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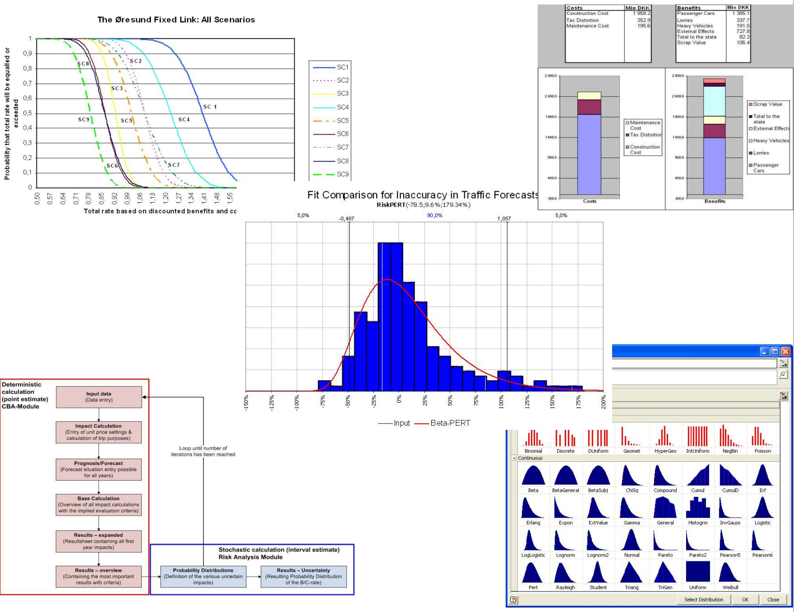

Assessment of Transport Projects: Risk Analysis and Decision Support

Kim Bang Salling

PhD thesis

August 2008

DTU Transport

Department of Transport

Preface

The following thesis completes my Ph.D. study entitled *Assessment of Transport Projects: Risk Analysis and Decision Support*. The study has been carried out at the Department of Transport (formerly known as Centre for Traffic and Transport) at the Technical University of Denmark (DTU Transport).

The Ph.D. study has been carried out in the period from August 2004 to July 2008 in a so-called ¾ time frame. During this period I have been assigned various projects among others in collaboration with the Danish Road Directorate, the Home Rule of Greenland and Rail Net Denmark. The experience from these projects is invaluable and has contributed to some of the case material presented in this report. Finally, I would like to acknowledge the Centre for Logistics and Freight Transport (CLG) for partially financing this Ph.D. study.

There are numerous ways a Ph.D. thesis can be structured. The following should be considered as a piece of model documentation concerning transport assessment, in which the assumptions and implementations are brought together in a report. The report is made up by 6 internationally peer-reviewed paper contributions placed in the end of this thesis. Furthermore, an appendix is enclosed outlining the modelling framework of CBA-DK serving as a model documentation but also useful as a user guidance report. The main focus of my study has been upon model applications and validation in which substantial effort has been made on data and empirical analyses. The software used in the CBA-DK model formulation is based upon a Microsoft Excel platform with add-on software implementing the risk analysis named @RISK from Palisade. Communicating the modelling framework outside of DTU-Transport has among others been made at the Palisade User Conferences 2006 and 2007. Herein, an application has been made available from the Palisade website: http://www.palisade.com/cases/ctt.asp.

One of the most intriguing and positive externalities in writing a doctoral dissertation and conducting a Ph.D. study is the fact that you meet a lot of interesting and engaged people. I would like to thank some of these for their

invaluable comments, help and support throughout the period. First and foremost I would like to thank my advisor at DTU Transport, Professor Dr. Techn. Steen Leleur for his endoresment and commitment in my study. The Decision Modelling Group consisting of Michael Bruhn Barfod, Anders Vestergaard Jensen, and Sara Lise Jeppesen also deserves my thanks for helpful discussions, proof readings, and co-authorships in some of the papers presented in this thesis. The Transport Studies Unit at Oxford University, in which I spent 2 months in 2008, is thanked as well. It was a fantastic experience getting to know you all, David Banister, Georgina Santos, David Bonilla, Moshe Givoni, and Christian Brand. A special gratitude is sent to my proof readers Stefan Mabit, Anders Schomacker and Sten Hansen – your time and effort were priceless. My deepest thanks go to my family and close friends. I am grateful for your never-ending care, interest, and support over the last years. Finally, thanks to my sweetheart Carina for putting up with a travelling and forgetable husband and to my newborn daughter Kaya for not crying throughout the whole night.

Hillerød, August 2008

Kim Bang Salling

Abstract

The subject of this thesis is risk analysis and decision support in the context of transport infrastructure assessment. During my research I have observed a tendency in studies of assessing transport projects of overlooking the substantial amount of uncertainties within the decision making process. Even though vast amounts of money are spent upon preliminary models, environmental investigations, public hearings, etc., the resulting outcome is given by point estimates, i.e. in terms of net present values or benefit-cost rates. This thesis highlights the perspective of risks when assessing transport projects, namely by moving from point estimates to interval results.

The main focus of this Ph.D. study has been to develop a valid, flexible and functional decision support tool in which risk oriented aspects of project evaluation is implemented. Throughout the study six papers have been produced laying the foundation with different case examples ranging from road, rail to air transport projects. Two major concerns in building the assessment model, CBA-DK, are to bring informed decision support to the decision-makers and to specify relevant probability distribution functions to feed into the Monte Carlo simulation, being the technique behind the quantitative risk analysis of CBA-DK. The informed decision support is dealt with by a set of resulting accumulated descending graphs (ADG) which makes it possible for decision-makers to come to terms with their risk aversion given a specific decision task. ADG depicts the decision-makers risk aversion towards a specific assessment task, i.e. by illustrating probabilities of an infeasible socio-economic rate of return.

To perform informed decision support as proposed by ADG it is necessary to determine a set of suitable probability distributions. This selection process has been conducted among others by literature studies, conference and seminar attendances and substantial amount of tests within CBA-DK. Currently, the model is made up by five different distributions further divided into two groups of non-parametric and parametric functions.

New research proved that specifically two impacts stood out in transport project assessment, namely, travel time savings and construction costs. The final concern of this study has been the fitting of distributions, e.g. by the use of data from major databases developed in which Optimism Bias and Reference Class Forecasting are implemented.

Throughout the entire research from the beginning in 2004 to this day, the modelling framework of CBA-DK has evolved and changed radically. Recently, Palisade Corporation, the developer of @RISK, issued the new version 5.0 allowing for a much greater freedom when choosing probability distributions and performing real term data fits. The perspective of this Ph.D. study presents newer and better understanding of assigning risks within assessment of transport projects.

