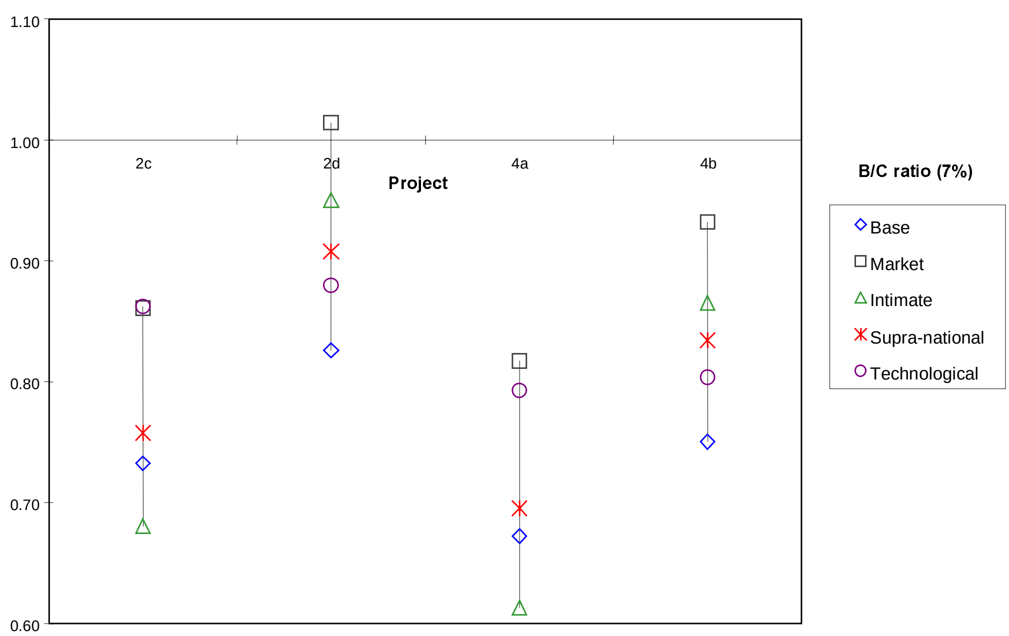
The robustness of each project alternative measured by NPV is illustrated below:

Figure 49 **Scenario project robustness based the NPV.**



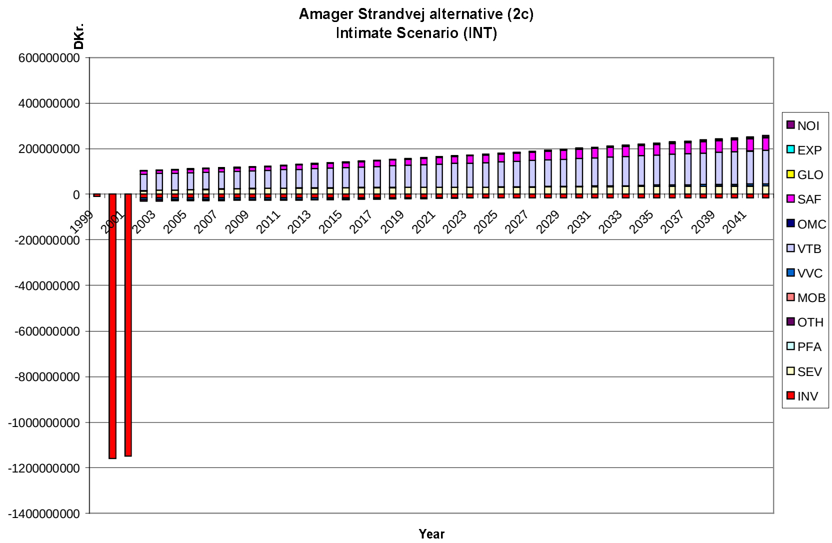
As it appears none of the projects seems consistently to produce a positive net present value. The most robust projects appear to be the Amager Strandvej alternatives (2c & 2d). The projects involving traffic calming in central Copenhagen (2d & 4b) perform better than the projects without traffic calming (2c & 4a) respectively.

Figure 50 **Scenario project robustness based the Benefit Cost Ratio.**



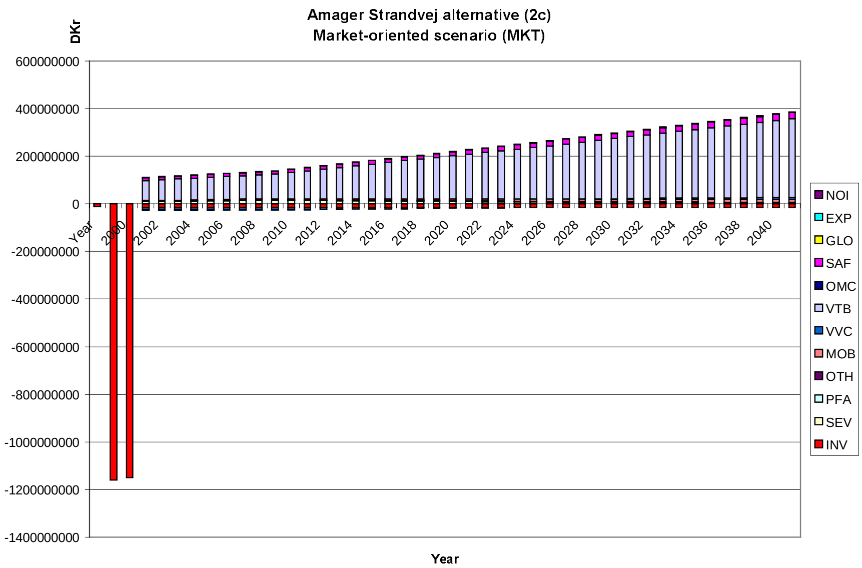
This seems to indicate that these projects almost inevitably will improve over time. The same may be said for the alternatives without traffic calming, but the tendency is less strong. This implies that in some near future the projects may well become feasible. This is also underlined by that fact that the relation between benefits and dis-benefits is decreasing over the period, from 10-13% in 2010 to between 3-6% in the year 2020. This is equally seen from the benefit stream analysis.

Figure 51 Benefit stream for the Amager Strandvej alternative (2c) in the Intimate scenario (INT)[1].



The projects without traffic calming score the poorest in the intimate scenario. The local environmental impacts (exposure, noise, severance) and safety impacts are valued high in this scenario.

Figure 52 Benefit stream for the Amager Strandvej alternative (2c) in the Market-oriented scenario (MKT)[1].



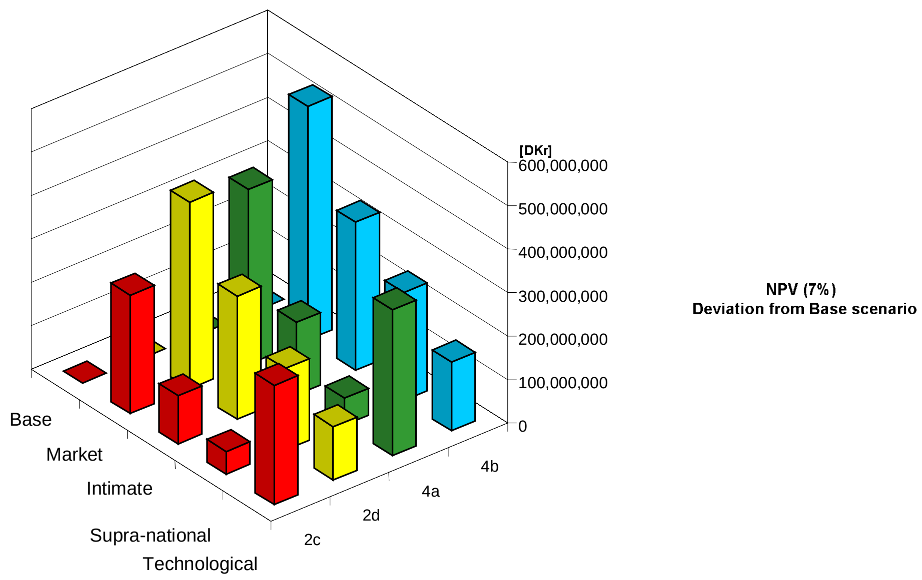
As a preliminary conclusion it seems as if the main reason for the poor efficiency of the projects stems from the fact that the project costs are quite substantial. All the project

[1] The abbreviations refer to different impact models: NOI – Noise, EXP – Exposure, GLO – Global environment, SAF – Safety, OMC – Operating and maintenance cost, VTB – Travel time benefits, VVC – Vehicle operating cost, MOB – Mobility, OTH – Other planning and policy issues, PFA – Private financial attractiveness, SEV – Severance and INV – Investment cost.

alternatives do develop rather significant benefits but these benefits are simply too small compared to the construction costs.

The scenario sensitivity of each project based on the comparison of the efficiency measures of the scenario and base scenario is seen in Figure 53 below:

Figure 53 A scenario sensitivity graph of the project alternatives.

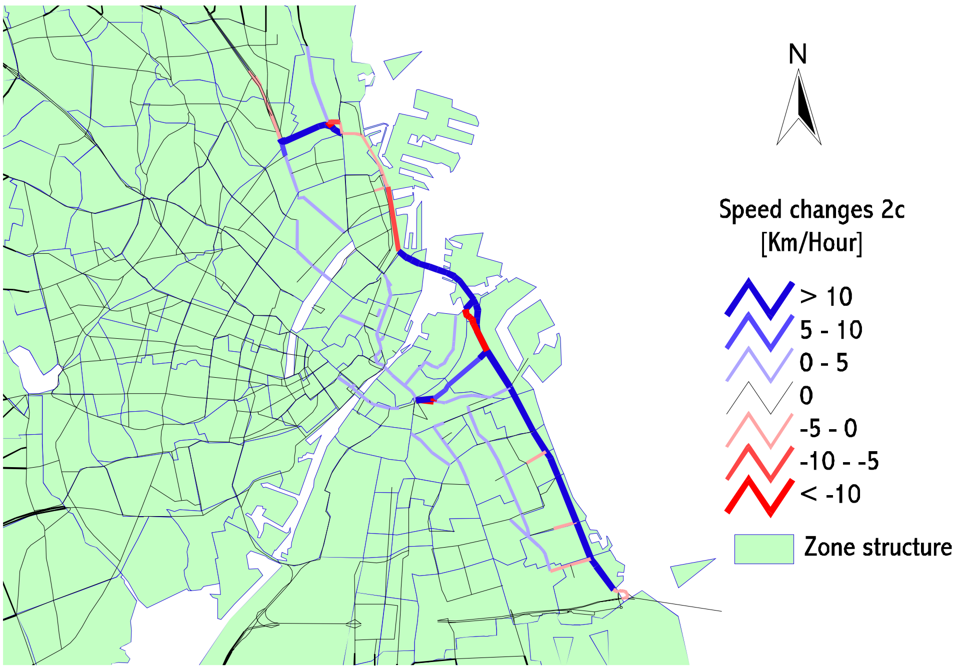


The scenario sensitivity graph reveals that the benefit distribution is different depending on whether the traffic calming scheme is comprised or not. In the cases without traffic calming (2c & 4a) the scenario scores are relatively evenly distributed around the base scenario, whereas in the traffic calming alternatives (2d & 4b) all scenario scores are higher than the score of the base scenario.

In general all project alternatives score best in the market-oriented scenario (MKT). This is also the scenario with the highest value of time (along with the Technological scenario (TEC)) but without the technological innovation influencing noise, accidents and emissions. As it appears the environmental benefits are limited in the project alternatives without traffic calming: This is seen by the fact that the sensitivity of the projects towards the intimate scenario is limited at the same time as the Technological scenario (TEC) scores almost as well as the Market-oriented scenario (MKT). If the environmental benefits were high, the Technological scenario would score lower and the Intimate scenario higher (and accordingly be more sensitive).

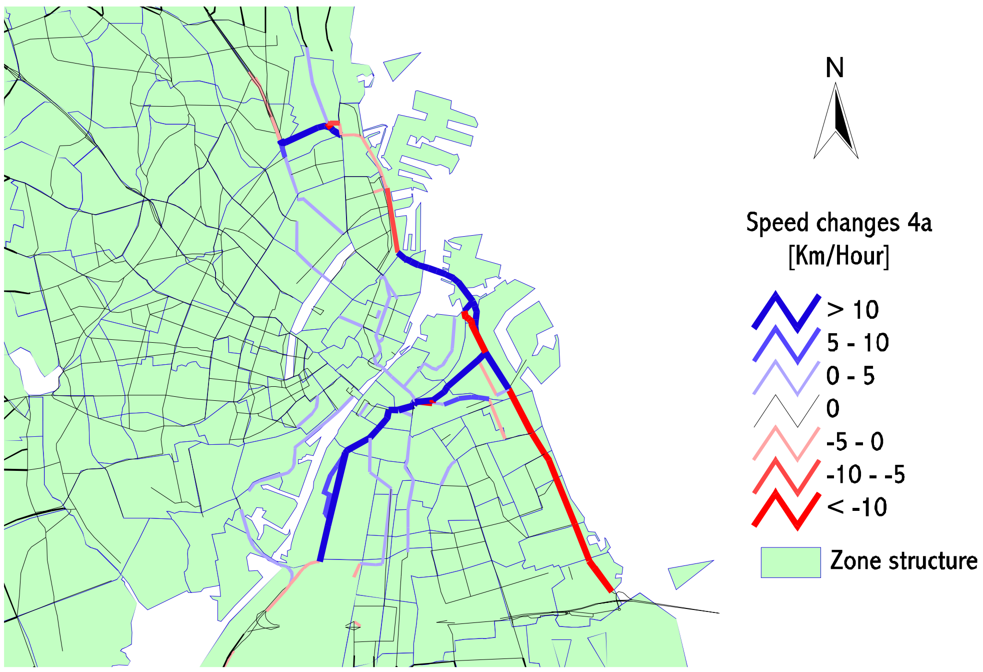
In general the travel time benefits (TTB) make up the majority of all benefits for all projects: ranging from 75% for the Ring road alternative in the Market-oriented scenario to 46% for the Amager Strandvej alternative with traffic calming (2d) in the Intimate scenario in 2010. These benefits stem mainly from the reductions in the flow on the main arterials and the subsequent increase in travel speed. The travel time benefits mainly stem from small time savings to a lot of travellers undertaking relatively short trips, rather than large savings to travellers on longer trips. From a study of the average travel speed on the main arterials one finds minor increases in speeds. These speed increases are in the range of 2-10 km/h.

Figure 54 **Speed changes on the main arterials in central Copenhagen for the Amager Strandvej alternative (2c).**



For the Ring road alternative the speed changes are as follows:

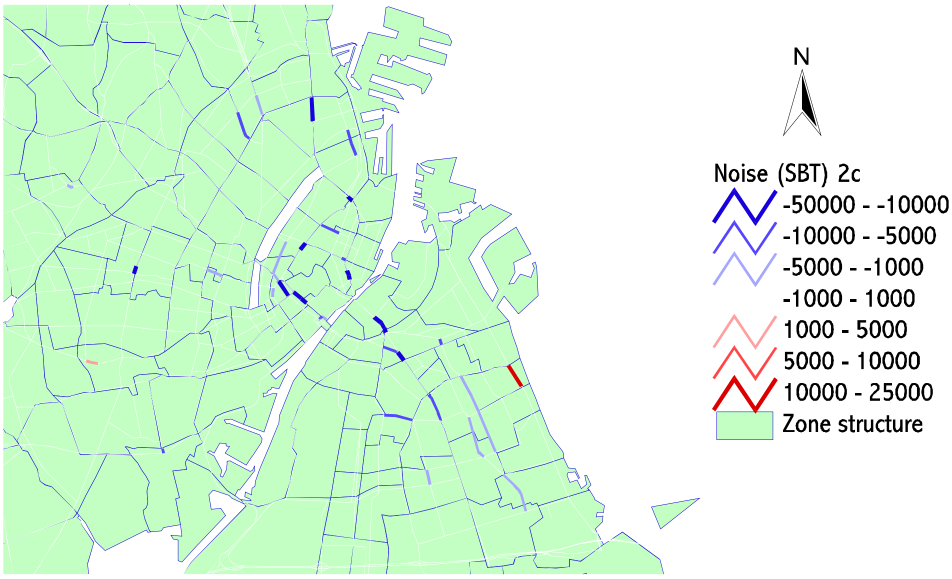
Figure 55 **Speed changes on the main arterials in central Copenhagen for the Ring road alternative (4a).**



In general the travel distances are also greater, which implies an increase in the vehicle operating cost (VOC). This is probably questionable as it seems that the increase in travel speed would make the operating costs decrease. The rather crude model used here is however not capable of taking this into consideration.

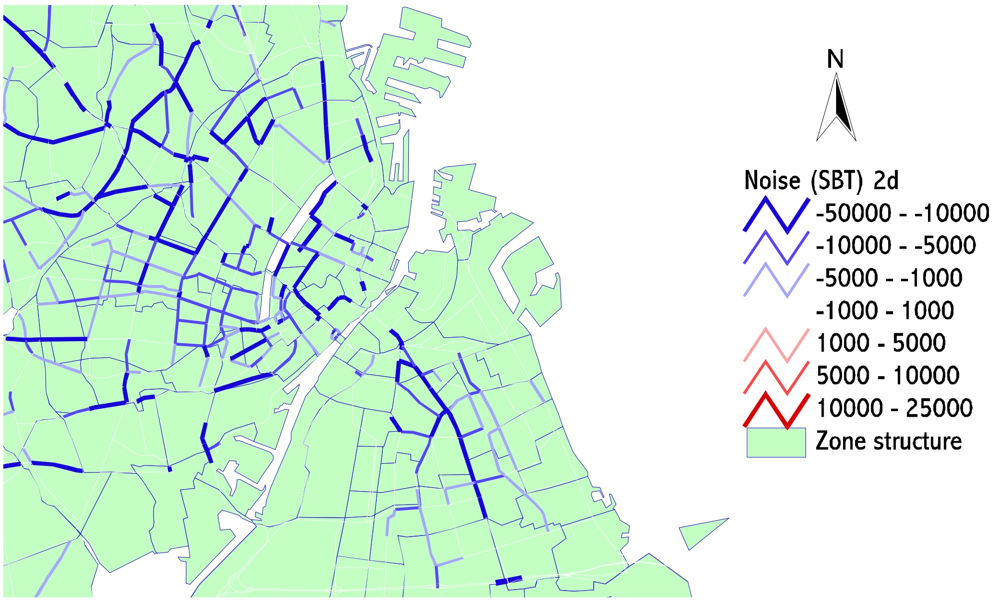
Another common feature is the reduction in the expected number of casualties. The number of link based accidents increase, but this increase is outweighed by the reduction in the expected number of intersection casualties due to the diversion of traffic. It has also been found that the local air pollution is a minor problem to these projects. The benefit elements are listed below:

Figure 56 **Noise level expressed through the SBT from each road link normalised by the length for the Amager Strandvej alternative (2c).**



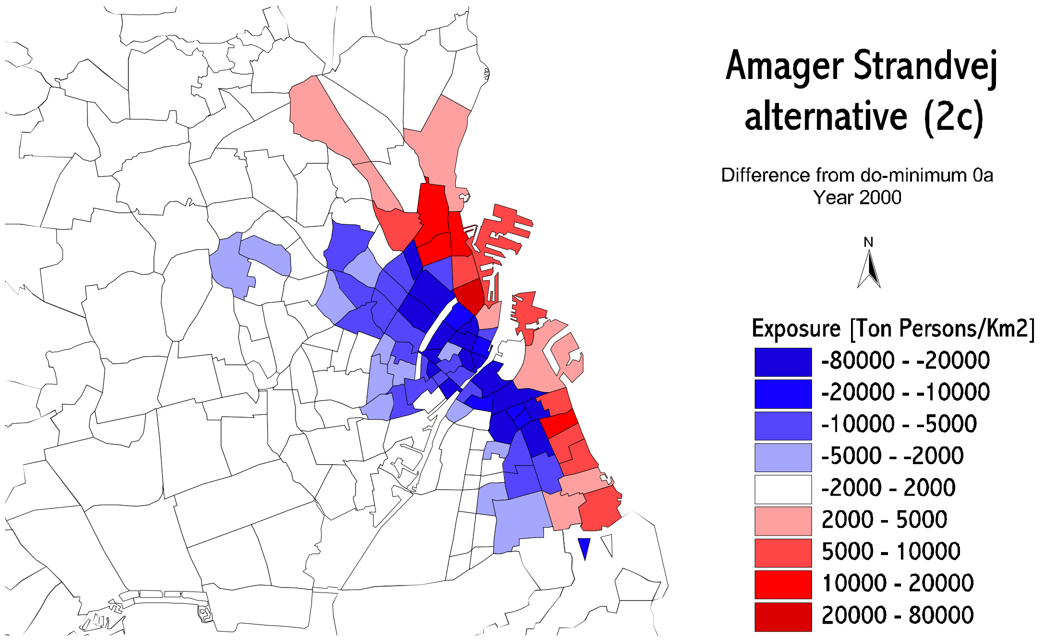
The level of noise is however substantially different. The Amager Strandvej alternative (2c) scores poorly mainly because of the insignificant reduction in the noise impact. The reduction of 10% in the average traffic flow in central Copenhagen is outweighed by the impact of the increase in travel speed. This also explains why the technological scenario scores so well for 2c. This scenario presumes that the noise problem is solved over time by technological innovation. The Ring road alternative (4a) does not experience quite such an increase in the noise impact. The main difference between the projects with and without traffic calming is mainly related to the noise impact.

Figure 57 **The change in the noise impact (SBT) for each road link normalised by the road length. The Amager Strandvej alternative with traffic calming in central Copenhagen (2d) compared to the do-minimum 0a so that the figure is directly comparable to the change seen in Figure 56**



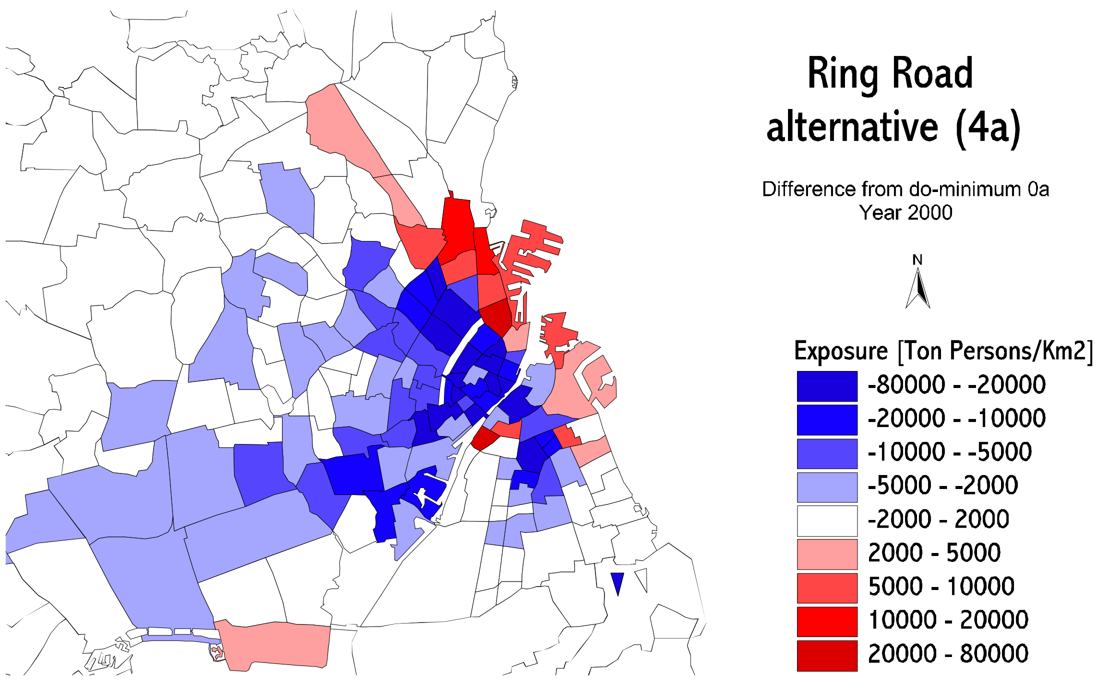
An interesting effect of the traffic calming in central Copenhagen is that it seems to increase the air pollution exposure mainly on Amager. It should be noted that these changes seem to be marginal. Even in the Intimate scenario (INT) where substantial emphasis is put on the local pollution the social cost only increases by approximately 2,5 million Dkr. for the Amager Strandvej alternative (2d) and 1 million for the Ring road alternative (4b) per year in 2030. This is marginal compared to the noise impact which amounts to around 100 and 150 million DKr per year in benefit respectively. As concerns the air pollution exposure it is noteworthy that the energy consumption (correlated with the emissions of CO_2) decreases even though the exposure (to NO_X, HC and CO) increases.

Figure 58 **The change in exposure from for the Amager Strandvej alternative (2c). The exposure is measured in Ton Persons per Km² per year.**



Another general issue concerns the redistribution of vehicles towards the larger roads following the traffic calming measures. This appears to be neutral with respect to the operation and maintenance cost (OMC), whereas the maintenance cost increases some without the traffic calming (above 0.4 million DKr. per year in 2010).

Figure 59 **The change in exposure from for the Ring road alternative (4a). The exposure is measured in Ton Persons per Km² per year.**



7.6.1 Assessment of the Amager Strandvej alternative (2c)

This project performs on the average even though it is in fact the cheapest of the alternative (see paragraph 7.2.3). This is mainly due to the relatively singular reliance on travel time benefits without these being substantially large. Furthermore there is an increase in the noise impact. The alternative is environmentally neutral with respect to air pollution exposure. It mainly redistributes the air pollution. It has some positive impact on the anticipated number of accidents. The project simply generates the wrong composition of benefits and too few of them.

This explains why the project scores well in the technological and market oriented scenarios with a high willingness to pay for travel time benefits, and poorly in the intimate scenario where the value of time decreases, and the value of noise increases. The Technological scenario scores best as the environmental problems are diminishing following the anticipated technological innovation.

7.6.2 Assessment of the Amager Strandvej alternative with traffic calming (2d)

Project 2d is a variant of 2c involving traffic calming of the medieval city centre of Copenhagen. The traffic calming involves a sufficiently large amount of extra benefits that the project is on the brink of becoming a feasible investment.

The air pollution exposure increases slightly. This is mainly due to increases in exposure on the Amager side along Amager Strandvej. The main environmental benefit does however stem from the noise and accident reductions. The travel time benefits are larger as increases in travel speed compared to not having traffic calming in central Copenhagen are larger. In a sense the traffic calming boosts the benefits when the do-minimum has not been re-estimated with respect to the modal split.

The technological scenario scores more poorly in this case as the noise problem over time diminishes due to technological innovation as set forward in the description. The base scenario scores poorest due to the medium value of travel time as well as the environment.

The market oriented scenario scores best due to combined benefit elements of the mobility (MOB), private financial attractiveness (PFA) and the other policy and planning issues (OTH) impacts which amount to 7.5% of the total benefits (16 million DKr. per year).

7.6.3 Assessment of the Ring road alternative (4a)

The composition of benefits for this project alternative is very similar to that of the Amager Strandvej alternative (2c). Only the construction costs are substantially greater, but the result is less robust. The additional benefit mainly stem from the travel time benefits to the local traffic using the upgraded Lossepladsvej as described above. Also the Ring road alternative (4a) generates no substantial benefits concerning noise, which makes it perform poorly in the environmentally sensitive scenarios. Essentially this means that the project is very sensitive towards the value of time as this is the sole real benefit element.

7.6.4 ASSESSMENT OF THE RING ROAD ALTERNATIVE WITH TRAFFIC CALMING (4B)

This project has in general the same benefit distribution as the Amager Strandvej alternative with traffic calming in central Copenhagen (2d). Only this project has the travel time benefits without relying solely on this single benefit item. The only dis-benefit for this project is an increase in the operations and maintenance costs (OMC) and the vehicle operating costs (VOC). The project is however also the most expensive (about 50% more expensive than 2c). But it should be kept in mind the type of vehicle operating cost model used in this study.

It is generally relatively robust with respect to the scenarios. The noise impact is quite substantial, but there is a slight increase in air pollution exposure. This also explains why the Intimate (INT) and the Supra-national (SUP) scenarios are performing relatively well. The Technological scenario is not performing so well in this scenario due to the reductions in noise benefits over time.

7.6.5 CONCLUDING REMARKS

As concerns the projects, none of them seems to be economically viable at this stage. As mentioned above they all generate substantial benefit. But the benefits are insufficient at present to justify the rather large investment in a tunnel. Also the projects are mainly relying on small travel time savings. This coincides with the findings of the traffic analysis in that the main users of the tunnel would be local and consist of short trips rather than long trips. Accordingly extra measures are required in central Copenhagen to generate some extra, mainly environmental benefits. It seems that the tunnel must be seen in connection with one or more other initiatives in order to be viable.

It is also noted that the inclusion of the maximum traffic scenario maximises the project benefits. This seems to imply that provided that this land-use development does not occur, the projects will perform worse than what is shown here.

There are a number of reservations concerning these conclusions which should be kept in mind when evaluating the results.

- There has been no explicit treatment of heavy vehicles.
  This may have a non-marginal influence on both the exposure and noise impacts. Especially in the case of 4a & 4b where a large amount of the harbour traffic can be expected to use the tunnel instead of passing through central Copenhagen (see Nielsen , O.A., Nielsen, E.R., Israelsen, T., 1998).

- The do-minimum 0b is a re-assignment of 0a
  The do-minimum 0b for 2d and 4b has not been assessed with respect to changes in modal split or land-use. Traffic calming in central Copenhagen without any Harbour Tunnel is likely to have a larger impact on the modal split than the Harbour Tunnel is expected to. Furhermore, it may cause businesses to relocate simply due to the reductions in mobility.

- The evaluation should be multi-modal
  The evaluation made here is based solely on a uni-modal basis as multi-modal traffic model results have not been available. A full-scale evaluation should include all modes as this may influence the results somewhat.

- The vehicle operating cost is a simple function of the transport work
  It seems appropriate to perform this analysis using a more sophisticated vehicle operating cost model, as the cars using the Harbour Tunnel will experience a more continuous flow at a higher speed, which is more energy efficient and which inflicts less wear and tear on the vehicle. This latter is important as the majority of the dis-benefits stem from vehicle operating cost, as this may not be the case.

- Some models are very crude
  This problems concerns specifically the noise model, the strategic mobility model ands the severance model. More sophisticated models are available, and as especially the noise impact seem to have quite an impact on project performance this would be appropriate.

It appears clear that the results found here cannot be used singularly to disregard a Harbour Tunnel at present. However there is a strong indication that it might be worth while waiting a number of years before making a final decision.

7.7 Conclusion following the use of the SEAM methodology

Even though this case study has been limited in scope, it has shown that the SEAM methodology brings forward elements of the project alternatives that would not otherwise have been acknowledged.

A sensitivity analysis based on the discount rate would generate a greater span compared to what the robustness measure provides. A change to a 4% discount rate will merely scale the score upwards, without providing much more information than what concerns the sensitivity of the projects with respect to the discount rate. A scenario-based analysis goes beyond this simple analysis by enveloping project uncertainties based on the appraisal approach and hereby illustrates project robustness.

The information provided is that of robustness under multiple futures indicating that with a given project it will perform well, but it does not provide specific information on exactly how well. It will offer a range within which the efficiency of the project will be for specific evaluation criteria.

As for the decision-making process it appears a useful tool for guidance. Public funds are scarce and it would appear easier to base a decision on what is sustainable in a future environment than to base a decision on a sensitivity analysis that provides little additional information to the single score.

It is interesting to note that the Supra-national scenario (SUP) has no specific implications for this type of local investment. The scenario is directed at investments that involve international issues or international transport, which is not found in this case study. Consequently the sensitivity towards this scenario is limited for all projects. In this case it resembles a down-scaled version of the Intimate scenario (INT). The difference from the Intimate scenario (INT) would however become more apparent in the case of a full-scale SEAM application involving also the traffic model.

The full implication of the SEAM methodology is hampered by the limited case study. It is hoped that this methodology will have the option of being tested on some future full-scale study, painting all development variables into a consistent set. This would involve painting of behavioural variables as well as variables for evaluation.

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8 CONCLUSIONS AND PERSPECTIVE

This thesis concerns the planning of large transport infrastructure investments. Special attention has been paid to the influence of uncertainty on project performance. The thesis consists of two parts: Part 1 forms the conceptual basis concerning uncertainty and scenario-based thinking whereas Part 2 is methodological and involves the presentation of a new scenario-based appraisal methodology – SEAM. The two parts interrelate as Part 1 ends up by outlining the prevailing modelling context, which in turn is the point of departure in Part 2 for the development of SEAM. In addition to the two parts, each of which is made up of four chapters, the thesis comprises three appendices that present information about detailed aspects relating to Part 2. To accompany and illustrate the SEAM methodology a comprehensive computer model has been developed.

The following provides some conclusions based on the work:

- Model uncertainty is often divided into exogenous and endogenous uncertainty. It has been shown that the endogenous model uncertainty can be categorised into objective, adaptive and subjective uncertainty. This reveals the influence that scenarios have on model uncertainty. On this basis a new conceptual model for the understanding of future uncertainty has been developed. This has been illustrated in Figure 3.9.
- On the basis of a review of appraisal methodologies, four stages in the development of appraisal methodologies have been indicated: the rational comprehensive planning approach, sensitivity testing, multi-criteria analysis and scenario painting. The latter stage in the development of appraisal methodologies along with the conceptual model for the understanding of future uncertainty sets out the background for a methodological formulation.
- A scenario-based appraisal methodology (SEAM) has been developed that incorporates the interdependencies between models and scenarios in the context of transport planning. The SEAM methodology acknowledges the influence from possible futures on the modelling at multiple levels and hereby performs a scenario based envelopment of the planning uncertainty. Specifically, the SEAM methodology contains guidelines for project evaluation in a context of scenario-based planning. The structure of SEAM is seen in Figure 5.1.
- In order to consider the SEAM methodology further, the methodology has been implemented as a comprehensive computer model for practical planning. The implementation and some case study results show that a scenario-based appraisal methodology can provide information that cannot be obtained by the use of more traditional appraisal methodologies.
- The SEAM methodology includes and utilises existing appraisal techniques as part of its scenario-based approach. By way of this inclusion, it has been illustrated in which ways the SEAM methodology can add to existing appraisal methodologies applied in transport planning. The existing methodologies comprise rational comprehensive planning, sensitivity testing and multi-criteria analysis.
- Some of the features of SEAM are made possible by the use of geographical information systems (GIS). This especially concerns the assessment of impacts with territorial affiliation. The exemplification of the application of GIS in the modelling has led to the development of a new type of exposure model. The model applies GIS tools for the conversion of link-based emissions into zone based pollu-

tion and further into a new type of exposure measure by way of socio-economic zone data. This use of exposure as the expression of the change in welfare is a more realistic measure for local pollution than the simple calculation of emissions.

- The potential of SEAM for the handling of a major infrastructure study has been examined by the use of the Copenhagen Harbour Tunnel case. It has been beyond the resource possibilities of the Ph.D.-study to consider and model all aspects of the project, but the calculations carried out show that a full SEAM analysis can improve the information about project consequences and their robustness considerably.

These conclusions open up for some interesting perspectives for future research in this field. Some relate to the application of the SEAM methodology in a full-scale analysis, others concern the further development of the methodology for a better understanding of the interdependencies in the transport planning. Some of the perspectives concerning the application of SEAM are:

- The level of integration between the stages in the modelling processes is today relatively limited. A scenario-based appraisal accentuates the need for a closer integration and understanding of the interdependencies of each model stage. This integrative modelling approach may be obtained through a painting of the entire planning system.
- The application of the SEAM methodology may prove helpful in the understanding of the interaction between transport modes. The consistent scenario painting of the multi-modal case will enable the determination of the critical success factors with respect to the potential of public transport.
- Through further research and the application of SEAM it is expected that a better understanding of model and project uncertainty will evolve. This will be possible through a horizontal comparison of parallel models, as illustrated in the computer version of SEAM.
- The further inclusion of sophisticated GIS-based modelling approaches will enhance the existing project evaluation techniques. The full potential of the application of GIS in transport planning has not yet been reached.
- The full range of models for impact assessment within the EUNET[2] frameworks will prove a strong tool in project appraisal in the future. Particularly, as methodologies evolve that clearly determine incidence groups in socio-economic evaluation. Further more, SEAM may be a useful tool for the handling and organising of the large amount of models, data and scenarios that are contained in the ongoing EU research project CODE-TEN[1].

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[2] Both EUNET and CODE-TEN are research projects with the Strategic Transport part of the European Unions 4th Framework Programme.

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APPENDIX A

1 GENERIC MULTI-MODAL EVALUATION FRAMEWORKS

Changes in the transport system by way of transport initiatives (investments, policies or technologies) are rarely isolated events that occur in secluded part of the transport systems. Changes for one mode may through ripple effects and changes in modal split influence the traffic intensity, traffic distribution in time, location patterns for businesses and residences, etc. as discussed in chapter 2.

Appraisal in such a planning system requires assessment of the impacts stemming from both the primary mode directly affected by the initiative as well as secondary modes which are affected as the system attempts to reach a state of equilibrium. These additional costs and benefits must be included in order to obtain a complete picture of the socio-economic impacts. To this end an evaluation framework constitutes the logical frame which should describe (CEC, 1996f);

- the relevant set of impacts (impact structure)
- how measure the impact variables (modelling or impact assessment approach)
- how to value or weigh the impacts together (appraisal method)
- how to present the results

Traditionally, evaluation frameworks have been uni-modal in the sense that they limited their scope to only one single mode, mainly because these evaluation frameworks were developed for the appraisal of inter-urban medium seized projects. The interaction between modes for inter-urban medium seized projects, is often limited and has thus been disregarded. Whether this will continue to be so is, however, questionable as large amounts of the European transport networks are becoming increasingly congested. Under congested conditions the influence even minor changes in the generalised travel cost have on the traffic pattern, may in fact be non-marginal.

This appendix is concerned with the setting up of multi-modal evaluation frameworks defining the relevant impacts and providing guidelines for the estimation of impact variables. The appraisal methods concerning valuation and weighing of impacts are discussed in chapter 4.

1.1 DEVELOPING MULTI-MODAL FRAMEWORKS

The European EURET concerted action 1.1 (CEC, 1996a-e) contains reviews of existing evaluation frameworks from European Union member states concerning road, rail, nodal point and waterway infrastructure. The findings showed that a range of impacts and appraisal methods are used by EU member states. The differences in appraisal methods were found to cover four groups (CEC, 1996f):

- Conventional cost-benefit analysis (CBA)
- Broad framework with emphasis on CBA
- Broad framework with emphasis on multi-criteria analysis (MCA)
- Mainly MCA with limited CBA

The range of impacts contained in selected European Union member states' national evaluation frameworks is listed in Table 1 below.

Table 48 **Impact variables used in the listed national evaluation frameworks concerning road infrastructure. The abbreviations cover DK- Denmark, F- France (F1 concerns inter-urban areas and F2 urban areas (CEC, 1996f)), D - Germany (D1 is a federal screening methodology (BVWP) and D2 is a socio-economic evaluation method (RAS-W) See e.g. Planco, 1992), GR - Greece, IR - Ireland, P - Portugal, UK - United Kingdom, I - Italy.**

IMPACT VARIABLE	DK	F_1	F_2	D_1	D_2	GR	IR	P	S	UK	I
Construction cost	✘			✘	✘	✘	✘	✘	✘	✘	✘
Operation and maintenance cost	✘			✘	✘	✘	✘	✘	✘	✘	✘
Vehicle operating cost	✘				✘	✘	✘	✘	✘	✘	✘
Travel time	✘			✘	✘	✘	✘	✘	✘	✘	✘
Accidents/safety/traffic safety	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘	✘
Noise/air pollution/environment	✘	✘	✘	✘	✘	✘		✘		✘	✘
Perceived barrier & risk	✘										
Economic development & territorial planning		✘									
User benefit		✘	✘								✘
Initial situation		✘	✘								
Modal effect/railway effect		✘		✘							
Employment & Public works		✘	✘	✘					✘		
Energy		✘	✘						✘		
Financial impact on public authority		✘									✘
CBA	✘	✘			✘		✘	✘	✘	✘	✘
Improvement domestic communication				✘							
Continuity/improve national routes			✘	✘							
Improve functioning built-up area			✘								
Reduction of traffic congestion			✘								
Land management			✘								
Costs			✘								
Transportation costs				✘							✘
Disruption due to construction										✘	
Spatial effects				✘							
Non-traffic related effects				✘							
Regional assessment				✘		✘					✘
Heritage/Conservation										✘	
Driver stress								✘		✘	
National defence						✘	✘				
Human environment							✘				
Transit role							✘	✘			
Physical planning								✘			
Severance				✘				✘		✘	
Visual impact								✘		✘	
Ecology				✘						✘	
Cultural heritage										✘	
Pedestrian amenity										✘	
Improved accessibility				✘							
Agriculture										✘	

The traditional transport economic impacts are marked with bold in Table 1. As seen a wide range of other impacts that address different planning objectives are included by the member states. The wording seems to indicate a great deal of overlap between the impacts. The list would accordingly not be applicable in its entirety for project appraisal. In general a well worked out evaluation frameworks should take account of four basic issues:

- Double counting
- Compliance with prevailing transport objectives
- Impact structure
  - Framework structure

Each of these issues will be discussed in the following paragraphs.