Resumé in Danish

Emnet for denne afhandling er kvantitativ risikoanalyse og beslutningsstøtte i forbindelse med vurdering af transportinfrastrukturprojekter. Hovedvægten i mit forskningsforløb har været at identificere og kvantificere den usikkerhed der eksisterer indenfor beslutningstagning ved transportprojekter. Selvom der investeres store summer i forundersøgelser, VVM[1]-redegørelser, offentlige høringer, m.v., beregnes der som regel kun punktestimater, såsom nettonutidsværdien eller benefit-cost raten. Denne afhandling forsøger at fremhæve de risikoelementer, der eksisterer ved vurderinger af transportprojekter, ved at ændre evalueringskriterierne fra punkt- til intervalestimater.

Hovedfokus i det nærværende Ph.D. studie har således været at udvikle et funktionelt, fleksibelt og valideret beslutningsstøttesystem, hvori risikoorienterede aspekter inddrages i så vidt muligt omfang. Igennem studiet er der produceret seks internationalt peer-reviewede papers, som alle lægger fundamentet for denne afhandling. Disse seks papers er ydermere opdelt udfra tre forskellige transport-middelvalg: Vej-, jernbane- og lufttransport.

Den udviklede beslutningsstøttemodel, CBA-DK, er opbygget udfra to hovedspecifikationer: At bringe informativ beslutningsstøtte til beslutningstagerne samt at definere relevante sandsynlighedsfordelinger til brug i Monte Carlo simulationen, som er teknikken bag den kvantitative risikoanalyse.

Ved hjælp af aftagende akkumulerede grafer (ADG) sandsynliggøres den informative beslutningsstøtte. ADG illustrerer beslutningstagernes risikoaversion imod en given beslutning – eksempelvis ved at angive sandsynligheder for, at det pågældende projekt returnerer et negativt socio-økonomisk afkast. For at kunne illustrere ADG er det nødvendigt at udvælge en række passende sandsynlighedsfordelinger. Denne udvælgelsesprocess er foregået igennem litteraturstudier, konference- og seminardeltagelser samt test i modelsystemet. I

[1] Vurdering af Virkninger på Miljøet

øjeblikket opereres der med fem forskellige fordelinger, differentieret i henholdsvis parametriske og ikke-parametriske fordelingsfunktioner.

Igennem studieforløbet er det dokumenteret, at især to transporteffekter skiller sig ud: Rejsetidsbesparelser og anlægsomkostninger. De nyeste forskningsresultater viser, at disse to effekter følger henholdsvis en beta-PERT og en Erlangfordeling. Ved at foretage et data fit ud fra en eksisterende database undersøges det, hvorvidt disse to sandsynlighedsfordelinger passer. Det sidste forskningsmæssige resultat har derfor været, at implementere og udnytte denne database, som bygger på principper indenfor Reference Class Forecasting og Optimism Bias.

Modelsystemet CBA-DK har igennem hele studieforløbet ændret sig radikalt. Modellen bygger på en Microsoft Excel Platform, hvori den deterministiske punktberegning finder sted. Indtil for nyligt bestod risikoanalysen ved add-on software fra Palisade Corporation, @RISK verison 4.5. Palisade introducerede en ny version 5.0 af @RISK, december 2007, som tillader en lang række forbedrede forhold, bl.a. i valg af fordelingsfunktioner samt data fitting. Denne udgave er netop blevet implementeret, som det også fremgår af det seneste paper, *Paper 6*. Perspektivet ved dette Ph.D. studium, repræsenterer nye og bedre muligheder både for at forstå og for at modellere usikkerheder i forbindelse med vurdering af transport-infrastrukturprojekter.

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Overview of papers

Paper 1: *Modelling decision support and uncertainty for large infrastructure projects: The CLG-DSS Model of the Øresund fixed link*
Co-Authors: Professor Steen Leleur (DTU Transport) and Scientific Assistant Anders Vestergaard Jensen (DTU Transport)
Proceedings: 15th Mini-EURO on Managing Uncertainty in Decision Support models (MUDSM), August 2004
Journal: *Decision Support Systems* (43) 2007 – pp. 1539-1547, Elsevier (ISI-Indexed)
Case: The Øresund Fixed Link, Denmark and Sweden
Methodologies: Cost Benefit Analysis, Computable General Equilibrium, Multi Criteria Analysis, Scenario Analysis & Risk Analysis

Paper 2: *Modelling decision support and uncertainty using @RISK: The COSIMA-ROAD model*
Co-author: Professor Steen Leleur (DTU Transport)
Proceedings: 1st European Palisade User Conference, May 2006
Case: Allerød by-pass road (urban road project), Denmark
Methodologies: Cost Benefit Analysis & Risk Analysis

Paper 3: *Appraisal of the railway line between Copenhagen and Ringsted by the use of a decision support model named COSIMA-DSS*
Co-Authors: Ph.D. Student Alex Landex (DTU Transport) and Ph.D. Student Michael Bruhn Barfod (DTU Transport)
Proceedings: 10th International Conference on Computer System Design and Operation in the Railway and other Transit Systems (COMPRAIL), July 2006

Journal: *Journal of Advanced Transportation* (accepted) 2008, ISSN: 0197-6729 (ISI-Indexed)
Case: Copenhagen-Ringsted railway link, Denmark
Methodologies: Cost Benefit Analysis, Multi Criteria Analysis, Composite Model for Assessment & Risk Analysis

Paper 4: *Transport appraisal and Monte Carlo simulation by use of the CBA-DK model*
Co-Author: Professor Steen Leleur (DTU Transport)
Proceedings: Winter Simulation Conference ’06 (WSC ’06) (ISI-indexed), December 2006
Journal: *Transport Policy* (under review) 2008, Elsevier
Case: Motorway extension in the northern part of Sjælland, Denmark
Methodologies: Cost Benefit Analysis & Risk Analysis

Paper 5: *Appraisal of airport alternatives in Greenland by the use of risk analysis and Monte Carlo simulation*
Co-Author: Professor Steen Leleur (DTU Transport)
Proceedings: Winter Simulation Conference ’07 (WSC ‘07) (ISI-indexed), December 2007
Case: Airports in Greenland (Nuuk), Greenland
Methodologies: Cost Benefit Analysis & Risk Analysis

Paper 6: *Assessment of Large-Scale Transport Infrastructure Projects: the CBA-DK Model*
Co-Author: Professor David Banister (TSU-Oxford University)
Proceedings: Accepted for Presentation at the International Conference on Infrastructure Systems (NGInfra), November 2008,
Journal: *European Journal of Transport and Infrastructure Research* (Invited) 2009, TUDelft (ISI-Indexed)
Case: Airports in Greenland (Nuuk), Greenland
Methodologies: Cost Benefit Analysis, Risk Analysis and Optimism Bias

1. Introduction

The need for making "good" decisions when evaluating transport infrastructure projects is vital for any government and private instance in the world. Especially in Denmark large-scale project investments such as the three major bridge projects (Great Belt, Oresund and Femern Belt fixed links) and the Metro system in Copenhagen have contributed to the demand for large-scale comprehensive decision support systems (DSS). According to standards set out by the Danish manual for socio-economic analysis in the transportation sector, the need for a specific customized decision support tool is mentioned (DMT 2003, p. 13). The purpose of socio-economic analysis is to examine individual investments on the basis of various societal objectives in order to maximise the society's welfare gain. When a project is well documented and has undergone a systematic evaluation of both benefits and costs it provides substantial support in the political decision process. Often transport infrastructure projects are evaluated by using cost-benefit analysis (CBA). Such an analysis lists all the effects from the new transport infrastructure and uses a set of relative unit values to estimate the total value of the project. Hereby the social value in monetary terms can be estimated. The main references made use of in this respect are Dasgupta & Pearce (1978), Gissel (1999), Leleur (2000), DMT (2003) and Leleur et al. (2004).