1.1.1 DOUBLE COUNTING

The problem of double counting is mostly relevant to cost-benefit analysis where the sum of impacts represent a social objective function. If impacts are correlated, impacts cannot be added directly. If they are, there is a risk of over-emphasising the importance of one or more impacts in the appraisal. By consciously avoiding double counting, the impacts will be genuinely additive and the practical application easier as the structure will avoid confusing decision-makers. Some multi-criteria methods are less sensitive towards this problem, even though clear unambiguous definitions of impacts ease the weighting of the impacts. In setting up the impact structure one should consequently aim at defining impacts that are perpendicular/orthogonal in which case costs and benefits may simply be summarised in a vertical aggregation.

1.1.2 COMPLIANCE WITH PREVAILING TRANSPORT OBJECTIVES

Evaluation frameworks should be developed in correspondence with the political planning objectives. The success of an appraisal depends among other things on whether the analysis reflects decision-maker requirements. Transport objectives are changing with the societal conditions and as a function of the planning level. This is observed as some impacts get increased or reduced attention depending on whether the planning level is local, regional, national or supra national. As an example the EU transport objectives involve issues concerning social equity and cohesion, which are rarely relevant on a regional level and which have traditionally not been included in the majority of the national evaluation frameworks. Strategic issues are becoming of increasing importance to national governments in the European Union. The EU transport objectives as compiled by Leleur et al. (1998) are:

2. Maximise transport efficiency (improved performance and development of each mode and their integration into a coherent transport system, socio-economic feasibility, improved comfort and level of service, etc.)

3. Improve transport safety (vehicle and infrastructure safety, dangerous transports, driver education and behaviour, socio-economic feasibility, etc.)

4. Contribute to environmental improvement (local air pollution, noise, severance, quality of built environment and landscape, socio-economic feasibility, etc.)

5. Improve strategic mobility (accessibility and European networks, nodal points, peripheral areas, missing links, etc.)

6. Contribute to strategic environmental improvement (greenhouse gases, ecological damage, use of energy resources, etc.)

7. Contribute to strategic economic development (regional economics, spatial planning considerations, etc.)

8. Contribute to technology development (innovation in transport technology and standards, telematics, etc.)

9. Contribute to implementation of Single Market (fair competition and pricing, technical harmonisation, etc.)

10. Contribute to social dimension (equity, working conditions, "Citizens' Network", people with reduced mobility, etc.)

11. Contribute to external dimension (network development and integration, agreements, technical assistance and co-operation, etc.)

The objectives as listed may be divided into three main groups according to the planning domain (Leleur et al., 1998).

- General design objectives about efficiency, safety and environment.
- Strategic objectives about strategic mobility, strategic environment and strategic economic development
  - General policy objectives

Leleur et al. (1998) states that "*It should be noted that these objectives are primarily set out at the Trans-national European level and that there can be agreement/disagreement with specific national and/or local trans-port objectives. Similarly, objectives could be set up for the national and regional/local level. Differences will then occur as: 1) lack of congruence (non-similar objective definitions) for the specific objective, and with similar objective definitions as: 2) different preference strength.*"

1.1.3 IMPACT STRUCTURE

The third issue concerns the development an impact structure that is both theoretically acceptable as well as practically implementable. In the EURET study a set of desirable characteristics of a multi-modal evaluation framework structure was defined (CEC, 1994)

- Common evaluation measures across different modes
- Comprehensiveness
  - Efficiency in terms of data use and analysis approach

Where the double counting issue concerned vertical aggregation, the common evaluation measures relate to the horizontal aggregation of impacts across modes. This aims at easing the comparability between modes. An example of such a horizontal aggregation is the computation of the total travel time savings in the transport system. Comprehensiveness is concerned with covering as wide a range of impacts as it appears feasible and possible in order to cover as many of the transport objectives as possible. Efficiency is about the modelling approaches, in terms of adjusting the data requirements to the planning and decision problem.

A fourth issue concerns the transparency of the impact structure. Transparency with respect to the clarification of incidence groups: Who are the beneficiaries and who are the bearers of cost following an infrastructure development. Some project may prove counter productive with respect to certain planning objectives even though this is not obvious from traditional appraisal.

1.1.4 FRAMEWORK STRUCTURE

Multi-modal evaluation frameworks can be developed according to two templates:

- Integrated approach
  - Segregated approach

The integrated approach involves a 'tailor-made' approach to certain planning problems. For instance frameworks for the competition between road and rail, high-speed rail and air transport etc. Alternatively this approach would involve the impacts to all modes. The modes unaffected by the initiative would get zero benefit for all impacts. This approach has the downside of being overly comprehensive and rigid, as it needs to involve any possible changes on any possible competing mode. This possibility is accordingly disregarded as option.

The segregated approach on the other hand involves a step-wise approach where a primary framework is determined by the primary mode or infrastructure at which the transport initiative is addressed. Subsequently, secondary frameworks are included sequentially when required according to the planning problem. This approach ensures flexibility of the evaluation frameworks.

1.2 MULTI-MODAL FRAMEWORK REVIEW

Different studies have addressed the issues concerning the development of multi-modal evaluation frameworks in different ways. Below a short review of three multi-modal framework studies is found, namely the European EURET and APAS/Road3 studies and the American NCHRP study. A more detailed review of the EUNET frameworks is found in section 1.3.

1.2.1 THE EURET STUDY

The EURET concerted action 1.1 study (CEC, 1996a-e) consisted of several subgroups which for each their mode provided a series of mode specific evaluation frameworks for medium seized projects. The main structure is common to all modes which divided the impacts into two main groups.

- Mandatory impacts
  - Discretionary impacts

Collectively, the studies made up a segregated multi-modal evaluation framework. In Table 2 below the evaluation framework for inter-urban road infrastructure is seen.

Table 49 Valuation and measurement methods in the EURET 1.1 framework for road projects (RP = Revealed Preference, SP = Stated Preference, WTP = Willingness To Pay, CV = Contingent Valuation)

MANDATORY IMPACTS	VALUATION/MEASUREMENT METHODS AVAILABLE
Construction	Factor cost, market prices adjusted for distortions and/or strategic environmental reasons, shadow prices
Maintenance	As construction
Vehicle operating costs	As construction
Travel time savings	Work time: RP, wage rates and resource costs Non-work time: WTP from RP, CV, SP
Safety	Indirect costs: human capital, WTP to avoid risk Direct costs: resource costs of medical and emergency services Non-economic costs: imputed value for pain and suffering
Local environment	Air pollution: SP, indirect methods (dose response) Noise: RP (hedonic pricing), SP, CV Amenity/landscape: CV, SP, travel cost method, expert judgement Severance: RP, SP, ranked scales
DISCRETIONARY IMPACTS	
Strategic environment	Political judgement, descriptive methods, targets
Economic development and planning	Net employment, expert/professional judgement, political objectives
Strategic policy	Indication of positive, negative, neutral effect

As concerns the evaluation it can be noted that the mandatory impacts have a 'local' orientation while the discretionary impacts have a 'non-local' orientation. Thus their valuation/measurement is less developed and more 'subjective' compared to the valuation/measurement of the mandatory impacts (Leleur et al., 1997).

1.2.2 THE APAS/ROAD3 STUDY

The APAS/Road3 study (CEC, 1996f) was concerned only with the evaluation of road infrastructure and ATT (Advanced Transport Telematics) projects. The frameworks concern large, medium-sized and small projects in urban as well as inter-urban environments. The reason this uni-modal framework has been included in the review pertains to the fact that this study used the EURET impact structure concerning road infrastructure as a stepping stone for refinement of the impact structure. The APAS/Road3 operates with three main impacts groups.

- Core impacts
- Non-core (non-strategic) impacts
- Non-core (strategic) impacts

The refinement and development concerned the 'soft' mode specific impacts in the non-core (non-strategic) impact group and a further development and specification of the strategic impacts in the non-core (strategic) impact group.

Table 50 APAS/Road3 framework for road infrastructure projects (+ = Only relevant for road infrastructure projects, - = Only relevant for ATT projects, CBA = Cost Benefit Analysis, MCA = Multi Criteria Analysis, ( ) = To be judged in the individual evaluation cases)

IMPACTS	ROAD INFRASTRUCTURE PROJECT TYPES	
	INTER-URBAN	URBAN

		Large	Medium -sized	Small	Large	Medium -sized	Small
Core impacts							
1.	Investment costs	CBA	CBA	CBA	CBA	CBA	CBA
2.	System operating and maintenance costs	CBA	CBA	CBA	CBA	CBA	CBA
3.	Vehicle operating costs	CBA	CBA	CBA	CBA	CBA	CBA
4.	Travel time savings	CBA	CBA	CBA	CBA	CBA	CBA
5.	Safety	CBA	CBA	CBA	CBA	CBA	CBA
6.	Local environment (air pollution, noise, severance)	CBA	CBA	CBA	CBA	CBA	CBA
Non-core (non-strategic) impacts							
7.	Driver convenience (comfort, stress)	MCA	MCA	MCA	MCA	MCA	MCA
8.	Public transport service level				MCA	MCA	MCA
9.	Urban quality & landscape	MCA	MCA	MCA	MCA	MCA	MCA
10.	Information	-	-	-	-	-	-
11.	Improved enforcement	-	-	-	-	-	-
Non-core (strategic) impacts							
12.	Strategic mobility (accessibility and networks)	MCA	(MCA)		MCA	(MCA)	
13.	Strategic environment (greenhouse gases, ecological damage)	MCA	(MCA)		MCA	(MCA)	
14.	Strategic economic development (regional effects)	MCA	(MCA)		MCA	(MCA)	
15.	Technology development	-	-		-	-	
16.	Other strategic policy and planning impacts	MCA	(MCA)		MCA	(MCA)	

The APAS/Road3 study involves, like the EURET study, a stepwise procedure. A minimum evaluation includes the core impacts (mandatory in the case of EURET), whereas the others may be added if possible or relevant. Furthermore, the APAS/Road3 study specifically suggests an evaluation approach made up of cost benefit analysis (CBA) and of multi-criteria analysis (MCA). The division was made due to the problems of properly assessing the economic value of the non-core impacts.

The project appraisal is consequently a mainly MCA based approach with an element of CBA. Project efficiency measured by the CBA, which will then enter as a single impact into a broader MCA approach. This approach is discussed in more detail in chapter 4.

1.2.3 The NCHRP approach

In America the Intermodal Surface Transportation Efficiency Act (ISTEA) was passed into law in 1992. The act governs how the U.S. government spends money on transport infrastructure. ISTEA requires of local government applying for governmental funding to present a plan for a transport system involving all modes. The approaches used by local governments to comply with this requirement were not uniform in any way. It was recognised that a common system for multi-modal project evaluation was required. A NCHRP study was inaugurated with this purpose (Rutherford, S. et al., 1994). The conclusion suggests an approach similar to the guidelines of the US Department of Transportation as seen below.

Table 51 Classification of criteria categories listed with typical criteria for definition (Compiled from Rutherford et al., 1994)).

GENERAL CATEGORY	CRITERIA
1. Transportation System Performance	Highway level of service (A-F)
2. Mobility	Mobility options, Improved movement of people
3. Accessibility	% within 30 minutes, Transit and highway speeds
4. System Development, Co-ordination and Integration	Terminal transitions, Regional importance, projects in existing plans
5. Land Use	Compatibility with land use plans, Growth inducement
6. Freight	Reduced gods movement costs
7. Socio-economic	Homes or businesses displaced. Maximise economic benefit, Historic impacts, Construction employment
8. Environmental	Air quality, noise, sensitive areas (% reduction of emissions, Areas with 80 dB or more)
9. Energy	Energy consumption
10. Safety and security	Annual accidents by mode, Safety ratings
11. Equity	Equity of benefit and burden
12. Costs and cost effectiveness	Travel time savings, Vehicle operating costs, Operation and maintenance cost, capital costs, Net benefits, Total cost per daily person miles of travel, Capital cost per hour of daily travel time savings, Additional jobs accessible within 30 minutes per $1000 project cost
13. Financial Arrangements	Funds required, Funding feasibility, Build/operate, Public/private sources
14. Institutional factors	Ease of staging and expansion, Non-implementing agency support
15. Other	Fatal flaw, Right of way opportunities, Enforcement, Recreation

Rutherford et al. (1994) note that (i) there is a substantial need for increased understanding of what has here been termed strategic mobility (multi-modal mobility) and (ii) the tables reveal that the performance measures may be redundant (involve double counting).

1.3 THE EUNET GENERIC MULTI-MODAL FRAMEWORKS

The EUNET study is the most recent study funded by the European Commission that involves the specification of an evaluation procedure.

The EURET Concerted Action 1.1 Study provided a consistent collection of European evaluation frameworks or methodologies concerning road, railway, waterway and inter-modal investments (CEC, 1996a, CEC, 1996b, CEC, 1996c, CEC, 1996d, CEC, 1996e). These reports attempted to clarify impacts and their incidence for each mode. The EUNET study is specifically multi-modal, aiming at developing a pan-European multi-modal evaluation methodology with a consistent determination of incidence groups (CEC, 1996f). The main emphasis is on passenger transport, but goods transport is equally included. The modes included in this presentation of the EUNET frameworks are:

- Roads
  Inter-urban car, lorry and bus transportation

- Railways
  Inter-urban rail, high speed rail

- Airports
  Major airport development or extension

- Inter-modal
  Major inter-modal infrastructure development or extension

Waterways and short-sea shipping are also included in the EUNET frameworks but these are not discussed here. Airports and inter-modal infrastructure are both nodal investments that facilitate inter-change between the modes. They are not only important for the efficiency of the entire transport system but equally constitute infrastructure that is quite different from traditional link based transport infrastructure.

Airports have been separated from the other nodal frameworks due to the importance of air transport for long distance travel and due to the specifics concerning air transport operations:

- Airports are a politically viewed as a special type of inter-modal infrastructure
  Due to their sheer size they receive significant national and international attention that justify a special treatment

- Passenger definition and descriptions traditions are different
  A traditional division of travellers relates to the trip purpose, such as working, commuting and leisure trips. The percentage of 'white collar' business trips is far greater than with any other mode.

- Airports are nodal points in which the capacity of departure is limited.
  Airport departure capacity is dependent on the efficiency of the taxiing routes, the number of runways and the safety systems that guide them. This is only also relevant to railway stations that are dealt with in connection to the railways, less it is an investment solely relating to the terminal which is an inter-modal investment.

Coaches play a vital role in regional passenger transport in some areas, but coaches are disregarded in this context.

1.3.1 Determination of framework variants

Transport initiatives (TI) can be seen as spanning a range of mode orientations (road, rail, waterways, air, inter-modal), domain orientations (infrastructure, ATT, policy), planning contexts (urban, inter-urban) and geographic scales (small, medium-sized, large) (Leleur et al., 1998). Each combination of these requires a framework variant (FV). This leads to the following combination of framework variants.

Table 52 A specific TI is determined by mode orientation (road = 1, rail = 2, air = 3, inter-modal = 4). It may also be divided by domain orientation (infrastructure, ATT, policy), but only the infrastructure part is reproduced here (based on Leleur et al., 1998).

Mode	Infrastructure
Road	TI 11
Rail	TI 21
Air	TI 31

As concerns the structuring of each FV, it is important to adopt a subdivision of impacts, which complies with the set of transport initiatives as listed previously. If the term core (from the APAS/Road3 study) is adopted as an impact cate-gory of basic importance for many transport initiatives. The term non-core, non-strategic is defined to comprise 'soft' mode specific characteris-tics. This leads to the fol-lowing generic impact subdivision as used in EUNET with the strategic impacts split into territorial and non-territorial impacts.

- Core impacts
  Basic impacts (A-impacts)

- Non-core, non-strategic impacts
  Mode specific impacts (B-impacts)

- Strategic, territorial impacts
  Impacts with territorial affiliation (C-impacts)

- Strategic, non-territorial impacts
  Other strategic impacts with no territorial affiliation (D-impacts)

These four impact categories (roughly following: hard & soft non-strategic and hard & soft strategic impacts) constitute a generic framework with A, B, C and D impacts. This framework accommodates the current development of making use of GIS in transport evaluation modelling. Territorial affiliation refers to impacts whose effects are external with respect to the transport network and the transport flow.

1.3.2 EVALUATION STUDY APPROACH

In the application of segregated evaluation frameworks of the type developed in EUNET the issue concerning the selection of primary mode is highly important. As will be noted, the C-impacts are the same for all frameworks and nearly all the D-impacts are common. Of the C-impacts at least the strategic mobility and strategic economic development are multi-modal in the sense that they do not relate to any specific mode. They are concerned with either the efficiency of the transport system (strategic mobility) (see e.g. Kronbak, J., 1998) or the regional/national economic effects (strategic economic development). As concerns the D-impacts, they are initiative specific in the sense that they only relate to the primary mode. As a rule, the C- and D-impacts are not additive across modes (with the possible exception of strategic environment depending on the modelling approach).

1.3.3 A NOTE ON TERRITORIAL IMPACTS

The division of the strategic impacts into two groups is a logical development following the increasing use of geographical information systems (GIS) for impact assessment (see e.g. Batty, M., 1993; Rehfeld, C., 1995; Nielsen, O.A. & Rehfeld, C., 1995; Rehfeld, C., 1997, Kronbak, J., 1998). Impacts with territorial affiliation relate to different spatial aggregation levels from the very local noise impact to the trans-national accessibility models. Impacts with territorial affiliation may benefit from being embedded in a GIS modelling structure. The territorial impacts ordered by their level of aggregation is seen in Table 6 below:

Table 53 The transport external impacts listed by their territorial affiliation, the aggregation level of the impact, the impact measure and the possible modelling approach for each of the impacts.

TRANSPORT EXTERNAL EFFECTS			
AGGREGATION LEVEL	IMPACT	POSSIBLE IMPACT MEASURE	POSSIBLE MODELLING APPROACH
Local	Noise	SBT	GIS-based (Rehfeld, C., 1995)
	Air Pollution	Kg/Inhab./year	GIS-based (Rehfeld, C., 1997, See appendix B)
	Severance	BRBT	GIS-based (Rehfeld, C., 1995), severance number
	Ecological impact	Descriptive	Point scale (-5,..,0,..,+5)
	Visual impact	Km^2, descriptive	GIS-based, point scale (-5,..,0,..,+5)
National	Mobility	Pointer, UTS	GIS-based (Chatelus, G. & Ulied, A., 1996; Kronbak, J., 1998)
	Land-use	Descriptive	GIS-Presentation, point scale (-5,..,0,..,+5) (Therivel, R. & Partidario, M.R., 1996)
	Economic development	Economic benefit	GIS-presentation, point scale (-5,..,0,..,+5), proxy variable (Christensen et al., 1990)
European Union	Mobility	Pointer, UTS	GIS-based (Chatelus, G. & Ulied, A., 1996; Kronbak, J., 1998)
	Strategic environ-ment (Energy consumption)	Total emissions (Tonnes/year)	GIS-presentation, energy consumption by region or population
	Economic development	Economic	GIS-presentation, point scale (-5,..,0,..,+5), proxy variable (Christensen et al., 1990)
	Equity, Cohesion, Harmonisation	Descriptive, UTS	GIS-based, descriptive, point-scale (-5,..,0,..,+5)
Global	Strategic environ-ment (Energy consumption)	Total emissions (Ton/year)	GIS-presentation, energy consumption be region or population

The intervals in the division of impact according to aggregation level should not be too narrow. The risk of double counting will significantly increase as the intervals decrease. The level of territorial accuracy is inversely proportional to the aggregation level from which the consequence is reviewed. It is also noted that as aggregation level increases the impact modelling approach tends to be increasingly descriptive. Despite significant research the global impacts are still poorly understood and virtually no practical modelling approaches are available.

1.4 THE EUNET FRAMEWORKS

The EUNET frameworks are made up of two main tables setting up the framework structure. One table is concerned with relevant variables for each impact whereas the other is concerned with the measurement and valuation methods. Only the tables concerned with variables are reproduced here.

1.4.1 ROAD INFRASTRUCTURE FRAMEWORK

Table 54 EUNET framework for inter-urban road infrastructure projects: Variables (Leleur et al., 1998)

FV 11-I LMS Impacts		Road infrastructure project types VARIABLES Inter-urban
Core impacts		
A1	Investment costs	Materials, labour, land and property acquisition (including compensation)
A2	System operating and maintenance costs	Structural repairs, carriageway delineation, signing, enforcement of traffic regulations
A3	Vehicle operating costs	Fuel and oil consumption, tyre wear, vehicle maintenance, depreciation
A4	Travel time benefits	Working time, home-work time and leisure time
A5	Safety	Fatalities, severe and slight injuries, damage only accidents
A6	Local environment	Noise and air pollution, severance
Non-core, non-strategic impacts		
B1	Driver convenience	Comfort, stress, smoothness
B2	Urban quality & landscape	Visual environment
Strategic, territorial impacts		
C1	Strategic mobility	Accessibility and networks
C2	Strategic environment	Greenhouse effect, strategic atmospheric pollution, loss and damage of ecological, historical, archaeological and scientific sites, energy consumption, natural resources
C3	Strategic economic development	Land use, economic development, employment impact
Strategic, non-territorial impacts		
D1	Private financial attractiveness	Financial internal rate of return, net present value or equal
D2	Other strategic policy and planning impacts	Conformity to other strategic policy and planning concerns

1.4.2 RAIL INFRASTRUCTURE FRAMEWORK

Table 55 EUNET framework for inter-urban rail infrastructure projects: Variables (Leleur et al., 1998).

FV 21-I LMS Impacts		Railway infrastructure project types VARIABLES Inter-urban
Core impacts		
A1	Investment costs	Materials, labour, land and property acquisition (including compensation), rolling stock
A2	System operating and maintenance costs	Track and structure repair, signalling, rolling stock
A3	Train operating costs	Fuel/power, crew costs, terminal costs, track costs, depreciation and interest, train planning, administration, advertising and publicity
A4	Generalised net user benefits	Time savings and quality effects to working, home-work and leisure trips and freight transport, change in fare and shipment prices
A5	Safety	Fatalities, severe and slight injuries, damage only accidents
A6	Local environment	Noise and air pollution, severance, vibration
A7	Revenue	Change in income on passengers and freight
Non-core, non-strategic impacts		
B1	Public transport facilities	Perception of the facilities while arriving, changing and waiting
B2	Urban quality & landscape	Visual environment
Strategic, territorial impacts		
C1	Strategic mobility	Accessibility and networks
C2	Strategic environment	Greenhouse effect, strategic atmospheric pollution, loss and damage of ecological, historical, archeological and scientific sites, energy consumption, natural resources
C3	Strategic economic development	Land use, economic development, employment impact
Strategic, non-territorial impacts		
D1	Private financial attractiveness	Financial internal rate of return, net present value or equal
D2	Technology development	New technology
D3	Other strategic policy and planning impacts	Conformity to other strategic policy and planning concerns

1.4.3 INTER-MODAL INFRASTRUCTURE FRAMEWORK

Table 56 EUNET framework for inter-modal projects (Leleur et al., 1998).

FV 51-I LMS		Inter-modal projects VARIABLES
Impacts		**Inter-Urban**
Core impacts		
A1	Investment costs	Materials, labour, land and property acquisition (including compensation), construction infrastructure, plant & machinery, goods handling sorting equipment, special vehicles or boats, telematics (hardware and software), telecommunications etc.
A2	System operating and maintenance costs	Improved nodal centre operating efficiency
A3	Vehicle operating & maintenance costs	Changes in costs of ownership and operation incl. Depreciation, fuel consumption, etc.
A4	Generalised net user benefits	Time savings and quality effects to working, home-work and leisure trips and freight transports (access time, waiting time, handling time), change in fare and shipment prices
A5	Safety	Fatalities, severe and slight injuries, damage only accidents
A6	Local environment	Noise, air pollution
A7	Revenue	Income from sales of services, rent of facilities, etc.
Non-core, non-strategic impacts		
B1	Passenger comfort	Perception of conditions for changing (transit time, distance, comfort, accessibility), facilities while waiting, passability
B2	Urban quality & landscape	Visual environment
B2	Goods handling	Perception of facilities for goods and express freight
Strategic, territorial impacts		
C1	Strategic mobility	Accessibility and networks
C2	Strategic territorial environment	Loss and damage of ecological, historical and archaeological and scientific sites, natural resources
C3	Strategic economic development	Land use, economic development, employment impact (direct employment at node, construction employment at node, generated employment in locality)
Strategic, non-territorial impacts		
D1	Private financial attractiveness	Financial internal rate of return, net present value or equal
D2	Technology development	New technology
D3	Other strategic policy and planning impacts	Conformity to larger sector plans, peripherality/distribution, cross border transit

1.4.4 AIRPORT DEVELOPMENT AND EXTENSION FRAMEWORK

Table 57 EUNET framework for airport development and extension: Variables (Leleur et al., 1998).

FV 41-I LM Impacts		Airport development and extension VARIABLES Inter-urban
Core impacts		
A1	Investment costs	Materials, labour, land and property acquisition (including compensation), equipment
A2	System operating and maintenance costs	Repair work and current maintenance, traffic control, staff costs and surveillance
A3	Airline operating and maintenance costs	Fuel, crew costs, terminal costs, maintenance, depreciation and interest, planning, administration, advertising and publicity
A4	Generalised net user benefits	Time savings and quality effects to business and leisure trips and freight transports (access time to airport, handling time, holding/taxiing time), change in fare and shipment prices
A5	Safety	Accident statistics, types of safety systems
A6	Local environment	Noise and air pollution, soil and ground water
A7	Revenue	Change in income on passengers and freight
Non-core, non-strategic impacts		
B1	Passenger comfort	Perception of the nodal point facilities while arriving, in transfer and waiting
B2	Urban quality & landscape	Visual environment
B3	Goods handling	Perception of facilities for goods and express freight
Strategic, territorial impacts		
C1	Strategic mobility	Accessibility and networks
C2	Strategic environment	Greenhouse effect, strategic atmospheric pollution, loss and damage of ecological, historical, archaeological and scientific sites, energy consumption, natural resources
C3	Strategic economic development	Land use, economic development, employment impact
Strategic, non-territorial impacts		
D1	Private financial attractiveness	Financial internal rate of return, net present value or equal
D2	Technology development	New technology
D3	Other strategic policy and planning impacts	Conformity to other strategic policy and planning concerns (CTP deregulation, etc.)

1.5 DETERMINATION OF INCIDENCE GROUPS

An incidence group comprises either a group of people or an organisation (including the government) which is either participant in the transport sector or affected by the external effects of the transport sector. The specification of these incidence groups is as mentioned becoming increasingly important in project appraisal. Both because of the importance of being able to clarify whom the beneficiaries and the bearers of cost stemming from an initiative are but equally well to due to the intensifying deregulation of the transport sector following EC directive 91/440. The incidence groups may in general be divided into two main categories:

- Transport internal
- Transport external

Each of these will be discussed in the following

1.5.1 TRANSPORT INTERNAL

It is not only the qualities of the different transport modes that distinguish them. The organisation around each mode of transportation is quite different. Several actors are involved, and surprisingly enough road transport may in fact be regarded as a special and simpler case of rail transport. In rail passenger transport there are three incidence groups:

- The provider (of infrastructure)
- The operator (of the train service)
- The traveller (on the train)

The provider maintains the rail infrastructure, the operator runs the trains on the rail tracks and the traveller pays for the service (the government may include some subsidies). It is important to specify the boundaries between the railway operator and the infrastructure provider in an evaluation. The cost components that concern the infrastructure and those that concern the train operations are not uniformly distributed between rolling stock and fixed installations. Special dependencies between investments in infrastructure and rolling stock exist which makes the organisational set-ups different for different countries (Bruzelius, N., Jensen, A. & Sjöstedt, L., 1996). The freedom of choice of rolling stock of the operator is in fact limited by the choice of the provider concerning e.g. signalling system. Some important notes of concern are:

- The spatial dissipation is limited to the railway network owned by the provider
- The choice in rolling stock is governed by the providers choice in track width, power solution, security system, etc.
- The potential number of passengers is influenced by the station layout and interchange possibilities, which may be owned by the provider.
- The efficiency (regularity, delays, etc.) of the train system is governed by the train security system, block distance, etc., which may be owned by the provider.

Consequently, the cost components relating to the maintenance and operating have been divided into one concerning the infrastructure and another concerning the train operations. No distinction has been made between the investment costs of the provider and the operator due to the special dependencies between investments in infrastructure and rolling stock.

Furthermore, as the traveller pays a fee to an operator for the transport service there may accrue benefits beyond the simple transfer payment between two incidence groups (CEC, 1996b; Roy, R., 1996).

Dependencies as those indicated are more vague in the road sector. In light of this discussion road transport is a special case as the operator and the traveller is one and the same. Consequently, no transfer payments do occur in the simple case. In the case of the review of a toll road, the structure of the rail framework must be applied in order to accommodate the possible revenue benefit.

As concerns goods transport the picture gets increasingly complicated as an additional incidence group appear. Shippers comprise a very broad group demanding goods to be transported without necessarily being operators themselves.

Incidence groups have in earlier socio-economic studies to varying degrees been apparent. The London airport study, including only social costs, attempted to clarify whom the gainers and losers were. This was equally attempted in the Mexico City airport study (De Neufville, R. & Keeney, R.L., 1974). For the siting of the third London airport the social costs related to the incidence groups listed below (Bruzelius, N., Jensen, A. & Sjöstedt, L., 1996):

Table 58 Social benefit elements included in the cost-benefit study of 1971, concerning the location of a third London airport (Bruzelius, N., Jensen, A. & Sjöstedt, L., 1996, p.203).

SOCIAL BENEFIT ELEMENTS	INCIDENCE GROUP	DESCRIPTION
Airspace movement costs (AMC)	Users	Change in the average travel time in the air dependent on location (Business, leisure, children, adult accompanying)
Passenger user costs (PUC)	Users	Change in the average travel time on the ground (Business, leisure, children, adult accompanying, paid drivers)
Noise costs (NC)	Local residents	Noise nuisance of dwellings in a 'noise zone' surrounding the airport due to a reduction in amenity
Other costs, including capital costs (OC)	Society	Mainly capital costs

The review made in the EUNET study revealed inconsistencies in the determination of which groups of individuals a given incidence group include. The term user is commonly applied without defining whether this involves travellers and/or shippers or has an even wider interpretation. For each investment type the relevant incidence groups were defined and described. The synthesis of the findings is seen below.

Table 59 **Multi-modal determination and description of incidence groups relevant to inter-urban infrastructure passenger projects (Compiled on the basis of CEC, 1996a-e) and Leleur et al., 1998)**

INCIDENCE GROUP	RELEVANT TO	DEFINITION & DESCRIPTION MODE SPECIFIC	COMMON
Transport internal			
Travellers	Road	Travellers divided into occupants of cars and lorries.	Divided by trip purpose: Working, Home-work & Leisure trips
	Rail		
	Inter-modal		
	Airports	The working trips are traditionally referred to as Business trips. Home-work trips are discarded.	
Shippers	Road		The group requesting goods transport
	Rail		
	Inter-modal		
	Airports		
Operators	Road	The operator and the traveller is the same individual	The operator offer services to travellers and shippers
	Rail	Different organisational set-ups may be applied. Signals and terminals may be viewed as infrastructure components and thus owned by the provider or vice versa.	
	Inter-modal		
	Airports		
Providers	Road		The owner and provider of the infrastructure
	Rail	The rail infrastructure is defined as: Tracks, land signals and terminals. Signals and terminals may be owned by the operator. See above.	
	Inter-modal	The owner of the land, buildings and facilities	
	Airports	The owner of the land, buildings and facilities	

1.5.2 TRANSPORT EXTERNAL

Incidence group definition has become increasingly interesting due to the possibilities of using GIS based models and presentations. With such models it is possible evaluate consequences for each dwelling or area, and as such clarify gainers as well as losers. A dimension to the socio-economic analyses that have only to a limited been made use of. This may be due to the difficulties in data collection and handling, but equally processing capabilities.

Table 60 Determination of the transport external incidence groups (Compiled on the basis of CEC, 1996a-e and Leleur et al., 1998)

INCIDENCE GROUP	DEFINITION & DESCRIPTION
Transport external	
Local residents	The people living nearby the infrastructure and people being influenced by local external effects
National society	Society defined as the receiver of external effects that are not included in and as geographically well defined as the local residents' incidence group.
European Union	Receiver of external effects, distributed effects and policy related benefits considered on a supra-national scale limited to the European Union
Global	Effects that surpass national and European borders.

In an evaluation incidence groups are defined according to the effect the investment considered has on them. The levels of aggregation with respect to the effects then influence the definition of incidence groups. The steps in such a division according to aggregation level should avoid having too small intervals, as the risk of double counting will significantly increase as the intervals decrease.

1.5.3 A NOTE ON EQUITY CONCERNS

One questions arising from the discussion on determining specific incidence groups concerns the distributions of willingness to pay across groups within each incidence groups. These groups could be different prices between countries due to different preference sets or income, different values of time for different social groups, etc. This quickly opens some serious ethical problems: Is the life of a Greek person less than that of a German due to the difference in income (involving a greater amount of lost economic output). These problems are equally great for the local impact such as noise and air pollution.

In the APAS/Road3 project the following note is made concerning this problem (CEC, 1996f, p. 55): "The importance of this problem of equity in the distribution of impacts may vary from one project to another and depend on the circumstances of the decision making. …In any case, its handling necessarily calls for subjective and political judgements which can be introduced into the analysis in many different way, either through the appropriate weighting of the costs and benefits or/and through the addition of a distribution criterion by multi-criteria analysis".

The question of equity does equally relate to cross-border projects. Roy (1996) suggests a sequential analysis of benefits, particularly relevant to international projects:

- Domestic economic benefits
  The benefits that accrue only to national incidence groups making local trip but benefiting from the infrastructure development.

- International economic benefits to residents
  Benefits to national traffic going abroad

- International economic benefits to non-residents
  Benefits to through traffic that has no specific errand in the country except for transit

Roy argues, along with the authors of the APAS/Road3 study, that prices should reflect the willingness to pay and accordingly be as specific as possible by incidence group. The EUNET study appears slightly ambivalent as to which approach to select and hence suggests a combination involving both national prices which will be similar to the Roy approach above, as well as pan-European prices apparently out of equity considerations (Nellthorp et al., 1997)

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APPENDIX B

1 IMPACT MODELLING APPROACHES

In appendix A the multi-modal EUNET transport evaluation framework was presented. This framework structure classified impacts into four main groups (Leleur et al., 1998):

- Core impacts (A-impacts)
  Basic impacts comprising transport economic and local environmental impacts.

- Non-core, non-strategic impacts (B-impacts)
  'Soft' mode specific impacts relating to the transport quality and the visual environment.

- Strategic, territorial impacts (C-impacts)
  Impacts with territorial affiliation such as mobility considerations, economic growth and global environment.

- Strategic, non-territorial impacts (D-impacts)
  Other strategic impacts with no territorial affiliation such as technology development and other policy and planning issues.

The models discussed here relate specifically to the implementations made in the SEAM DSS discussed in chapter 6 and used in the case study described in chapter 7. No attempt is made at offering a comprehensive presentation of existing impact assessment methods.

2 CORE-IMPACTS

As described in appendix A, the Core Impacts (A-impacts) concerning road infrastructure is made up of 6 impact types. The impacts are:

- A1. Investment costs (INV)
- A2. System operating and Maintenance Cost (OMC)
- A3. Vehicle Operating Cost (VOC)
- A4. Travel Time Benefits (TTB)
- A5. Accidents (SAF)
- A6. Local environmental impacts
  - Severance (SEV)
  - Noise (NOI)
  - Air Pollution (EMI/POL/EXP)

The local environmental impacts are dealt with individually.

2.1 INVESTMENT COST (INV)

Investment costs are very initiative specific and no attempt to provide guidelines for the assessment of investment costs will be made. These must be dealt with separately. The initial capital cost do however normally comprise (Nellthorp et al., 1997):

- Construction costs
- Disruption costs
  - Land and property costs

Construction costs concern the actual construction whereas disruption costs relate to the ecological costs (land reclaim, disruption of wildlife, ecological sensitive areas, etc.). The land and property costs cover costs associated with expropriation of land and property following the investment.

2.2 SYSTEM OPERATION AND MAINTENANCE COSTS (OMC)

System operation and maintenance costs comprise all cost elements associated with road network operation and maintenance. There are four main cost elements.

- Ordinary repair work
  Repair of the surface, maintenance of the verges and shoulders, incl. flow and security improving measures.

- Winter maintenance
  Snow clearing, gritting, curing/salting

- Other maintenance
  Lighting (electricity) and other operation expenses

  - Bridge maintenance

The Danish system operation and maintenance cost model concerns trunk roads and motorways (VD, 1992). The model is based on an analysis of the average operation and maintenance costs per road km. The model has been estimated on the basis of geometry (road width or number of lanes) and the traffic flow in annual average daily traffic (AADT). The model is based on the operation and maintenance costs of a standard trunk road or motorway. A standard road for trunk roads has 4-lanes and for motorways 4-lane which are 7 meters wide for each pair of lanes. The model is made up of a fixed maintenance cost (*F*) share plus a traffic flow dependent share (*V*). The average operation and maintenance costs are subsequently scaled according to the specific link geometry. For inter-urban trunk roads the following expression is found:

Eq. 1
$$OMC_{TR} = (F_{TR} + V_{TR}\frac{AADT}{1000}) \cdot (0.65 + 0.35\frac{number\ of\ lanes}{4})$$

As concerns motorways the operation and maintenance cost is found as:

Eq. 2
$$OMC_{MW} = (F_{MW} + V_{MW}\frac{AADT}{1000}) \cdot (0.65 + 0.35\frac{road\ width}{7})$$

The fixed and variable cost elements variables in 1985 and 1994 prices are:

Table 61 **Fixed and variable cost variables for operation and maintaining Danish inter-urban trunk roads and motorways (VD, 1992). *) The values for 1994 are estimated on the basis of the indices for Construction cost indices for trunk roads and motorway work as seen Table 61 below.**

OMC	TRUNK ROADS		MOTORWAYS	
[DKR]	F_{TR}	V_{TR}	F_{MW}	V_{MW}
1985	44590	3260	120600	3110
1994*	77141	5640	206226	5318

The 1994 prices are estimated on the basis of the available 1985 prices (VD, 1992) through the construction cost indices for trunk roads and motorway work (Danmarks Statistik, 1995).

Table 62 **Construction cost indices for trunk roads and motorway work. 1968 = 100. * The value for 1994 is estimated as a prolongation of the existing data by the author. (Danmarks Statistik, 1995).**

ANNUAL AVERAGE	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994*
Trunk roads	515	508	547	578	607	635	656	648	668	688*
Motorways	528	522	562	594	623	647	670	661	679	699*

Investment specific system operation and maintenance costs associated with large bridges or tunnels should be dealt with separately. No general models are available for these impacts.

As it appears the model applied has been developed mainly for inter-urban investment. The system operation and maintenance costs of the road network in urban areas are however only affected to a limited degree by the redistribution of traffic. Als,o the influence the system operation and maintenance costs has on project performance is limited. Consequently the application of this model appears acceptable.

2.3 VEHICLE OPERATING COST (VOC)

The vehicle operating cost (VOC) is a complex function of multiple variables. These comprise road gradients, travel pattern (constant flow, abrupt flow), average speed, distance, road surface conditions etc. The vehicle operating costs are composed of the standing costs and the operating costs (PLANCO, 1997). Transport initiatives may result in reductions as well as in increases in both standing as well as operating costs.

In case of only limited information regarding the quality of the transport network the vehicle operating cost can be estimated as a function of the transport work (vehicle km/year). This is a reasonable approach in rural areas but more questionable in urban areas where the average travel speed may be so low that a longer travel distance at a higher speed will be less costly per kilometre.

2.4 TRAVEL TIME BENEFITS (TTB)

A substantial part of project benefits from new road infrastructure stem from reductions in travel time. The value of time (VoT) for a traveller will differ by trip purpose (e.g. commuter, leisure/other, work), by annual income and by the mode of transport. The difference between mode choices stem from different underlying preferences between time, money and convenience. Hence, it may not be concluded that travellers by certain modes by definition have a lower value of time.

Ideally, the travel time savings and the value of time should be disaggregated across income groups and trip purpose in the appraisal. Forecasted flows are however rarely available in such detail. Furthermore, for equity reasons the disaggregated approach is rarely applied. Provided that it was applied, transport investments servicing high income travellers would be emphasised in project appraisal. One classification of trip purposes similar to the one traditionally used in Denmark is (Nellthorp et al., 1997):

- Work
  Trips made on the employer's business or, in the case of self-employed individuals in the course of his/her occupation

- Commuting
  Trips made between home and workplace

- Other
  Trips made for reasons unrelated to work, including personal business, shopping, education and leisure

In certain cases the trip purposes is disaggregated further if one social group constitutes a large amount of the trips such as e.g. students.