The obtained single point results of the assessment, e.g. in terms of benefit cost rates (BCR) depict the most likely[2] value of the evaluation performed in the CBA. Clearly, the possibility of deriving a BCR containing the correct result is not very likely due to underlying model uncertainties, difficulties within the data

[2] In statistical terms this value is often referred to as the mode value

collection, and various pricing strategies[3]. These sets of uncertainties or risks contribute to the fact that a quantitative risk analysis (QRA) could provide better and more informed decision support. QRA enables the analyst or modeller to calculate BCRs as distributions and not just as aggregated point results. Moreover it enables the decision-makers to receive probabilistic information with respect to the total BCR, in order to judge whether the project is desirable or not by seeing whether the ratio is above or below 1.00. The main references made use of in this respect are Hertz & Thomas (1984), Vose (2000), Law & Kelton (2000) and Palisade (2002, 2007).

Ultimately, the two modules CBA and QRA are comprised within the modelling framework of CBA-DK respectively in what is generally referred to as a deterministic and a stochastic module. This adoption outlines the feasibility risk assessment (FRA) procedure in which decision-maker and stakeholder involvement is vital. Informed decision support as illustrated by the use of CBA-DK results in a set of accumulated descending graphs (ADG) where decision-makers are able to incorporate their risk aversion towards a given project. Normally, as concerns larger project assessment schemes in Denmark, a sensitivity analysis is conducted in order to test the various model assumptions. However, these sensitivity tests are all performed with single point entries e.g. a 50% increase of costs or a 1% decrease in discount ratio, etc. Running the model again produces single point BCRs which ultimately leaves the decision-makers with the same difficulty in assessing the project. The proposed methodologies in this thesis, FRA and ADG, enhances the single point results that can be produced in the sensitivity analysis into probabilities of occurence. Thus, decision-makers are able to judge the project in terms of 'certainties' instead of point relationships.

The thesis is organized as follows: the remainder of this chapter discusses cost-benefit analysis, quantitative risk analysis and the proposed concept of feasibility risk assessment. Chapter 2 describes the developed modelling tool of CBA-DK. The CBA-DK decision support model consists of a Microsoft Excel platform that forms the basis for actual decision making e.g. by calculating BCRs. The handling of the model uncertainties are assessed by the use of @RISK version 4.5 (Palisade 2002) and 5.0 (Palisade 2007) developed by Palisade Corporation. Chapter 3 presents the scope and findings of the six papers enclosed at the end of this thesis. Finally, chapter 4 gives a conclusion and perspective of the study.

[3] Pricing strategies in this context refer to the deriviation of unit price settings

1.1 Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) seeks to determine whether or not a certain output shall be produced and, if so, how best to produce it. CBA calls for the examination of all costs related to the production and consumption of an output, whether the costs are borne by the producer, the consumer, or a third party. Similarly, the method requires an examination of all benefits regardless of who realizes the benefits (Dasgupta & Pearce 1978). Because the ultimate objective of CBA is the comparison of benefits and costs, they both must be evaluated in the same unit of measurement. The procedure with respect to transport related issues are traditionally treated with a set of alternative projects. The benefits of each alternative are then valued and compared to their expected costs. The alternative for which benefits exceed costs by the greatest amount is identified as the project alternative to be suggested for implementation. The following sections describe how such comparative measures are produced related to decision support models within transport infrastructure investments.

Basic Principles

When considering social welfare instead of private revenue, the problem for the decision-maker is similar to that of the company management: where the company management wants to maximize the revenue for the company, the decision-maker(s) considering a public investment wants to maximize the welfare towards the society. Hence, the change in welfare following the project, i.e. all possible benefits and costs accruing to the society as a consequence of the project are investigated. This concept is traditionally referred to as micro-economic welfare theory where the fundamental assumption relies on the rational consumer. This theory comprises the “rule” that any consumer only buys a commodity, if and only if, the utility associated with the purchase is higher than the cost (Dasgupta & Pearce 1978; Gissel 1999).

Project evaluation in the field of transportation makes use of a set of economic indicators and concepts determining the ground rules for decision making. CBA is based on the basic principle of demand and supply and is manifested in utility theory. The general economic concept in this context can be illustrated as a traditional demand curve shown in Figure 1, presenting a particular commodity. The hyperbola curve indicates the quantity (x-axis) of the commodity that consumers as a whole will purchase at any particular price (y-axis). It slopes downward to the right because consumers can be expected to purchase larger quantities at lower prices than at higher ones (Leleur 2000). A useful property of the demand curve is that it traces out the prices which consumers are *just* willing to pay for an additional unit. Thus, the price consumers are willing to pay represents in economical terms the marginal value.

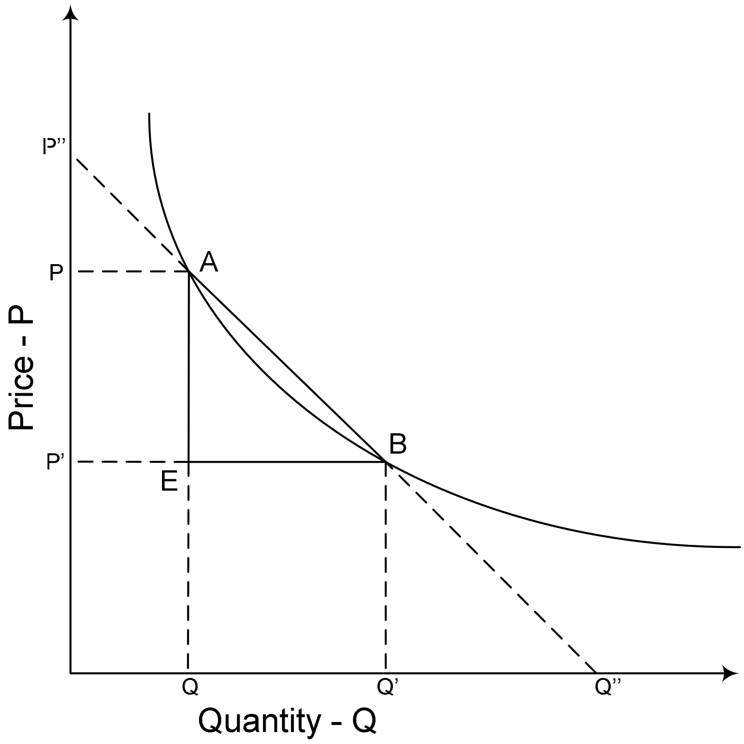

Figure 1. Demand curves, where the hyperbola function represents relatively large changes in the generalized cost and the estimated linear function (*P'' Q''*) represents small changes (Leleur et al. 2004, p. 16).