The valuation of travel time savings has been the objective of multiple studies and probably will continue to be. The problems concerning the valuation of time are a vast research field and no attempt will be made here to discuss these problems in any even remote detail (see e.g. Bruzelius, N., 1979). The concern here is merely the assessment of travel time savings through modelling for the purpose of project appraisal. The value of time used in Denmark is listed in the table below (VD, 1995):

Table 63 Value of time for Denmark in 1994 prices (VD, 1995)

1994 – DKr/Hour	Value of Time – Denmark	
Trip purpose	Per individual	Per car
Work	145.13	175.61
Commute	37.86	48.08
Other	22.72	39.53
Weighed average	34.19	54.14

The value of time used in Denmark is based on the average wage in industry and trade including all additions. Only individuals above the age of 16 is included in the calculations as minors are expected to have no value of time. Traffic flows normally contain information regarding the number of passenger cars and lorries. The disaggregation by trip purpose is more rare. Estimates of vehicle occupancy rates are essential for a proper assessment of the travel time benefits. The occupancy rates used in Denmark are (VD, 1995):

Table 64 Danish vehicle occupancy rates (VD, 1995). The total share of the average hourly wage is weighed on the basis of trip purpose in passenger kilometre.

Trip purpose	Share of passenger car transport work	Number of person above the age of 16 per car	Share of passenger car transport work	Share of the average hourly wage
Work	9.3 %	1.21	7.1 %	115 %
Commute	22.9 %	1.27	18.4 %	30 %
Other	67.8 %	1.74	74.5 %	18 %
Total	100 %	1.59	100 %	26 %

The work value of time is based on a survey that showed that the average wage for travelling employees is approximately 15% higher than the average wage in industry and trade.

2.5 Accidents (SAF)

The reduction in road accidents along with travel time savings traditionally constitute a substantial part of project benefits. Appropriate modelling of the expected number of accidents is accordingly very important in most project appraisals.

2.5.1 Link accidents

The model for link accidents has the following form:

Eq. 3 $$U = a \cdot N^{p} \cdot L$$

where; U is the expected number of casualty accidents per km
N is the annual average daily traffic
L is the length
a, p are model constants

The expected number of accidents is not only a function of the annual average daily traffic but is also a function of e.g. the road alignment, the number of lanes, the road width, the possible ribbon development etc. To accommodate these differences, links with similar characteristics are classified into ap-types (VD, 1990b). The classification involves the geometry (road width, number of lanes) and the surrounding land use (urban, inter-urban). The classification of links into ap-types is seen below in Table 65:

Table 65 **The Danish a, p classification system for road network links used for the appraisal of trunk roads (VD, 1992)**

LINK TYPE	TYPE NO.	$A \cdot 10^6$	P
Urban area			
2-Lane road less than 6 m wide	113	544	0.82
2-Lane road 6 - 6.9 m wide	114	3311	0.61
2-Lane road 7 - 7.9 m wide	115	3918	0.61
2-Lane road 8 - 8.9 m wide	116	4576	0.6
2-Lane road 9 m wide	117	10150	0.51
3-Lane normal road	118	2725	0.7
4-Lane normal road	119	195923	0.22
Rural area			
Highway	121	112	0.8
Motor Highway	122	776	0.63
2-Lane road less than 6 m wide	123	974	0.68
2-Lane road 6 - 6.9 m wide	124	491	0.76
2-Lane road 7 - 7.9 m wide	125	481	0.75
2-Lane road 8 - 8.9 m wide	126	950	0.68
2-Lane road 9 m wide	127	42004	0.25
3-Lane normal road	128	56699	0.27
4-Lane normal road	129	175785	0.13

2.5.2 INTERSECTION ACCIDENTS

A model similar to the one used for links accidents has been developed for the prediction of intersection accidents:

Eq. 4 $$UT = a \cdot N_p^{p_p} \cdot N_s^{p_s}$$

where; UT is the expected number of casualty accidents
N_p, N_s is the annual average daily traffic
a, p_p, p_s are model constants

The expected number of accidents is a function of the physical layout of the intersections (the number of legs), whether the intersection is canalised or not and the surrounding land-use. As was the case for the links the intersections are divided into ap-types as listed in Table 66 below:

Table 66 The Danish a, p classification system for road network intersections used for the appraisal of trunk roads (VD, 1992)

INTERSECTION TYPE		TYPE NO.	$A \cdot 10^6$	P_P	P_S
3-legged intersections					
Signalised		130	57	0.7	0.32
Non signalised					
Flared:	Urban	136	22	0.78	0.31
	Rural	137	310	0.41	0.42
Non flared:	Urban	138	32	0.56	0.51
	Rural	139	30	0.49	0.67
4-legged intersections					
Signalized					
Flared:	Urban	142	430	0.43	0.43
	Rural	143	166	0.44	0.54
Non flared:	Urban	144	10796	0.30	0.19
	Rural	145	-	-	-
Non signalized					
Flared:	Urban	146	327	0.02	0.96
	Rural	147	421	0.15	0.82
Non flared:	Urban	148	556	0.07	0.81
	Rural	149	110	0.36	0.76

2.5.3 VALUE OF ACCIDENTS

The value of an accident depends on the type of accidents ordered by the severity of the accident, the definition with respect to the boundaries between each type of casualty and the cost elements associated with the accident. The majority of European Union member states including Denmark uses the following classification and definition (Nellthorp, 1998):

- Fatality
  Death within 30 days for causes arising out of the accident

- Serious injury
  Casualties who require hospital treatment and have lasting injuries, but do not die within the recording period of a fatality.

- Slight injury
  Casualties whose injuries do not hospital treatment or, if they do, the effect effects of the injuries quickly subside

- Damage only
  No casualties - may be sub-divided into minor and major damage

The cost elements associated with each type of accidents consists of two main cost types; Resource costs incurred by society following the accident including the loss of the expected contribution to the national production and a human cost related loss of welfare. The accident cost items include (Nellthorp et al., 1997):

- Material damage
- Police, fire and rescue, legal and insurance administration costs
- Delays to other traffic
- Medical costs (including hospital treatment and ambulances)
- Lost economic output
- Welfare loss (consumption)
  - Human cost including pain, grief and suffering

The Danish model described above predicts the expected number of casualty accidents per link or per intersection. A casualty accidents is composed of a proportion of fatalities, serious injuries and slight injuries (see Table 67). To be able to estimate the cost of an accident the share of slight injuries, serious injuries and fatalities per accident must be known. An average accident involving casualties in 1994 had 1.24 casualties and was composed of 0.066 fatalities, 0.68 seriously injured and 0.49 slightly injured. The following composition of the social cost of accidents is used in Denmark:

Table 67 The accident cost for police reported accidents in 1992 prices (Leleur, S., 1994).

ACCIDENT COSTS DKR. PER 1. JULY 1992	RESOURCE COST	WELFARE LOSS	TOTAL SOCIAL COST
Fatality	1,742,000	3,485,00	5,227,000
Serious Injury	160,000	54,000	214,000
Slight Injury	41,000	3,000	44,000
Social cost per casualty accident			1,181,000

The welfare loss used in Denmark cover a societal willingness to pay to avoid accidents. The welfare loss is calculated as a proportion of the resource cost, which is 2 for fatalities, $^1/_3$ for serious accidents and $^1/_{15}$ for slight accidents (Leleur, S., 1994).

2.6 NOISE (NOI)

The equivalent noise level (L_{eq}) is a common approach to modelling noise in most European Union member states. The differences relate to the assessment of the nuisance of the noise. In assessing noise the following must be considered (CEC, 1996a):

- The regularity of the noise
- The area affected: geography, number of type of buildings, urban/rural
- The threshold beyond which the noise becomes a nuisance
- The time distribution of the noise (day/night)
  - The traffic composition and volume (particularly the proportion of heavy vehicles/trains/aeroplanes, etc.)

These elements are of importance to the modelling of noise from all modes.

2.6.1 ROAD NOISE

The assessment of the noise impact is most often based a method comparable to the Common Scandinavian Noise Model (Naturvårdsverket, 1989). The model is sequential in the sense that incremental adjustments are made according to the context and data. The starting point of a calculation is the equivalent noise level 10 m from the road centre ($L_{Aeq,10m}$) based on an annual average daily traffic of 24.000 vehicles driving at a speed of 50 km/h. The noise level is adjusted by flow, speed, flow composition (percentage of heavy vehicles) and geometrical conditions and possibly a range of other corrections. Depending on country, the equivalent noise level will most often be $L_{Aeq,10m}$ = 68 dB(A).

Not all modelling approaches for noise are equally applicable to all planning environments. Specifically, noise modelling on an aggregate level is often associated with problems of obtaining qualified data as road noise is a very local impact. On the other hand very detailed models suffer the problem of being overly detailed for project appraisal. There are four basic methods for modelling the noise impacts:

- Purely numerical approach
- Vector based GIS approach
  - Buffer approach
  - Levelling approach
  - Raster based GIS approach

The purely numerical approaches are useful for low data assessment on an aggregate level, whereas the GIS based approaches are relatively data intensive. (For implementation examples see e.g. Rehfeld, C., 1996; Kias et al., 1989 & Miljøstyrelsen, 1996).

The degree to which noise is a nuisance is not a linear function with respect to the noise level. The nuisance is expressed through a noise factor, which is a function of the equivalent noise level.

Table 68 Nuisance factors for variables A = 0.01, B = 4.22 and K = 41 (VD, 1985).

DB(A) INTERVAL	55-60	60-65	65-70	70-75	>75
NUISANCE FACTOR	NF_A	NF_B	NF_C	NF_D	NF_E
NF	0.11	0.22	0.45	0.93	1.92

The nuisance as a function of the noise level and the land-use has been found to resemble a power function (VD, 1985):

Eq. 5 $$NF = A \cdot B^{0.1(L_{Aeq}-K)}$$

where; A = 0.01
B = 4.22
K = 41 for residential areas (outside)
K = 16 for all houses including summerhouses, etc. (inside)
K = 36 for summerhouses, allotment areas etc. (outside)

The total noise impact is expressed through a noise load number (NLN) as the sum of the number of dwellings affected by each noise level and scaled by the severity. The noise load number is defined as:

Eq. 6 $$NLN = NF_A \cdot B_A + NF_B \cdot B_B + NF_C \cdot B_C + NF_D \cdot B_D + NF_E \cdot B_E$$

where; B_i is the number of dwellings in each noise interval i.
NF_i is the nuisance factor

The assessment of the social cost of noise in Denmark is a hedonic pricing method based on the differences in the value of comparable single family dwellings (or villas) at different levels of noise. The noise impact number (SBT) has been developed on the basis of an interview survey. This approach disregards any of the social impacts of noise. In Denmark the social aspects of noise are set at 50% of the annual economic loss, so that the composition of the value of noise in Denmark in 1994 prices is (VD, 1995):

Table 69 The Danish value of noise in 1994 prices (VD, 1995).

Annual loss from reduction in house price	22,180.37 DKr per SBT
Cost of the social impact of noise	11,090.19 DKr per SBT
Value of noise	33,270.56 DKr per SBT

2.6.1.1 A simple noise model

In the case study no detailed spatial modelling approach is possible due to a lack of data. Consequently a purely numeric solution has been applied. The data requirements associated with the road network concerns:

- Average number of floors on the houses along each link
  - The distance from the road centre to the facade of the building

Assuming that each floor has a height of approximately 3 meters, the average receiver height above the road can be calculated as:

Eq. 7 $$RH = \frac{n \cdot 3}{2} + 1.5m + 0.5m$$

The 1.5m's stem from the fact that it is assumed that the upper half of the body receives the noise and the 0.5m's from the fact that the floor of the ground floor rooms are assumed slightly elevated. The distance to the facade in central urban areas is calculated as (in meters);

Eq. 8
$$Distance = \frac{Road\ width}{2} + A$$

In urban areas the additional distance A for sidewalks etc. is assumed 2 m, and in suburban areas 10 meters. The utilisation degree of the land on both sides of the road in a dense urban area is assumed 0.8, such that 20% of the length of a road goes to adjoining roads, small parks, parking lots, etc. In many urban multi storey houses, the ground level includes shops, which are not included in the evaluation. This leads to the following assumptions (both directions):

Table 70 Basic assumptions necessary for a noise model with low data requirements for Copenhagen.

AREA	DEGREE OF UTILISATION	LENGTH OF FACADE	DWELLINGS PER FACADE KM	DWELLING SIZE	PERSONS PER FACADE KM
Central Copenhagen	0.80	8	200	1.6	160
Frederiksberg	0.80	10	160	1.6	128
Other	0.50	20	50	2.6	65

As a rule of thumb apartments have a depth of around 10-12 meters in order to secure reasonable light in all rooms. As the majority of apartments in central Copenhagen is around 65 - 70 m^2 excluding the stairways, the facade will in average have a length of 8 meters. The municipality of Frederiksberg has in general slightly larger apartments than central Copenhagen, hence the slightly higher average facade length. The Other's group cover the suburban areas surrounding Copenhagen in which the land-use is more dispersed and consequently a degree of utilisation of 50% is assumed along with a longer average length of the facade. On this basis the noise impact number is assessed.

2.7 AIR POLLUTION (EMI/POL/EXP)

Air pollution stemming from transport is getting increasing public attention due to the health hazards associated with the exposure to the emissions. In Copenhagen the concentration of pollutants has not increased, but the public awareness has (Københavns Kommune, 1997b). Emissions from combustion engines are made up of a number of gasses of which approximately 1% are pollutants. The main parts of the emissions are however natural gasses (Bendtsen, H. & Madsen, J., 1990).

Table 71 Composition of exhaust gasses from a gasoline engine (Bendtsen, H. & Madsen, J., 1990)

N_2	O_2	H_2O	CO_2	POLLUTANTS
71 %	0.7 %	9.2 %	18.1 %	1 %

The most important pollutants are NO_X, CO, HC and particles that are especially relevant to diesel engines. Other pollutants are ozone (O_3), which is created through a chemical reaction between NO_X and HC in sunlight, and lead (Pb), which for many years has been a softening and octane-improving additive to gasoline. In connection with leaded gasoline, dioxin emissions, which are highly contagious have been measured. In order to reach the same octane level for unleaded gasoline other additives are added to the gasoline to improve combustion. This may lead to other types of contagious emissions.

2.7.1 THE HEALTH EFFECTS OF AIR POLLUTION

The main types of emissions and their health effects are listed below (Bendtsen, H. & Madsen, J.L., 1990).

Table 72 Origin and health effects of the main pollutants in emissions from road traffic. (Based on Bendtsen, H. & Madsen, J., 1990)

POLLUTANT	BACKGROUND	HEALTH EFFECT
NO_X (NO, NO_2)	Chemical substances created in the combustion	NO_2 influences the function of the lunges particularly with asthmatics and children. The concentration of NO is rarely a problem with respect to road traffic.
CO	Chemical substance created in the combustion	CO connection to the bloods haemoglobin reducing the oxygen intake. Particularly dangerous to unborn children and people with bad blood circulation.
HC (H_xC_y)	Non-combusted gasoline from the exhaust or fumes from gasoline stations	A very large group of substances some of which are potential carcinogens. The effects are mainly long term. The percentage of carcinogens is higher from diesel cars.
Lead (Pb)	Additive to leaded gasoline	Lead is accumulated in the body, and influences the central nerve system. Lead has been found to influence intelligence in children.
Particles	Product of wear on tyres, road surfaces, brakes and from exhaust fumes	A large share of urban dust stems from road traffic. Exhaust particles mainly origin from diesel engines. Particles are of interest due to their ability to bind dangerous substances such as HC
Combination effects	The combination of several pollutants instead of one at a time	It has been found that the combination of pollutants has a synergetic effect in the sense that the impact of the combination is higher than that of the single pollutant. Knowledge in this area is limited.

Not all emissions have impacts on all both the local, regional and global level. Whether they do depends upon their chemical characteristics. The geographical impact of different gasses is listed in Table 73 below. The local impacts are those that influence people and nature very close to the point of emission. Following the dispersion of the emissions they enter the mass of air that may be transported over rather large distances. Regional impacts are measured either through background emissions added to the local ones, or causing impacts on nature such as acidification of forests. Finally as concerns the global impacts CO_2 is neither locally or regionally a pollutant whereas it is a greenhouse gas. Evidence seems to suggest that combustion of fossil energy will cause global heating of the earth. The geographical impact of the different gasses is listed below.

Table 73 Geographical location of the impacts of different emissions (Bendtsen, H. & Madsen, J., 1990).

	Geographical level		
Substance	**Local**	**Regional**	**Global**
CO_2			✓
NOX	✓	✓	
HC	✓	✓	✓
SO_2	✓	✓	
O_3	✓	✓	✓
Pb	✓	✓	
Particles	✓		

Having briefly presented and discussed the impacts stemming from vehicle emissions, the following sections will deal with approaches to modelling of impacts on all three geographical levels. As seen in appendix A on evaluation frameworks, different aspects of the impacts of emissions are suggested treated in different impact groups. This is due partly to the fundamental difference in both the impact and the ability to locate the impact spatially. As the geographical level increases our ability to predict the impact spatially decreases. Local impacts are grouped under A7 – Local Environmental Impacts, whereas the regional and global impacts are grouped together under C3 – Global Environmental Impacts.

2.7.2 A NEW MODELLING APPROACH FOR LOCAL AIR POLLUTION

Local air pollution is very difficult to handle from a modelling point of view. The impact depends on the prevailing meteorological conditions (prevailing wind direction, humidity, sun light, etc.). The pollution is rapidly dispersed and can be very difficult to detect. Sophisticated models have been developed that can estimate concentrations in specific points under certain conditions. Such an approach is however too detailed for project assessment.

There has been a discrepancy in project appraisal between the way that investigations into the total social cost of air pollution have been performed and the way air pollution has been modelled. Air pollution is traditionally modelled through an assessment of the total emissions by link, which is then aggregated. This is however not a reasonable proxy for the local impact of air pollution. Primarily because emissions relatively quickly disperse and may be emitted in areas where no people live. There may be a social cost of the regional or global pollution, but there will be no local cost associated with the emissions. To advance the modelling of local air pollution a three stage modelling structure has been developed comprising:

- An emission model
- A pollution model
    - An exposure model

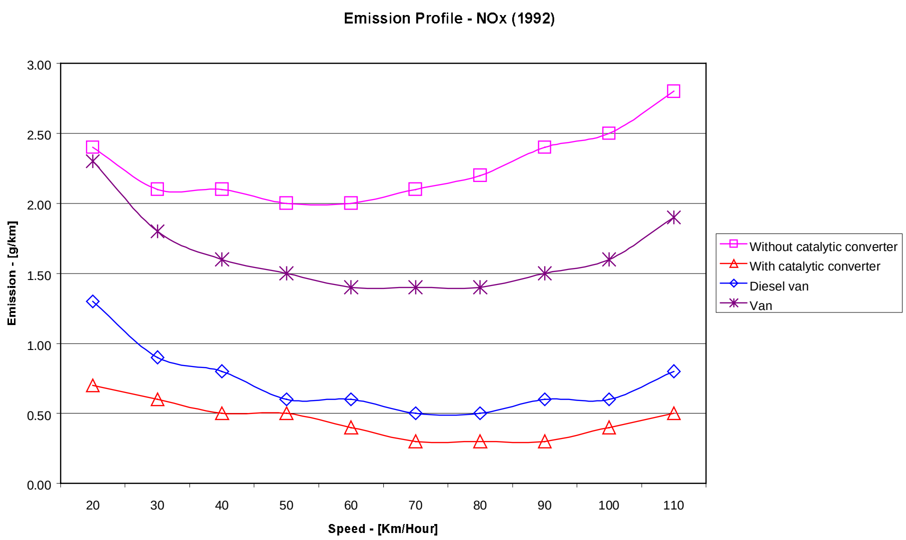
Emission models normally assess the total amount of exhaust gasses per link. Through the use of standard GIS tools an overlay of a zone structure and the road network the total amount of pollutant per zone can be calculated. This gives an estimate of the pollution because it provides an estimate of the concentration of each pollutant per zone. Finally socio-economic data on the zone level is used for the estimation of the exposure to local air pollution, which provides an estimate of the expected social cost by zone of the pollution. In this way the model may assess the spatial impacts of diverted traffic flows in a clearer fashion.

The following three sections describe and discuss the details of the modelling approach in each of the stages of the modelling structure.