The following paragraph only looks on relative small changes in prices (costs) in which a linear relationships of the demand curve can be achieved (*P''Q''*). In Figure 1, the demand curve shows that consumers can be expected to buy quantity *Q* at price *P* (intersection *A*). This reference scenario is referred to as the basis with an actual willingness-to-pay for the commodity of *P''*. To induce consumers to increase purchases of the commodity to *Q'*, prices must fall to *P'*. This new group of consumers is illustrated in utility theory by the area of *QAP''*, however, since the actual price for the commodity is illustrated by the area of *QAP*, this group of consumers actual receives a fictitious surplus (area *PAP''*). This area is treated as the so-called consumer surplus (*CS*) in economic theory. The *CS* is defined as the benefit which a consumer enjoys in excess of the costs which he or she perceives (Leleur 2000).

For example, if a journey would be undertaken by a traveller provided it takes no more than 20 minutes, but not if it takes more than 20 minutes, then the total value of the journey is equivalent to the cost to that traveller of 20 minutes of travel time[4]. If actual travel time for the journey is only 15 minutes, then the traveller enjoys a surplus of 5 minutes. If a new proposal reduces travel time further, to 12 minutes, then the increase in *CS* from the new proposal is 3 minutes (Gissel 1999).

If the price for the commodity *Q* is lowered to *P'* it will force an increase in demand, shown by the change from *Q* to *Q'*. Thus, the new situation can be illustrated by the area of *Q'BP''* and the new *CS* is depicted by the triangular area of *P'BP''*. This increase in quantities and decrease of costs can be explained in terms of changes in the consumer surplus. Subtracting the *CS* in the before situation from the *CS* in the after situation results in the area of *P'BAP*. Again, if the demand curve can be assumed to be linear, provided the changes in costs are small, then the triangular area of *ABE* will be the welfare gain for new travellers (also known as induced traffic). This approximated area together with the area depicting the existing travellers is then expressed as the total welfare gain or benefit (Equation 1):

$$B(CS) = \underbrace{(P-P')\cdot Q}_{Existing\ Travellers} + \underbrace{\frac{1}{2}\cdot(P-P')\cdot(Q'-Q)}_{Newly\ Generated\ Travellers} = \frac{1}{2}\cdot(P-P')\cdot(Q+Q') \qquad (1)$$

This convention is also known as the 'Rule of a Half' (RoH), and assumes implicitly that there is a linear relationship between the cost and demand. If this is not the case, and the demand curve is convex to the origin, then the RoH will tend to overstate the benefits: with very small changes in cost, the inaccuracy is, however, not significant.

The difference between linearity and non-linearity of the demand curve has been further investigated in Salling (2003). Salling (2003) is an ex-post investigation of the Øresund Fixed Link where the RoH was applied for induced traffic towards private cars and rail transportation, where a general comparison between a linear demand curve and a non-linear demand curve (the hyperbola function as depicted in Figure 1) were performed. The work showed that by integrating the hyperbola function a correction factor could be derived based on the average daily traffic on the link. By integrating the function in Equation (2) the "real" consumer surplus for the induced traffic was determined:

$$Q = k \cdot P^{\alpha} \qquad (2)$$

[4] In this example time equals price on the demand curve

where k and α both denotes two constants[5]. The α value is often referred to as the so-called 'price elasticity index' which is a relative measure between price and demand changes. Herein the price elasticity can be described by the following expression from Leleur (2000, pp. 94-95) in Equation (3):

$$\alpha = e_p = \frac{\partial Q}{\partial P} \cdot \frac{P}{Q} \qquad (3)$$

Equation (3) illustrates the elasticity of a given transport mode or in other words the robustness. For instance if one has an e_p value of -0.3 and a price reduction of 10% on the given transport mode is achieved the demand in passengers will increase with 3%. The price elasticity is particularly vital in the transport models where the future traffic and passenger flows are calculated and fed into the decision support model.

Investment Criteria

In order to assess which objectives that should be pursued and how these objectives should be accomplished a set of decision variables (or in the following denoted as criteria) are introduced. Figure 2 illustrates how a traditional transport infrastructure project evolves over time including benefits and costs. In this sense it is necessary to adopt decision criteria which take the time distribution of benefits and costs into account.

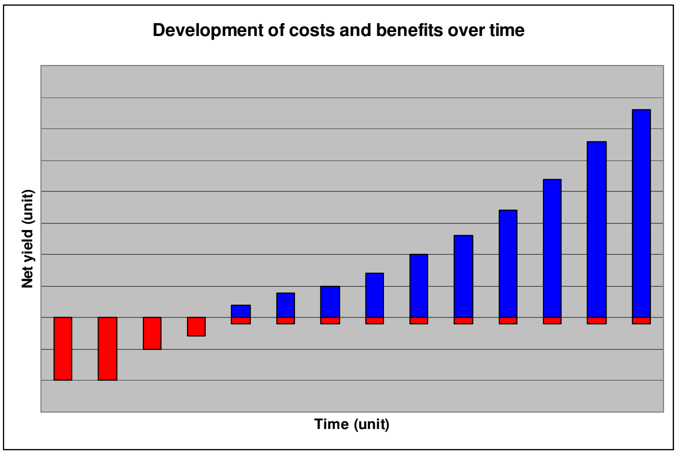

Figure 2. The development of costs (under the horizontal axis) and benefits (above the horizontal axis) over time (adapted from Leleur (2000) p. 100).

[5] To associate hyperbola function depicted in Figure 1, the formula expression must fulfil the following relationships, $\alpha < 0$ and $k > 0$.

The development of costs C_t and benefits B_t over time t can be comprised into the following three evaluation criteria:

- Net Present Value (NPV)
- Benefit-Cost Ratio (BCR)
- Internal Rate of Return (IRR)

The following makes use of the work performed by Dasgupta & Pearce (1978), Gissel (1999) and Leleur (2000).

The Net Present Value

The net present value (NPV) criterion requires that Equation (4) is to be evaluated for all investment alternatives. The criterion provides that the alternative to be undertaken has a positive NPV. Furthermore, the NPV associated with the alternative that has the highest societal value should be chosen. If the criterion is positive, this condition ensures that the activity is worth undertaking; that is, it contributes more in benefits than it absorbs in costs. The second condition results in the optimum amount of benefits being efficiently produced:

$$NPV = \sum_{t=0}^{T} \frac{(B-C)_t}{(1+r)^t} = \sum_{t=0}^{T} \frac{B_t}{(1+r)^t} - \sum_{t=0}^{T} \frac{C_t}{(1+r)^t} \tag{4}$$

where NPV is the discounted net present value of a series of benefits (*B*) and costs (*C*). *T* equals the total number of periods in the evaluation period of the project and *r* depicts the discount rate. The principal content of the NPV calculation consists of the different time-dependent weights attached to the time-displaced benefits and costs by use of the so-called discount factor $(1 + r)^{-t}$, where $r > 0$. The higher the values of *r* and *t*, the lesser the added contribution from the discounted values (Figure 3).

The actual value of the discount rate is an expression of the emphasis on benefits in the near future as compared with benefits in a more distant future. Due to the types of projects associated with these benefit types, a low rate will favour larger projects with a long project life, while a high rate will lead to a comparatively higher profitability of projects lesser in costs and size.

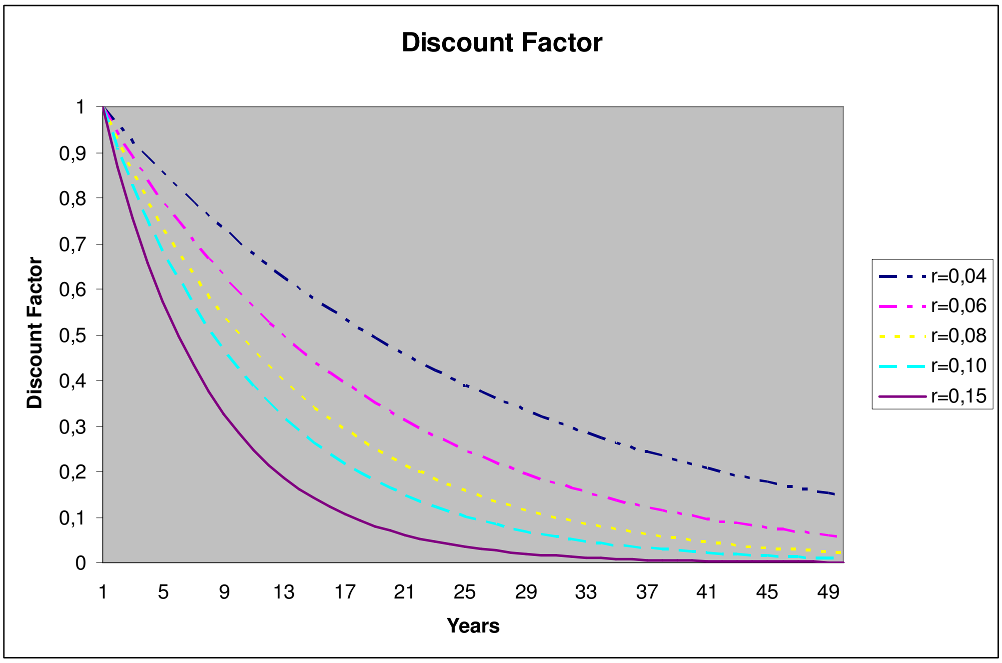

Figure 3. The discount factor $(1+r)^{-t}$ as a function of *t* and discount rate *r* (adapted from Leleur (2000) p. 101).

In Denmark the discount rate has been changed from 7% in 2000 to 6% in 2003. The rate varies across Europe, in the so-called HEATCO[6] project the rate is set to 3% for EU assessment projects, whereas the overall rate used for Scandinavian infrastructure projects across boundaries are found to be 4%[7] (Lyk-Jensen 2007, p. 27). When conducting a NPV calculation, a base year must be determined for the price level. No attention is paid to inflation, but account can be taken of forecasted growth in real terms of some of the benefit components' unit prices.

Using the NPV as the decision criterion implies that all projects with a positive NPV should be carried through. However, if there are only limited financial resources and not all projects with a positive NPV can be implemented, the relative value of these projects must be considered in order to rank them.

[6] HEATCO stands for Harmonised European Approaches for Transport COsting and is a set of guidelines for project assessment on EU level (recommendation)

[7] The discount rate is set to 4% in Sweden, 4.5% in Norway and 5% in Finland (Lyk-Jensen 2007)

The Benefit Cost Ratio

The second investment criterion is the benefit cost ratio (BCR). It is used in order to perform a project ranking. It is defined as the present value of benefits divided by costs, and is given by the following Equation (5):

$$BCR = \frac{\sum_{t=0}^{T} \frac{B_t}{(1+r)^t}}{\sum_{t=0}^{T} \frac{C_t}{(1+r)^t}} = \frac{\sum_{t=0}^{T} B_t \cdot (1+r)^{-t}}{\sum_{t=0}^{T} C_t \cdot (1+r)^{-t}} \qquad (5)$$

The ratio indicates the present value of the benefits that will result per present value invested. A proposed activity with a ratio of at least one will return at least as much in benefits as it costs to undertake. This corresponds to having a positive or zero net present value and indicates that an objective is worth undertaking.

For alternatives which are independent of each other, the BCR can be used correctly to rank independent projects as to which are most cost-beneficial. Given the usual constraint of a limited budget, projects can be pursued from highest to lowest ratio until the budget is exhausted. However, when a selection must be made between competing alternatives that are interdependent the BCR fails. Interdependence occurs when the benefits or costs of one alternative depend on whether or not certain other alternatives are also selected. Interdependence will in its most extreme result in mutual exclusivity - when selection of one alternative precludes selection of any of the others. In these cases, a combination of both the NPV and BCR approach can be helpful.

The Internal Rate of Return

The internal rate of return (IRR) is defined as that discount rate which equates the present value of the stream of expected benefits in excess of cost to zero, i.e. it solves Equation (6). In other words, it is the highest discount rate at which the project will not have a negative NPV. To apply the criterion, it is necessary to compute the IRR and then compare it with the prescribed 6% discount rate (DMT 2006). If the IRR is greater than or equal to 6% the project should be undertaken for its NPV is non-negative. If the IRR is less than 6%, the project has a negative NPV and should not be undertaken:

$$\sum_{t=0}^{T} (B_t - C_t) \cdot (1 + IRR)^{-t} = 0 \qquad (6)$$

While the IRR method is effective in deciding whether or not a project is worth undertaking, it is difficult to utilize in ranking projects. It is not unusual for rankings established by the IRR method to be inconsistent with those of the NPV and BCR criteria (Leleur 2000, p. 102).

Pros and Cons of CBA

The pros concerning CBA are all more or less described in the previous section. The main advantage of implementing the method is basically that it sums up all aspects of the decision problem in one single aggregated value. Thus, the CBA provides a tool for comparing projects or alternatives. This makes the method a convenient decision support tool in the planning process. Furthermore, the methodology provides a set of criteria that make the variety of projects comparable and consistent.