2.7.2.1 Estimating emissions

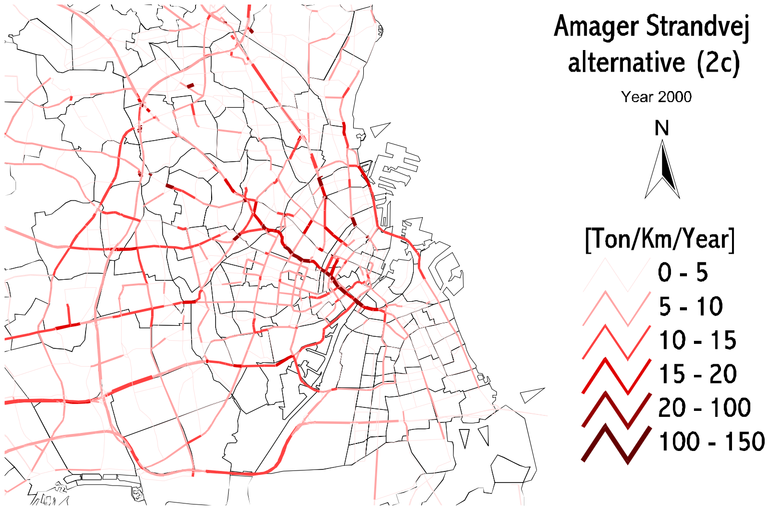
Transport emissions are normally estimated by link either through a speed sensitive formula for each dominant vehicle type or through the use of look-up tables describing the emissions by speed and vehicle type (Rehfeld, C., 1997) or finally as a linear function of the travel work (VD, 1992). The linear approach is a very convenient way of making estimates for inter-urban projects, where the travel speed is unaffected by changes in the transport network.

Figure 60 Emission factor profile for NO_X (Bendtsen, H. & Madsen, J., 1990).



If the road network is congested, the linear approach may provide misguiding results. On congested networks the average travel speed will often be between 20-50 km/h. The traffic flow will be very unstable and the vehicle engines will be running inefficiently.

Figure 61 Emissions by road link for NO_X.



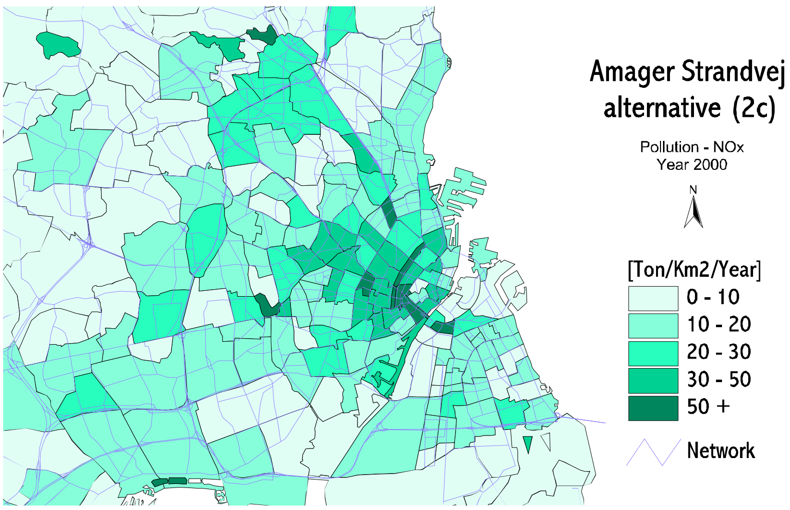
Consequently, a diversion of traffic that increases the average travel speed and reduces the amount of abrupt flows may have a very positive effect on the total emission even though the average travel length increases. In most urban areas a speed dependent approach is required for a reasonable assessment of the emissions.

2.7.2.2 Estimating pollution

Air pollution is measured as a concentration measure of pollutants per cubic metre. The measure of pollution used here is a concentration measure of pollutants per square metre. The conversion from the link-based emission measure described above to an area-based pollution measure utilises an advanced combination of standardised GIS functionalities.

By overlaying a zonal structure, possibly the one used by the traffic model, and the road network the percentage of all road links inside each zone is determined and the links share of emission within each zone is assigned to the zone. A pollution map is seen in Figure 62.

Figure 62 Pollution measure per traffic model zone.



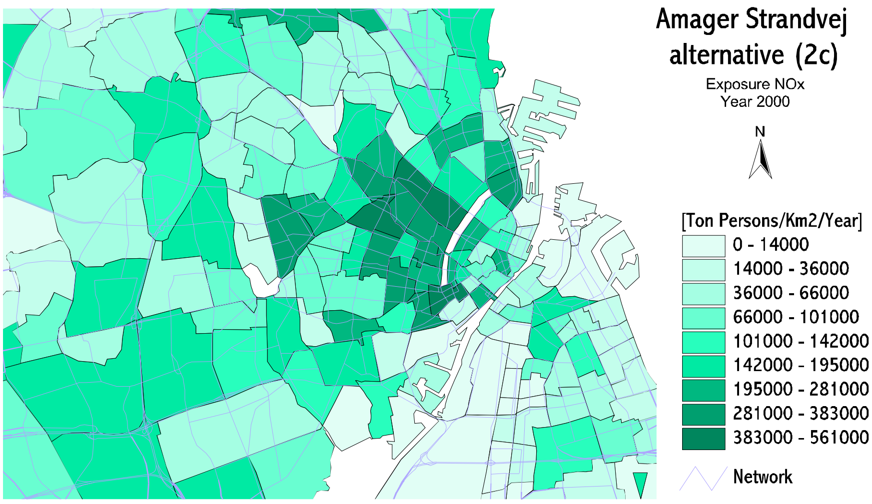
The third and final sub-model undertakes the estimation of the exposure to the emissions.

2.7.2.3 Estimating exposure

Traffic emissions have a health impact if people are exposed to them. By combining the pollution measure described above with socio-economic data an estimate on the degree of exposure by zone is obtained. Assuming that the zonal-structure used for the pollution measure is the traffic model zones, socio-economic data is likely to be available. But any other perhaps more detailed or accommodated zonal data containing information on population can be a used.

To make the estimate on exposure as accurate as possible the entire day should be covered. This implies a weighting of the residential population against the people that only work in the zone to assess the average daily population. As a working day covers approximately 8 hours this implies a weight of 66% for the residential population. The people that are unemployed, working at home, on vacation, are children or are elderly are arguments for the increase of this share. The weight in all the scenarios have been set to 75% for the residential population and 25% for the people working.

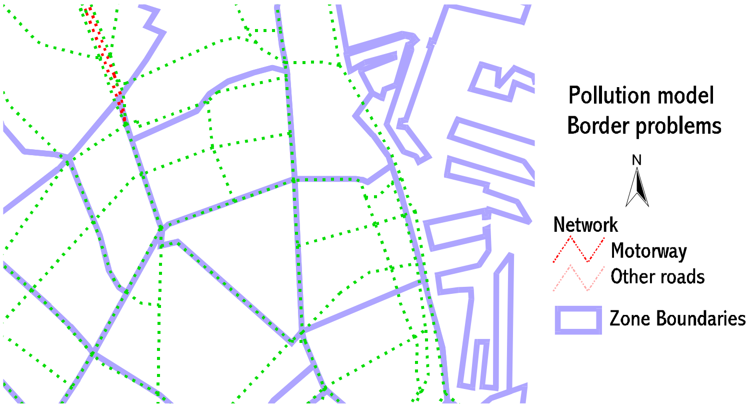
Figure 63 Exposure measure.



The weights are not necessarily scenario robust. Increased tele commuting would further increase the weight put on the residential population. This has not been done here as seen in chapter 5.

The conversion from link based emissions to zone based pollution is not without problems. The zones used are in this case the traffic model zones. The traffic model zones will be created around homogenous areas around which the major arterial normally runs. Assuming that a densely populated area is located just next to a recreational area only divided by a road then it may be unclear, which zone the emissions are actually collected in. Potentially the emissions are all collected in the recreational area where no-one lives, and accordingly no exposure is registered by the model.

Figure 64 **Border problems of the pollution model. The dotted lines indicate the roads, which in some cases are overlapping with the zone borders.**



2.8 SEVERANCE (SEV)

Severance is in Denmark assessed using a double measure involving a measure of the severance and the perceived risk. Severance is a measure of the expected perception of the difficulty, disamenity or delay experienced by the individuals wishing to cross a road. Perceived risk on the other hand is a measure of the expected difficulty or disamenity experienced by the individuals going alongside a road. The total level of severance is derived as the sum of the two (VD, 1992).

Severance and perceived risk are attempts to model two effects that are difficult to quantify and describe at the same time as they are none the less easy to understand. The problems of severance are particularly related to town areas where crossings are frequent, whereas perceived risk is generally applicable.

2.8.1 SEVERANCE

The severance is a function of the need to cross determined by the land-use pattern and the road barrier determined by the traffic characteristics. The severance is computed as the product of the two. A land-use index is used for the assessment of the need to cross.

Table 74 **Weights assigned to each zone which refer to the land-use of the zone (VD, 1992)**

ZONE CHARACTERISTICS	WEIGHT (W)
Shops, Public offices, schools, Apartment buildings	4
Dwellings, conglomerate of dwellings	3
Summer cottages and allotment areas	2
Industrial, recreational town areas	1
Undeveloped	0

The need to cross (*NC*) is estimated by:

Eq. 9 $$NC = W_R \cdot W_L \cdot L$$

Where; W_L, W_R are zone weights to the left and right of the road

L is the length of the road.

The barrier perception is a function of the traffic speed (V), the annual average daily traffic (AADT), the percentage of heavy vehicles (L_A), the length of the road (L) and the number of pedestrians crossing per km (K). The barrier perception is calculated as:

Eq. 10 $$BP = 0{,}1 \cdot \sqrt{AADT} \cdot \left(\frac{V}{50}\right)^3 \cdot \left(1{,}87 \cdot L_A + 0{,}63\left(1 - \frac{K}{20 \cdot L}\right)\right)$$

Where; $1 - \frac{K}{20 \cdot L}$ is the resistance towards crossing

$1{,}87\ L_A + 0{,}63$ is the correction for heavy vehicles

The severance is thus calculated as:

Eq. 11 $$SE = BP \cdot NC$$

If the severance measure (SE) equals or is found larger than 15 the severance is set to 15 and the road is considered impassable.

2.8.2 PERCEIVED RISK

The perceived risk (PR) is related to the 'soft' traffic going alongside the road. The perceived risk is obtained as the sum of the perceived risk for each side of the road. The perceived risk is calculated as the sum of the need to travel alongside the road and the risk effect (RE). The need to travel is based on the product of the land-use index and the road length (L):

Eq. 12 $$NT = L \cdot W$$

The risk effect is a function of the elements in the road cross section such as footpaths, bicycle tracks, and/or a combination of those.

Table 75 **The C and F factors which indicates the risk related to the traffic going alongside a road, as a function of the cross section elements aimed at either pedestrians or bicycles (VD, 1992).**

CROSS SECTION ELEMENT	F
No footpath	0.5
Only footpath on the other side	0.4
Common bicycle track and footpath	0.3
Footpath	0.1

CROSS SECTION ELEMENT	C
No bicycle track	0.5
Bi-directional bicycle track on the other side	0.4
Common bicycle track and footpath	0.3
Bicycle lane	0.2
Bicycle track	0.1

The risk effect for one roadside is calculated as:

Eq. 13 $$RE = ½ \cdot 0{,}1 \cdot \sqrt{AADT} \cdot \left(\frac{V}{50}\right)^3 \cdot (1{,}87 \cdot L_A + 0{,}63) \cdot (C + F)$$

The perceived risk is calculated as:

Eq. 14 $$PR = RE \cdot (NT_R + NT_L)$$

The total measure of severance is found as the sum of the severance and the perceived risk.

In the case study it has not been possible to acquire any data applicable to a reasonable assessment of the severance. It is a model which is not very easily implemented in e.g. a GIS (see e.g. Rehfeld, C., 1996 for suggestions). In this case the severance has been assessed using a point scale (see chapter 7). The point scale used in this study for a variety of models is discussed in section 10 below.

3 NON-CORE, NON-STRATEGIC IMPACTS

The non-core, non-strategic impacts (B-impacts) concerns the mode specific and 'soft' impacts. For road infrastructure is this group is made up of 2 impacts.

- B1. Driver convenience (DCO)
  - B2. Urban quality & landscape (UQL)

The B-impacts across all modes are mainly 'soft' mode specific impacts, but does equally include an assessment of the local impact on the urban quality and landscape.

For passenger car transport the driver convenience concerns a variety of issues related to the 'soft' elements of transport. Some of these elements are purely descriptive whereas other may be assessed by means of models. The driver convenience can be made up of:

- Riding quality
  Longitudinal, traversing, road smoothness expressed by e.g. the riding index (see e.g. HDM, 1987)

- Visual environment
  - Alignment qualities of the road

This impact has not been assessed for the case study discussed in chapter 7.

The urban quality and landscape impact cover changes that may occur either in urban areas affecting the visual impact or the aesthetics of the town scape which may again influence the city structure. In rural areas the impact is mainly directed at the visual degradation of the rural environment. This impact has not been assessed for the case study discussed in chapter 7.

4 STRATEGIC TERRITORIAL IMPACTS

Strategic territorial impacts are impacts with territorial affiliation. This group of impacts involve economic development, strategic mobility effects (including accessibility) and strategic environment. Modelling approaches to these impacts are discussed only briefly.

- C1. Strategic mobility (MOB)
- C2. Strategic environment (GLO)
  - C3. Strategic economic development (ECO)

4.1 STRATEGIC MOBILITY (MOB)

Mobility and accessibility as defined by Koenig, J.G. (1980) and Dalvi, M.Q. (1978) is:

- Accessibility denotes the ease with which any land-use activity can be reached from a location, using a particular transport system.
- Mobility denotes the ease with which an individual can move away from a location, using a particular transport system.

The UTS study applied an accessibility indicator based on the potential for human contact (Chatelus, G. & Ulied, A., 1996). On this basis strategic mobility may be defined as (Leleur et al., 1998):

- Strategic mobility denotes the potential (or opportunity) that an individual has in reaching selected land-use activities, using a particular transport system.

One such model for the international level is the POINTER index (Leleur et al., 1998). However this model is not directly applicable to an urban area. It has been beyond the resource available to implement a local strategic mobility model. Consequently a point score as described in section 10 is used to assess the strategic mobility in the case study.

4.2 STRATEGIC ENVIRONMENT (ENV)

The strategic environmental impact is especially concerned with the greenhouse effect, the acidification of forests etc. Impacts that if they were to be modelled in detail would be quite advanced. A lot of research effort has gone into the assessment of the strategic environmental impacts, there have been few practical suggestions with respect to the modelling of this impact (see e.g. Thérivel et al., 1992; Thérivel, R. & Partidário, M.R., 1996; OECD, 1994).

The addition to the green house effect from road traffic mainly stems mainly from the CO_2 and HC as discussed above. As the emission of CO_2 is linearly correlated with the energy consumption, the energy consumption is used as a proxy for the strategic environmental impact in the case study. So far this seems like the only feasible approach for project appraisal.

4.3 STRATEGIC ECONOMIC DEVELOPMENT (ECO)

The strategic economic development impact is based on an assessment of the value added to the national economy stemming from the transport infrastructure investment. Whether such additional impacts will in fact accrue in industrialised countries has been a topic of some controversy. It has been beyond the scope of this study to assess this impact directly.

COWI suggests the newly generated traffic as a proxy for the importance of peripheral access to an area with a high economic activity for international transport investments (Christensen et al., 1990). As the traffic model for the Harbour Tunnel did not indicate induced traffic of any significant proportions this impact has been set to zero in the case study.

5 STRATEGIC, NON-TERRITORIAL IMPACTS

This group of impacts is made up of issues that have strategic importance beyond what is covered by the C-impacts and more specifically without any territorial affiliation. The impacts in this group are:

- D1. Private financial attractiveness (PFA)
  - D2. Other strategic policy and planning impacts (OTH)

The D-impacts are made up of two main impacts. These involve the private financial attractiveness of a project and those that involve technology development, which may relate to railway, airports, transport telematics or inter-modal infrastructure development.

Both these impacts must be assessed through a point scale relevant to each project. The technology development has been disregarded in this case, as the Harbour Tunnel is unlikely to entail any technological developments.

The Private Financial Attractiveness of the Harbour Tunnel may however be significant as both the owner of land on the Refshale Island and the Port of Copenhagen are interested in the construction of a tunnel under the harbour (see chapter 7).

5.1 POINT SCALES FOR THE ASSESSMENT OF NON-MODELLED IMPACTS

The impacts included in the analyses of the Harbour Tunnel where a modelling approach has not been available have been assessed through a point scale. This point scale is a discontinuous scale from -5 to 5, where 5 means very large improvement compared to the do-minimum and 0 that there is no difference. The interpretation is found in below:

Table 76 below:

Table 76 Point scale used for the assessment of non-modelled impacts.

VALUE	INTERPRETATION
-5	Large deterioration
-3	Medium deterioration
-1	Little deterioration
0	No Change
1	Little improvement
3	Medium improvement
5	Large improvement

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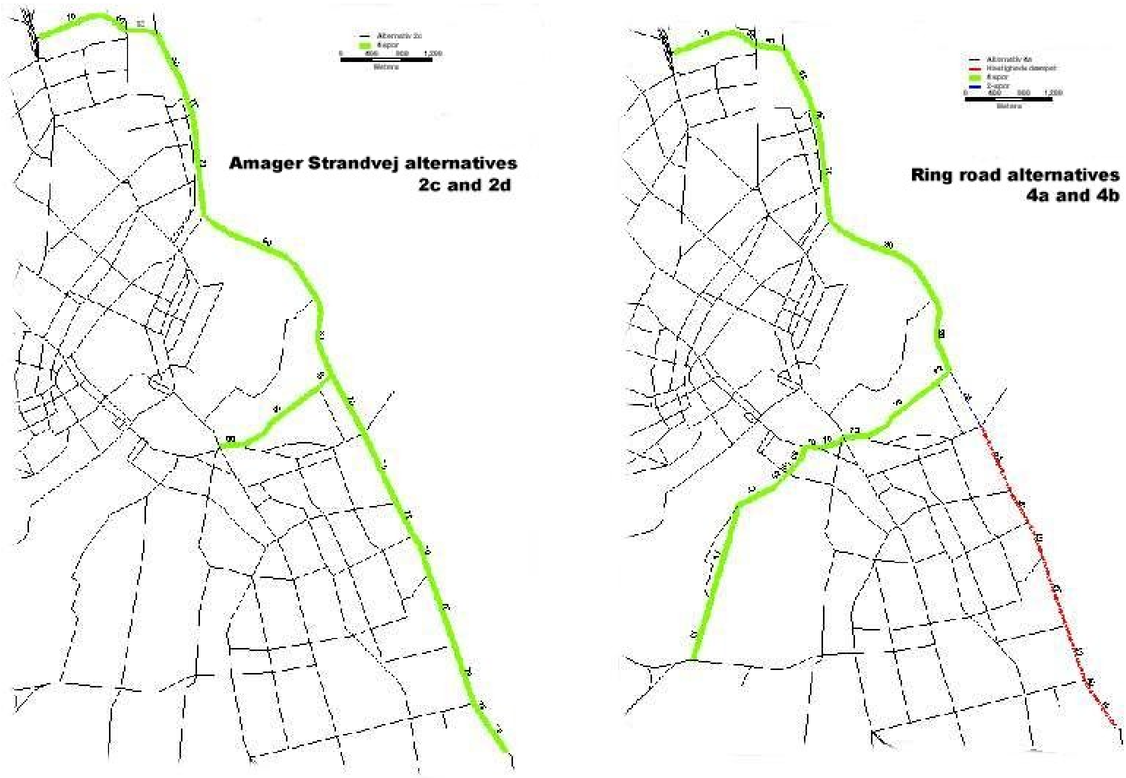
APPENDIX C

1 SOME RESULTS FROM THE APPLICATION EXAMPLE

This appendix comprises a selection of maps illustrating the case study discussed in chapter 7. The maps will refer to the four project alternatives and the two do-minimum alternatives. The project alternatives are seen below:

Figure 65 The project alternatives appraised in the case study.



The are two separate alignments of the project alternatives. One project alternative which continues along Amager Strandvej (2c) and another project alternative which will be part of a Ring road around Copenhagen (4a). Each of the project alternatives is combined with a traffic calming scheme in central Copenhagen (2d & 4b).

The three figures illustrating the traffic flows stem from the report by Nielsen, Nielsen and Israelsen (1998) whereas all the impact model results are from this study. Only a limited amount of the available maps have been provided as the ones found offer an overview of the spatial distribution of some of the impacts.

Figure 66 Modelled traffic flow in the central part of Copenhagen in 1992 (Do-minimum – 0a).