Even though a key advantage of using CBA is the transparency of modelling, this may also be considered as a weakness. The method relies on single result values where all the considerations and calculations are reduced to just a single number. The general public would most often see the methodology as a “black box” approach (Gissel 1999, pp. 44-46). Clearly, a practical measurement problem exists in the quantification of “non-market” impacts, such as accidents saved, air pollution, etc. Subsequently, the discounting of costs and benefits disclose some problematic issues due to the generational gap between present and future populations. This way of realizing costs and benefits disregards the desires and needs of future generations hence are the impacts of today the same in 30 years from now? Finally, interpreting the society as a whole entity and not looking on individuals surely results in some critiques. The idea of aggregating social welfare where the sum of benefits outweighs the sum of costs is problematic.

The idea of converting ‘abstract’ measures into monetary values is difficult to understand by many. The sources of uncertainty embedded within this ‘conversion’ are highly problematic. Presumably, to set a “price tag” on an accident, the time saved in a vehicle or the emission of one tonne of CO_2 is a challenging task. Therefore, assumptions and hereby standard measures are developed, to comprehend with some of the uncertainty issues related both to the transport unit pricing (DMT 2006) and the handling of the embedded modelling uncertainties. The term uncertainty is adopted from Banister & Berechman (2000) where it has been defined that uncertainty is the degree of inaccuracy associated with the determination of the benefits and costs of the transport project.

Nature of Uncertainty

Vose (2000) and Walker et al. (2003) claims that the nature of uncertainty can be seen in the separation of variability (ontological) and uncertainty (epistemic). The decision-makers are enabled to view exactly where further modelling can be of relevance and hereby where future financing can contribute in the enhancement and control of the associated uncertainty (Figure 4).

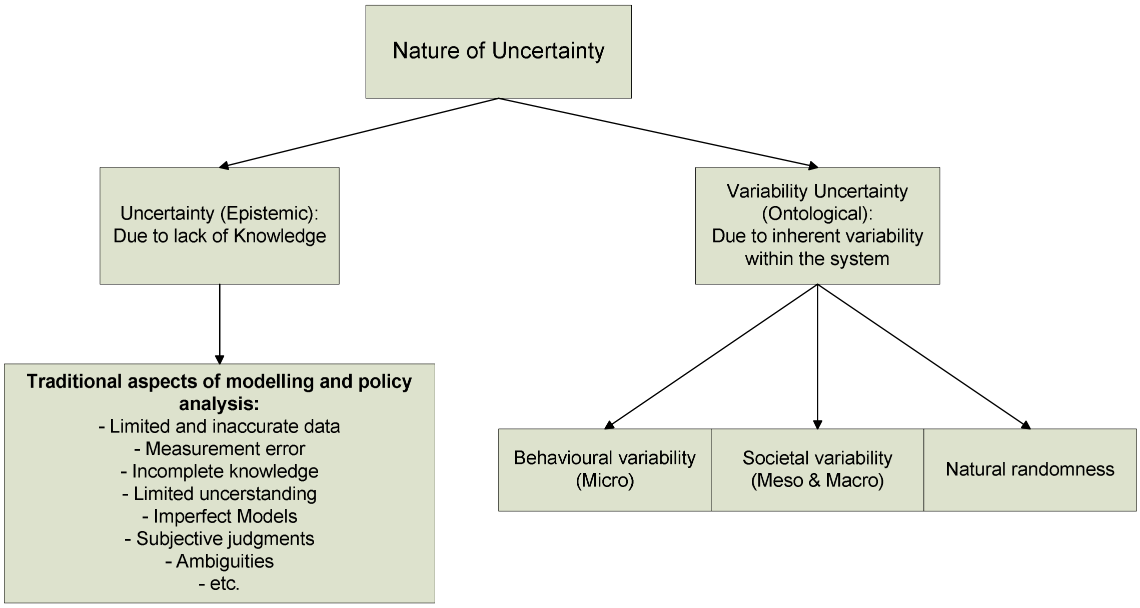

Figure 4. The nature of uncertainty: inherent variability or lack of knowledge (figure adapted from Vose (2000) and Walker et al. (2003)).

Vose (2000) makes recommendations in splitting the uncertainties either by calculating, by empirical formulas, the uncertainty and then simulate the variability or vice versa. Even though he advocates for the separation of the two terminologies he also states that dependent on the circumstances more uncertainty can be added to the model if the calculation and simulation procedure is not performed accordingly (Vose 2000, pp. 203-209).

Moreover conference attendance and discussion with '*Titans*[8]' in the simulation community such as *David Kelton (2007)*, *Jim Wilson (2006)* and *Averill Law (2006)* has led me to the belief that any uncertainty division demands further investigations. In this context and the description presented in Vose (2000, pp.

[8] Within the Winter Simulation Conferences (2006, 2007), the term *Titans* are used for individuals with major contributions within the simulation and risk analysis society

203-209) it has been determined not to implement the separation of variability and uncertainty in the context of this Ph.D. thesis. However, earlier studies have been made, where the separation of uncertainty and variability has been investigated and tested within the modelling framework (Salling & Leleur 2006a).

Sources of Uncertainty

Dealing with uncertainties in transport appraisal is henceforward divided into two categories, unit pricing and modelling uncertainties. A schematically overview of the provided sources of uncertainty in transport appraisal is shown in Figure 5.

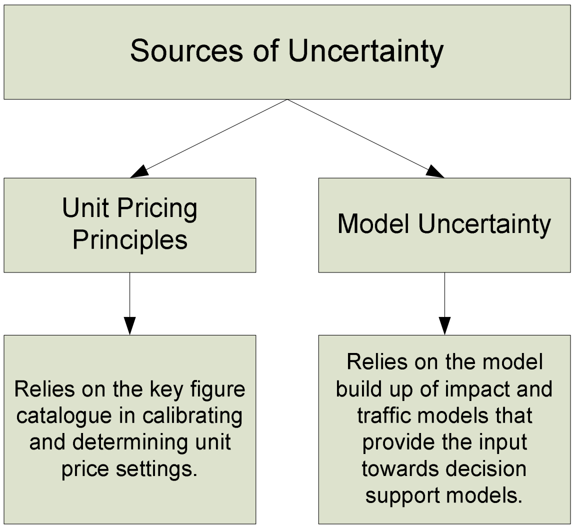

Figure 5. Schematically overview illustrating the sources of uncertainty embedded within transport infrastructure assessment.

The sources of uncertainty correspond to a combination of both lack of knowledge and inherent randomness in the system.

Transport Unit Pricing

According to Danish standards set out in the manual (DMT 2003) a set of unit pricing principles are assigned in the evaluation of transport infrastructure projects. The background in making CBA is the valuation of the various types of cost and benefits accruing from the project. These typical impacts are non quantifiable in common sense, i.e. the consequences are not traded in any market. For these non-marked impacts the valuation scheme set out relies on the key figure catalogue[9] published by the Danish Ministry of Transport (DMT 2006). The following small selection of pricing strategies accounts for two of the most influential impacts in transport assessment schemes. Important impacts such as accident savings, air pollution, and maintenance unit costs are all determined through fixed unit price calculations which are made evident in later sections since they appear in some of the enclosed papers.

Travel Time Savings

By far the largest contributor of direct benefits from any given transportation project is the travel time savings (TTS). Benefits originating from this category often make up a share in the range of 70-90% of the overall benefits (Mackie et al. 2003). These benefits are comprised by three components making up the overall monetary value of TTS, namely: 1. money costs, 2. opportunity cost of time and 3. disutility of travelling (Banister & Berechman 2000, p. 178). The money costs are associated directly with the choice of travelling namely tolls, fares or car purchase, sometimes referred to as the *out-of-pocket* direct travel costs. The opportunity costs refer to the alternative use of time spent on travelling, i.e. using the time productively to accomplish other activities such as work. Obviously, this time value varies considerably between people, thus its value lies between 0 (time saved cannot be used productively elsewhere) and 1 (time saved can be fully utilized into other alternative use). Finally, the third component is the experience of travelling which among others can be expressed by the lack of comfort. Thus, this component makes up the inconvenience that travelling creates (Banister & Berechman 2000).

TTS are generally determined with respect to 3 categories: Business, home/work and leisure trips. These categories are further split into travel related utilities such as in-vehicle time, waiting time, queuing time, etc. All these aspects are gathered in the key figure catalogue (DMT 2006) where frequent updates are made. Banister & Berechman (2000) table 7.2 and Leleur (2000) table 4.6 combine information of the substantial variation between countries of values of travel time savings by trip purposes. It is clear from these figures, that even though extensive effort has been put on deriving valid TTS data, variation exists between countries and moreover how the TTS are implemented in different evaluation methods.

[9] Recently, DTU-Transport and COWI Consult have published in co-operation with the Danish Ministry of Transport a new set of transport unit prices (February 2008). Unfortunately, due to time constraint, these unit prices are not implemented in this thesis report (www.transport.dtu.dk/forskning/modelcenter).

Construction Costs

Secondly, the impact with the highest overall significance on any given appraisal study in the pre-stage is the construction cost. In order for the transport authorities or government to prepare reliable financial transport infrastructure programmes, accurate estimates of future funding are vital. Within the construction of, e.g. road infrastructure projects in Denmark, forecasting future construction costs has been achieved basically by constructing a unit rate, e.g. Danish Kroner (DKr) per kilometre highway of a predefined road type (Lahrmann & Leleur 1997). This method is, however, considered unreliable due to site conditions such as topography, soil, land prices, environment, traffic loads varying sufficiently from location to location, etc. (Wilmot & Cheng 2003). Current studies have shown extensive underestimation of future costs resulting in budget overruns by up to 100% (Flyvbjerg et al. 2003). Such budget overruns are clearly not acceptable. Therefore more and ‘better’ construction cost estimates are needed in order to make validated and trusthworthy decision support.

Model Uncertainties

The second major source of uncertainty relates to the *embedded model uncertainty* defined in context with the derivation of first year impacts and forecast scenarios. When all models is an abstraction of a real life system they all contain some embedded uncertainty in both input as well as output (Law & Kelton 2000). The *unit price principles* depicts various shortcomings and deficiencies in determining “correct” unit price values whereas the *model uncertainties* depicts shortcomings in prognosis, impact and transport models.

The travel time savings and the construction costs have proved to be very difficult to derive through modelling. Flyvbjerg et al. (2003) actually concludes that in the case of Danish bridge and tunnel projects, on average, construction costs were 50% to 100% undervalued whereas traffic forecast, laying the foundation for the travel time savings effect, were about 60% overestimated (compared with the opening year traffic situation). The majority of proposed transport systems on average, costs 50% more than their ex-ante estimates, while the ex-post demands within travel savings are about 50% below the estimated demand. This stems with an established *maxime* in transportation CBA stating that in order to derive benefit and cost values of an infrastructure project one should normally halve the predicted benefits and double its estimated costs (Banister & Berechman 2000, p. 187).

Optimism Bias and Reference Class Forecasting

These more or less consistent overestimations of benefits and underestimations of costs within transport infrastructure appraisals have been named Optimism Bias. As discussed previously, decision-makers and analysts tend to be overly optimistic with respect to construction costs and future traffic. A new technique developed for the British Department for Transport provided a set of guidelines trying to cope with some of these shortcomings (Flyvbjerg & COWI 2004).

The Optimism Bias approach is dealt with by the use of a well-established technique named Reference Class Forecasting (RCF). The theoretical background of RCF is made up by prospect theory[10] developed by Kahneman & Tversky in 1979[11]. A reference class denotes a pool of past projects similar to the one being appraised. Herein a systematically collection of past errors is gathered for a range of projects, comparing the deficiencies in the planning stage. Experience from past projects is then collected and compared so that "planning fallacy" can be avoided (Flyvbjerg 2007, p. 29).

Four categories of causes with respect to Optimism Bias have been found: technical, psychological, political and economical. Traditionally, a fifth cause is included namely unplanned or unforeseen events. However, this cause should be eliminated in the preliminary stages by inducing contingencies in the budget. The reason for implementing the procedure is to eliminate or at least minimize the tendency of Optimism Bias within infrastructure planning. The methodology is very data demanding in gathering empirical evidence from past projects. The classification divides transport schemes into a number of groups where the projects can be treated as similar. The similarities are hereafter translated into so-called uplifts which are averaged values from the reference classes. These uplifts are associated with the initial construction cost, thus, a presumed budget exceeding can be calculated (Flyvbjerg & COWI 2004).

A schematic overview of the Optimism Bias approach applied for British transport infrastructure investments are shown in Figure 6.

[10] In short prospect theory describes decisions between alternatives that involve risk, i.e. alternatives where the general outcome is uncertain but the associated probabilities are known.
[11] Daniel Kahneman received the Nobel prize in Economics in 2002 for his work in collaboration with Amos Tversky (1937-1996).