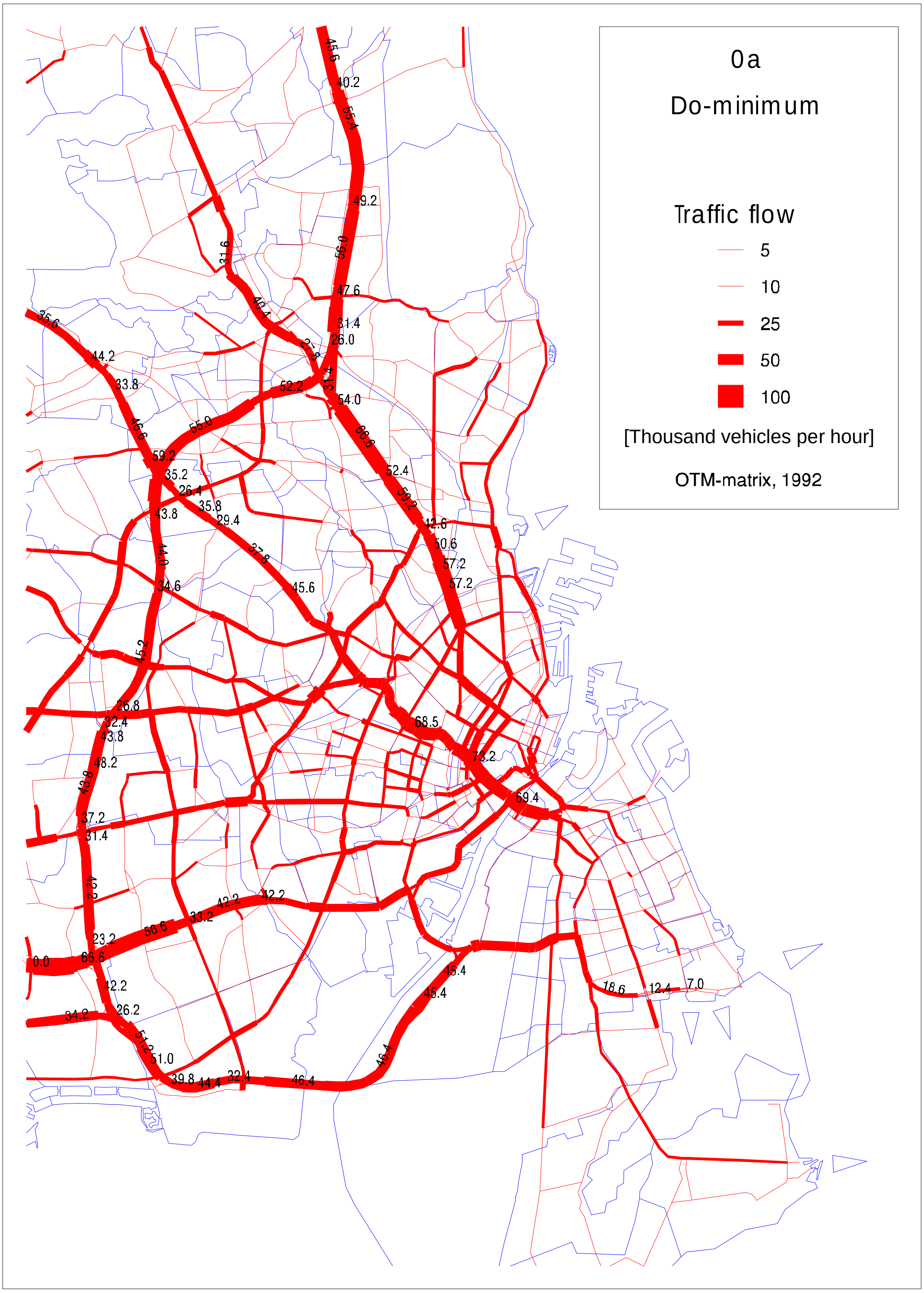


Figure 67 **Modelled traffic flow in the central part of Copenhagen for the Amager Strandvej alternative (2c) in 1992.**

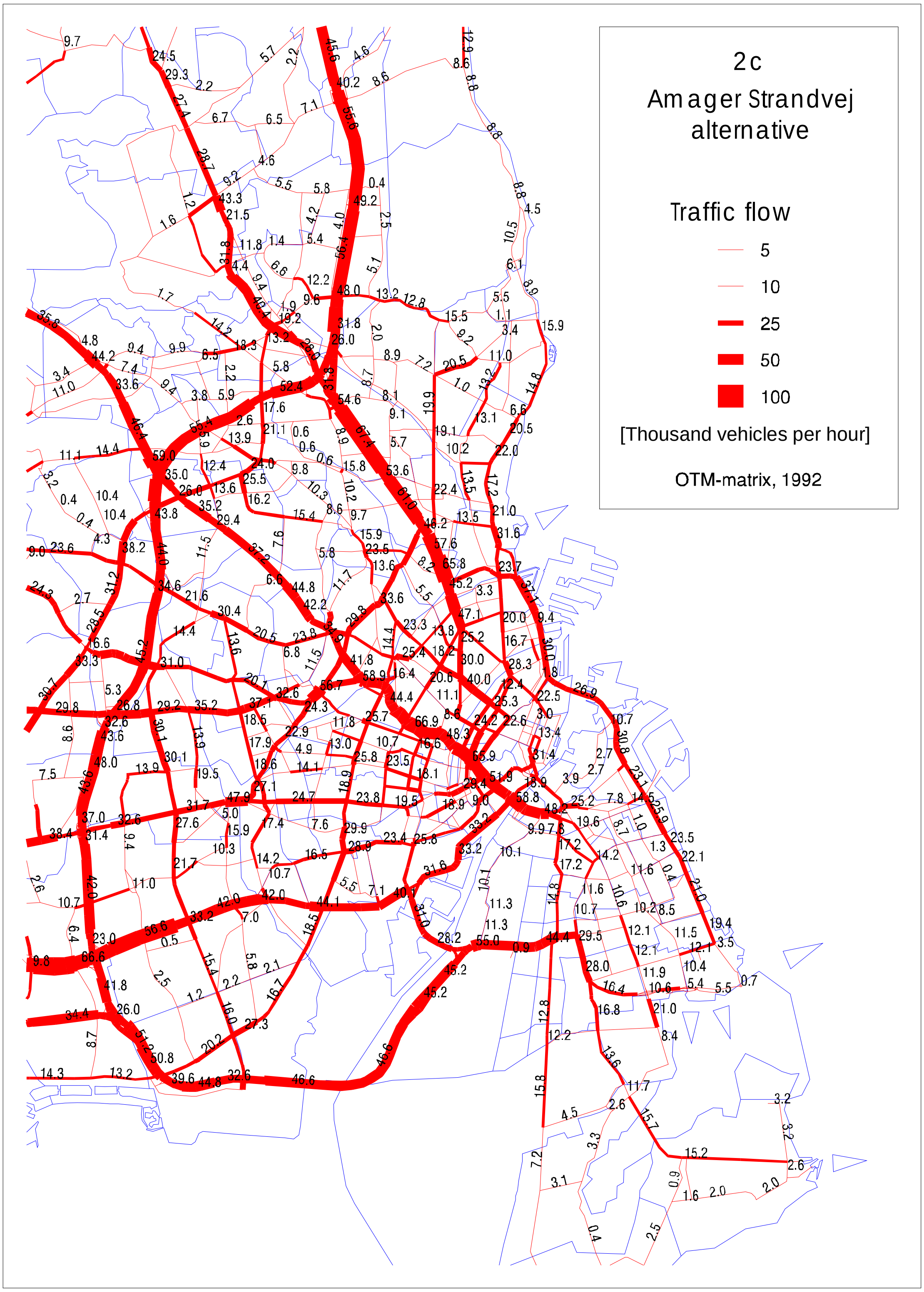


Figure 68 Modelled traffic flow in the central part of Copenhagen for the Ring road alternative (4a) in 1992.

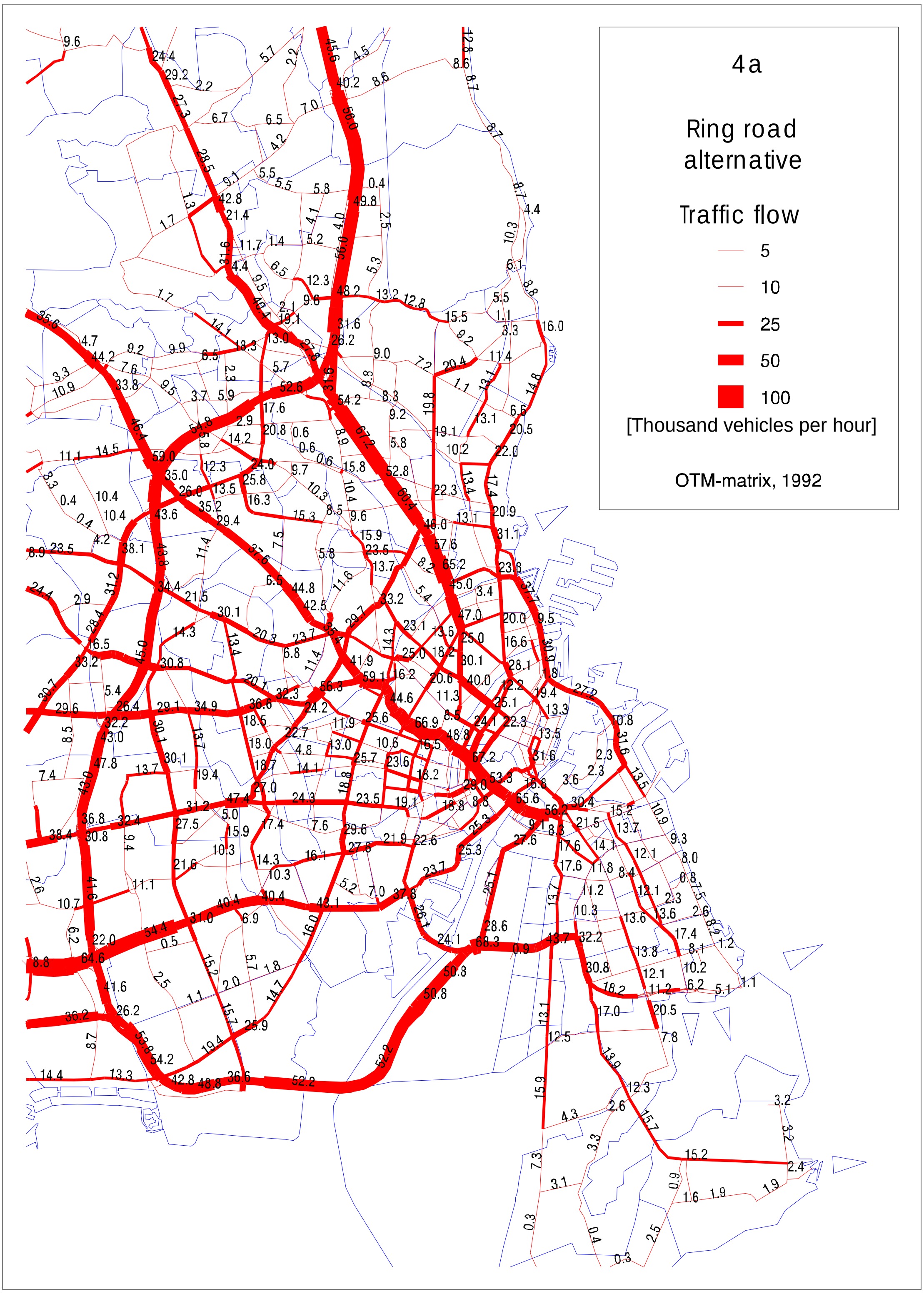


Figure 69 **The change in air pollution exposure (NO_X) for the Amager Strandvej alternative (2c) for the year 2000.**

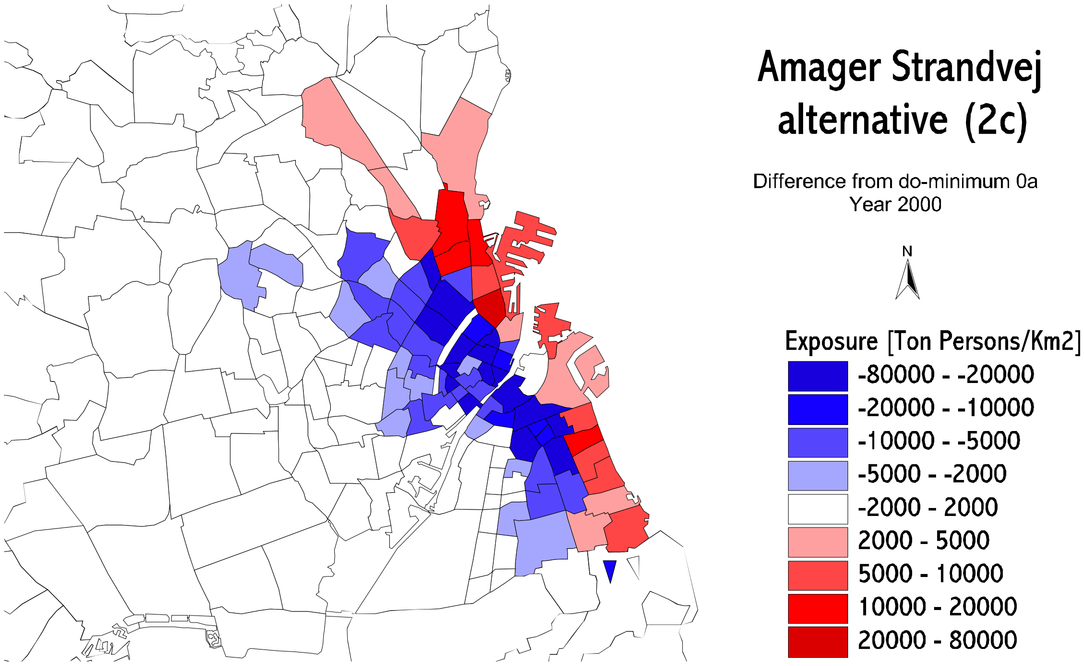


Figure 70 **The change in air pollution exposure (NO_X) for the Amager Strandvej alternative (2d) for the year 2000 with a traffic calming scheme in central Copenhagen.**

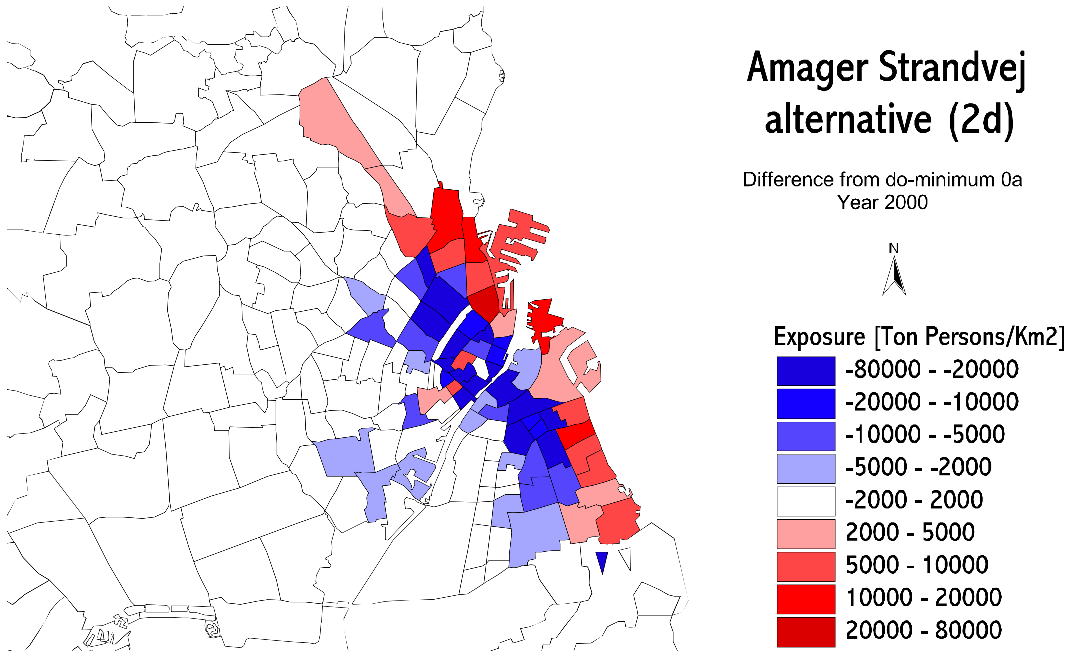


Figure 71 **The change in air pollution exposure (NO_X) for the Ring road alternative (4a) for the year 2000.**

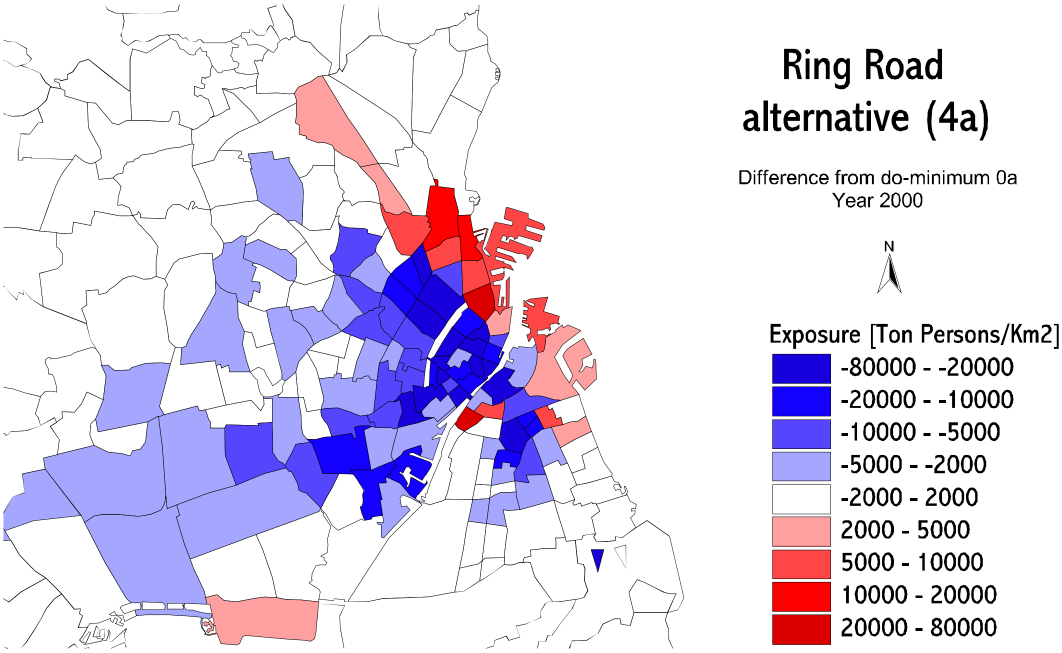


Figure 72 **The change in air pollution exposure (NO_X) for the Ring road alternative (4b) for the year 2000 with a traffic calming scheme in central Copenhagen.**

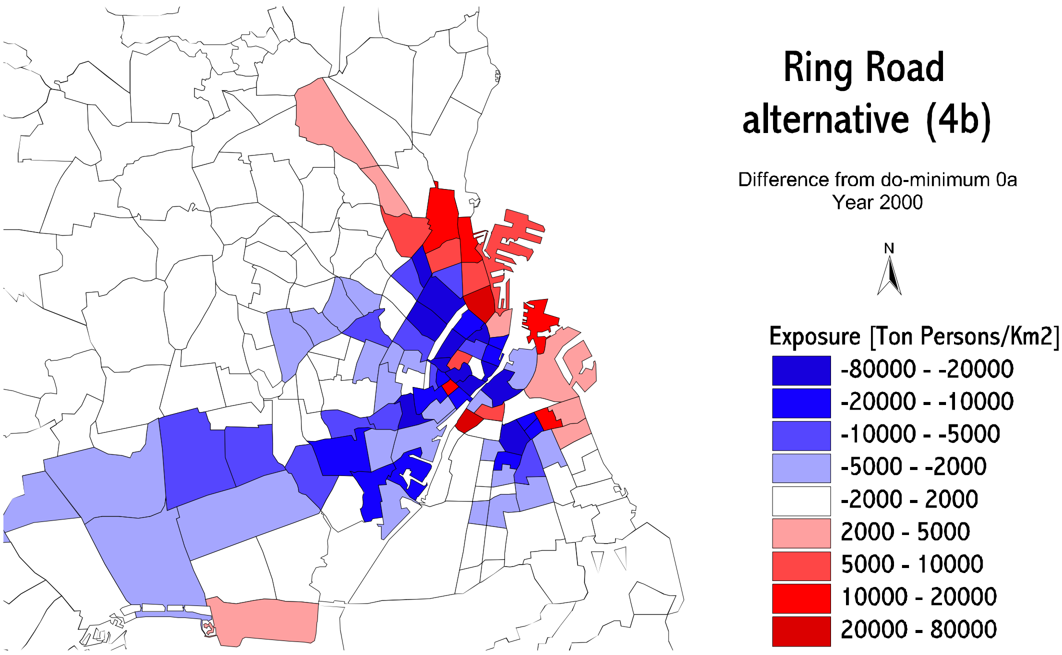


Figure 73 **The change in the noise impact measured by the change in the noise load number (SBT) for the Amager Strandvej alternative (2c).**

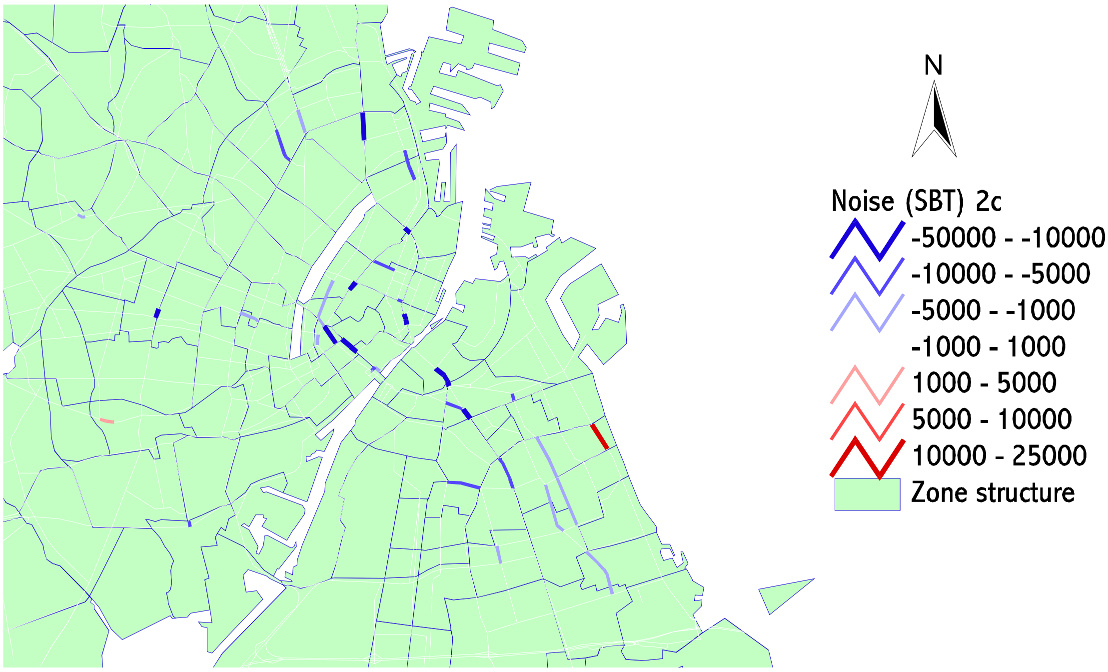


Figure 74 **The change in the noise impact measured by the change in the noise load number (SBT) for the Amager Strandvej alternative (2d) with a traffic calming scheme in central Copenhagen compared to the do-minimum 0a.**

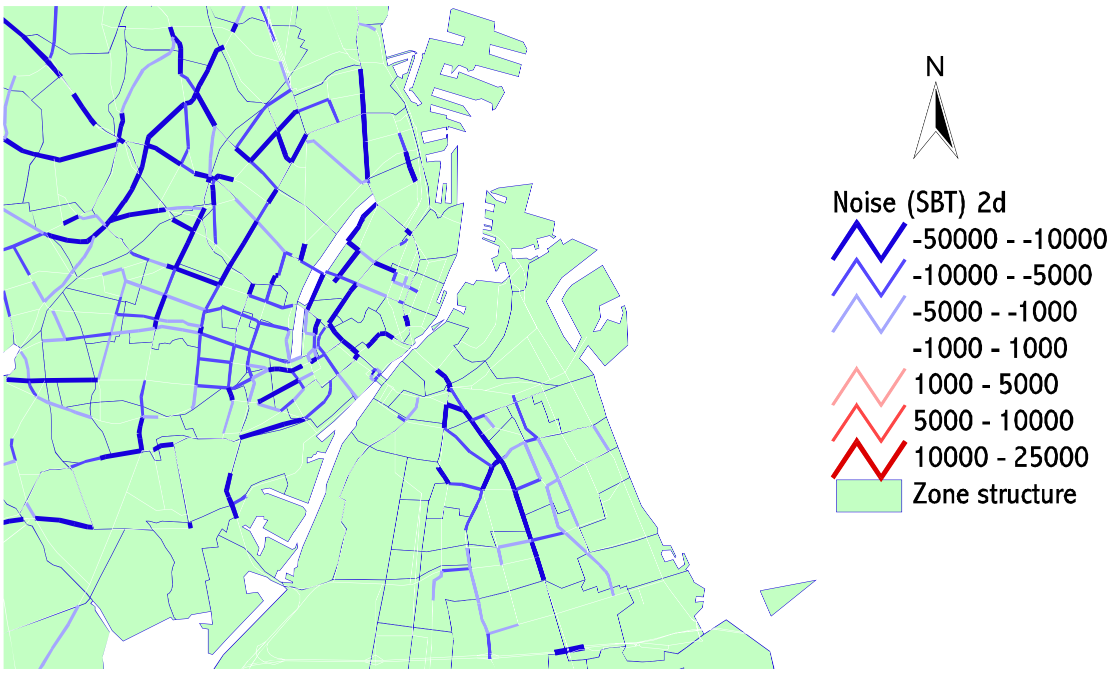


Figure 75 **The change in the noise impact measured by the change in the noise load number (SBT) for the Ring road alternative (4a).**

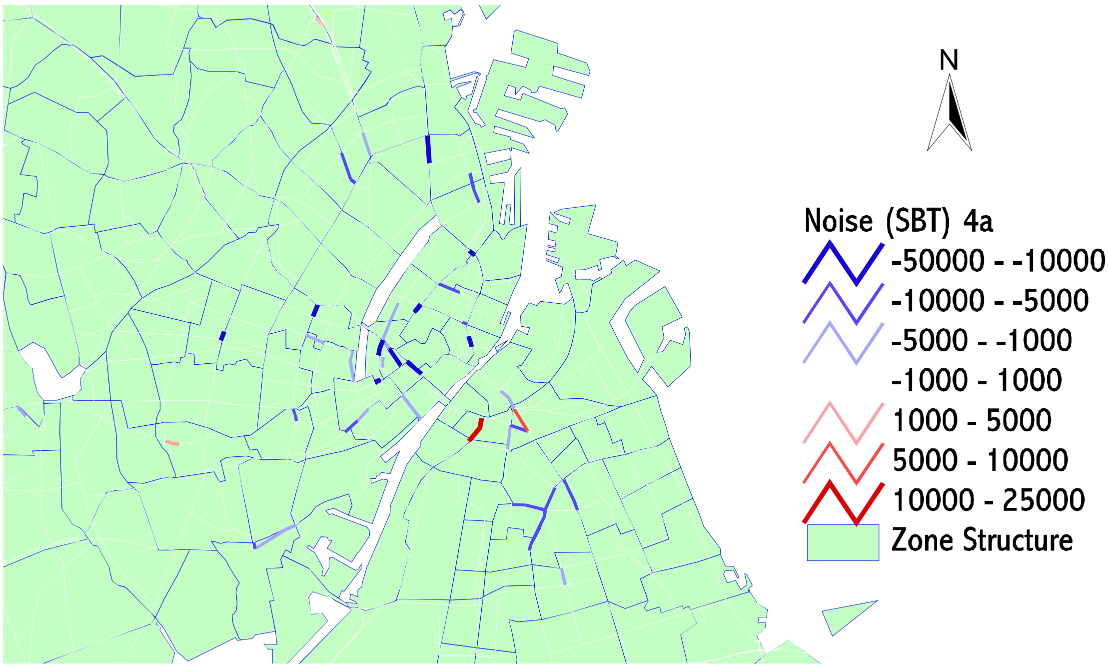


Figure 76 **The change in the noise impact measured by the change in the noise load number (SBT) for the Ring road alternative (4b) with a traffic calming scheme in central Copenhagen compared to the do-minimum 0a.**

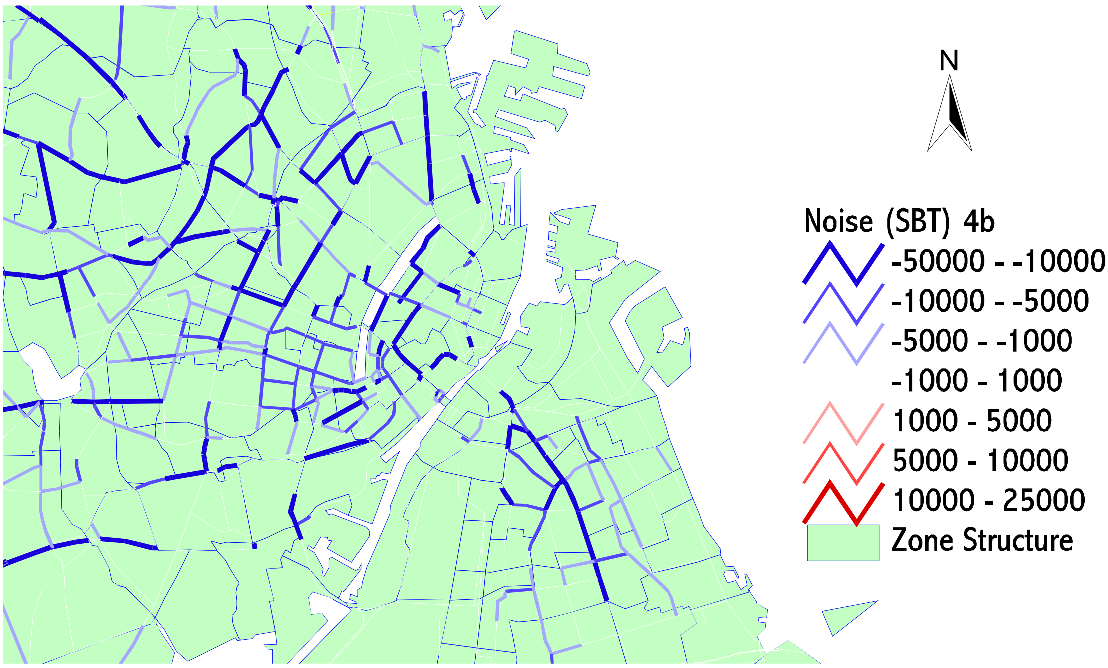


Figure 77 **The change in the number of accidents for the Amager Strandvej alternative (2c).**

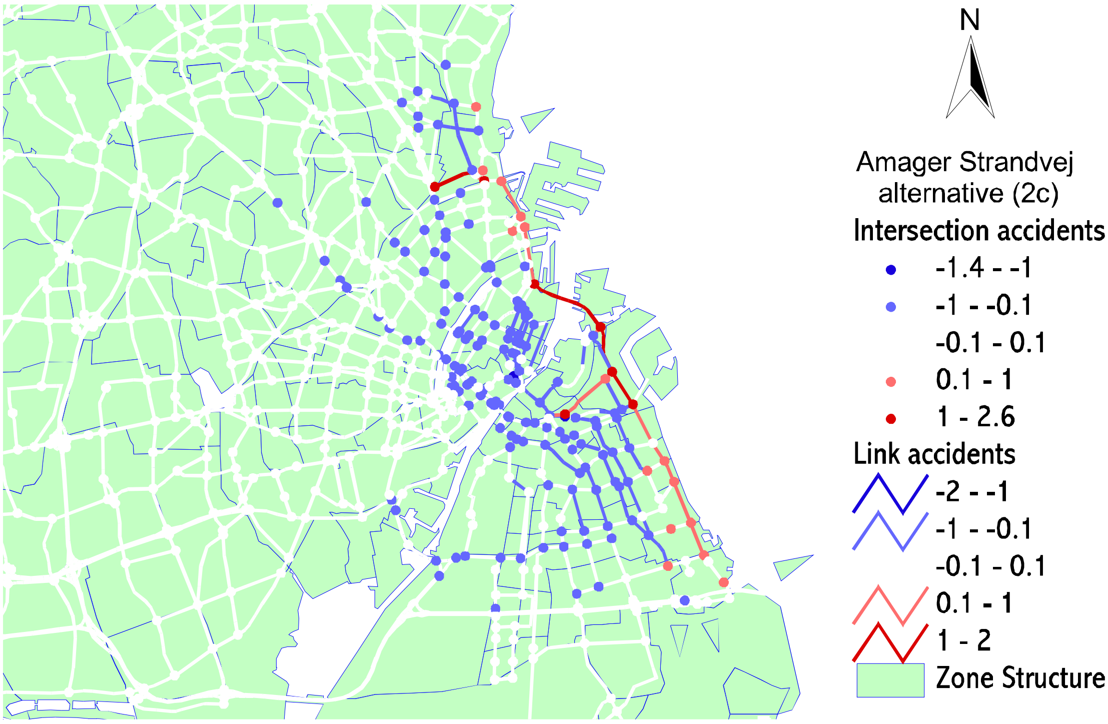


Figure 78 **The change in the number of accidents for the Amager Strandvej alternative (2d) with a traffic calming scheme in central Copenhagen compared to the do-minimum 0b.**

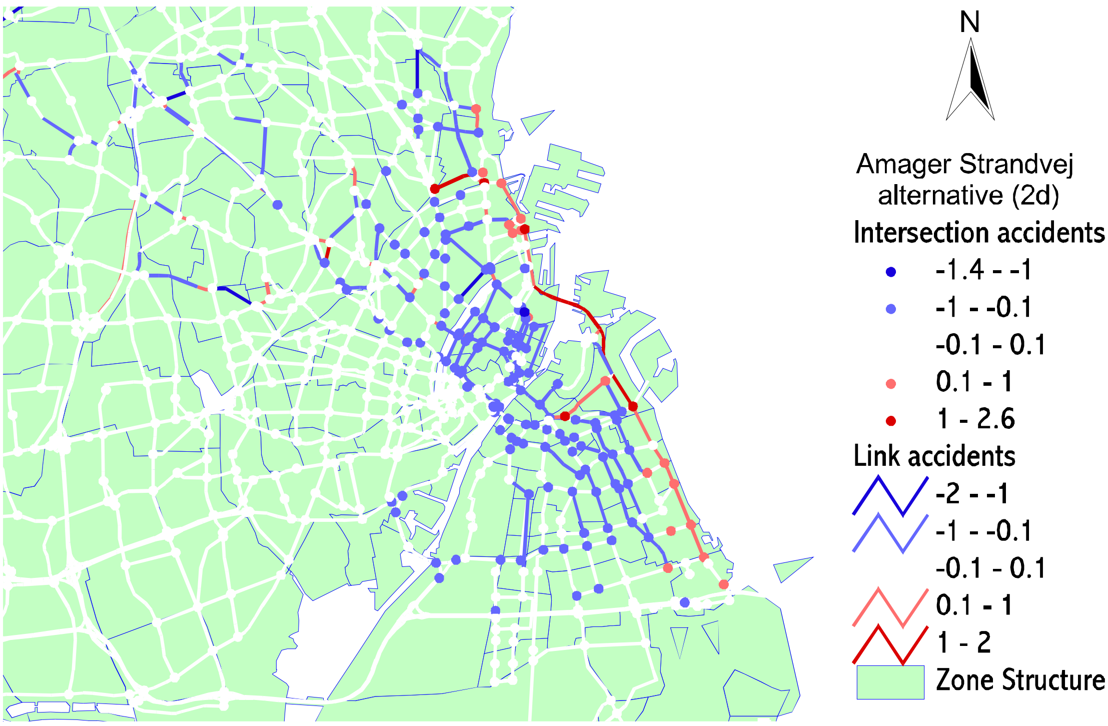


Figure 79 The change in the number of accidents for the Ring road alternative (4a).

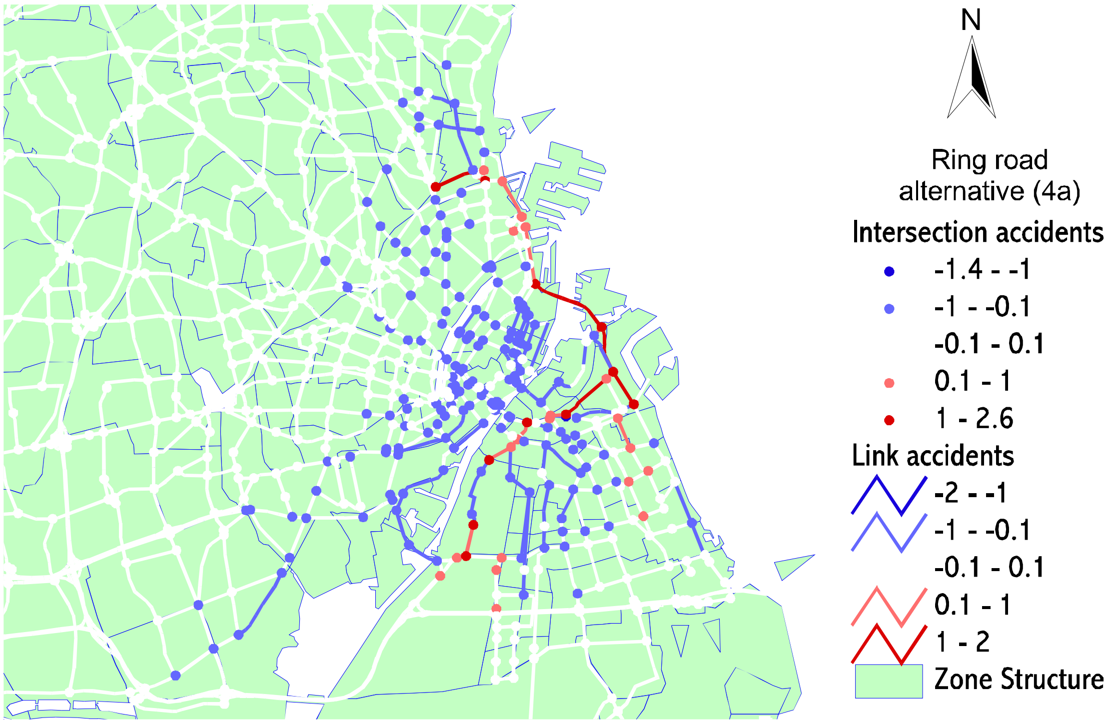
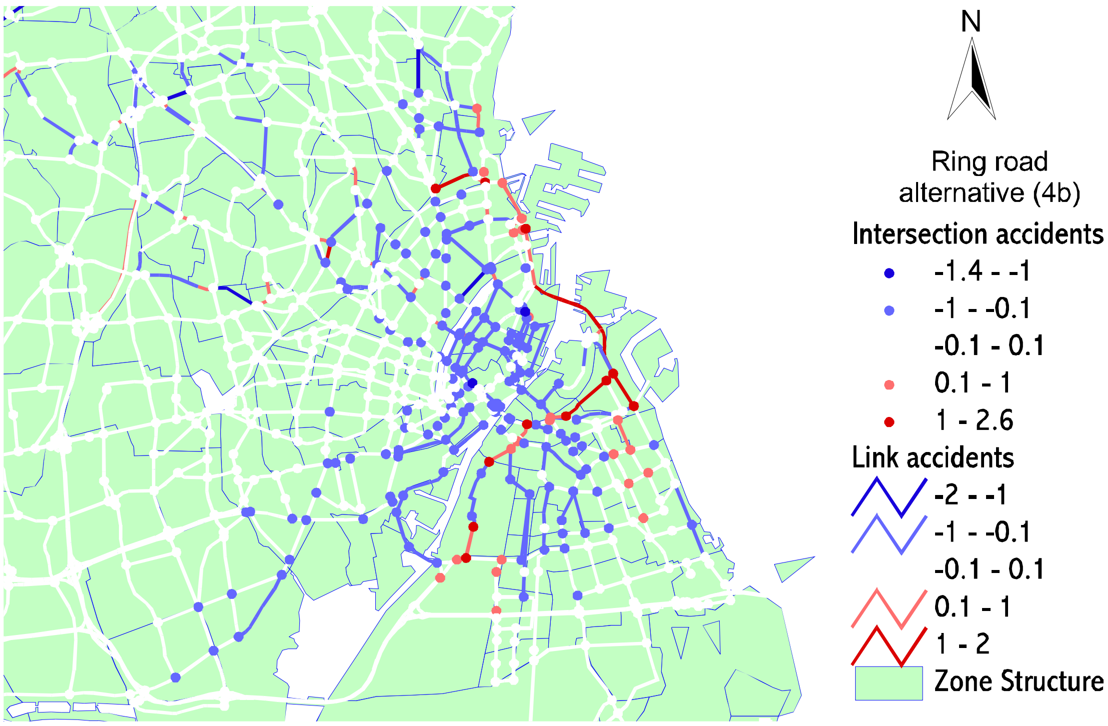


Figure 80 The change in the number of accidents for the Ring road alternative (2d) with a traffic calming scheme in central Copenhagen compared to the do-minimum 0b.



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