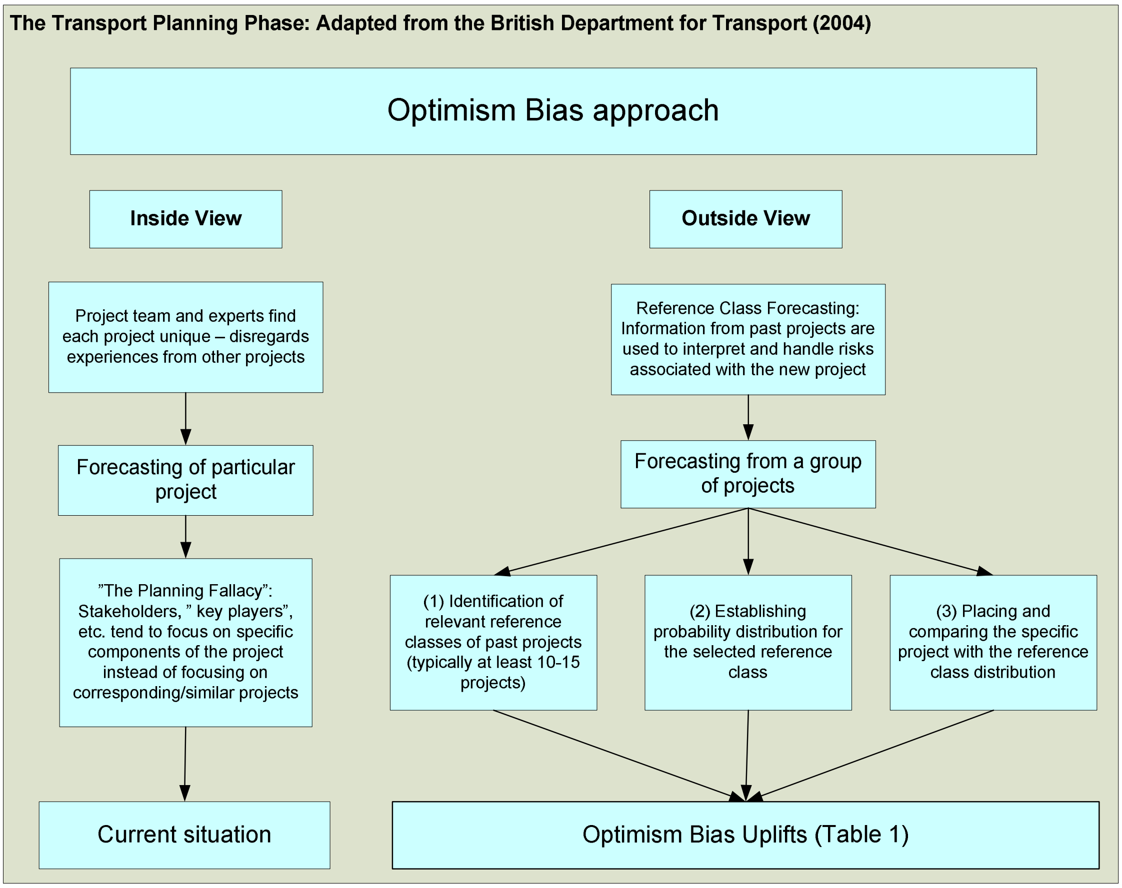

Figure 6. Principles for Optimism Bias and Reference Class Forecasting (Flyvbjerg & COWI 2004).

Optimism Bias and RCF basically take two different perspectives, namely an inside and an outside view. The *inside view* is always present within project appraisal even though the risks associated are well known. The inside view is held by the project team and "experts" closely associated with the project. Herein Optimism Bias is present in some degree on the risks of cost increases, time schedule delays, and benefit shortfalls (The Benchmark Center 2007).

The *outside view* is introduced where information on a reference class of similar or comparable projects are used in order to derive information about future possible events. By presuming that previous similar projects can lay the foundation for forecast scenarios, the outside view contributes to placing a statistical distribution based upon prior knowledge. The forecasting from a group of projects is included in a three-step procedure respectively, identifying relevant projects in a pool, establishing probability distributions, e.g. by fitting on derived data and finally placing the distribution on the specific project. RCF does not try to predict specific and uncertain events affecting the project in question. On the contrary it places statistical evident distributions describing the projects in the reference class to be evaluated (The Benchmark Center 2007).

The resulting outcome from the reference classes are determined by the Optimism Bias uplifts which are to be associated with the preliminary construction cost predictions. The uplifts should be applied to the estimated budget costs at the time of decision to build. Thus, uplifts are referred to as the cost overruns calculated in fixed prices. Table 1 shows some of the uplifts applicable within transport infrastructure projects, for different levels of certainty ranging from 50-90%.

	50%	**60%**	**70%**	**80%**	**90%**
Road	15%	24%	27%	32%	45%
Rail	40%	45%	51%	57%	68%
Fixed Links	23%	26%	34%	55%	83%

Table 1. Applicable capital expenditure uplifts for selected percentiles applied to constant prices (adapted from Flyvbjerg & COWI 2004).

The Optimism Bias uplifts shown above are classified according to the risk aversion of decision-makers in terms of cost overruns. If a group of decision-makers decides that the risk of a cost overrun must be less than 20% for a road type project, the construction cost estimate must be uplifted by 32%. Thus, if the initial budget estimate was 100 mio DKr the final budget taking into account the Optimism Bias at an 80% probability level would be 132 mio DKr. Flyvbjerg & COWI (2004) suggest only shifting between the 50 percentile (lower) and the 80 percentile (upper), thus, the upper percentile denotes investors with a high degree of certainty that cost overruns will not occur. This is typically present when no additional funds are available. The lower percentile should only be applied if decision-makers are willing to take a high risk that cost overruns can occur.

The key question now is how to assess and quantify the risk aversion each decision-maker holds and to make a generalized way of illustrating this. The proposed way in this thesis is to apply quantitative risk analysis (QRA) making use of Monte Carlo simulation (MCS). The following section describes the MCS in general together with a short summary of the applied probability distributions found relevant in the context of transport infrastructure project evaluation.

1.2 Quantitative Risk Analysis

The main objective of any risk analysis is to establish a rational foundation for objective decision making. The risk analysis aims at quantifying the undesirable effects that a given activity may impose on humans, environment or economical values. The objective of the decision process is then to identify the solution that in some sense minimizes the risk of the considered activity (Friis-Hansen 2005). Traditional risk analysis gives the decision-maker a mean by which he can look ahead to the totality of any future outcome. The advantage of using a quantitative risk analysis (QRA) approach is the possibility of differentiating the feature of risk information in terms of outcome criteria by probability distributions (Hertz & Thomas 1984).

QRA is traditionally used in the financial sector where the risks of buying stocks or bonds are determined (Vose 2000). Converting the QRA to transportation problems is done by defining a set of uncertain transport related impacts and hereafter determine the most descriptive discrete or continuous probability distribution function. Hereafter, each impact will be assigned a probability distribution where after the impacts are weighed together by the probability of occurrence. The theoretical foundation of assigning probability distributions on the uncertain impacts dates back to the Second World War (Rubinstein 1981). Two scientists, von Neumann and Ulam, code named their research in neutron fission in their search for the nuclear bomb: *Monte Carlo* s*imulation (MCS)*.

A complete risk assessment procedure is likely to consist of five steps (Vose 2000, p. 6), where the quantitative risk analysis is based in point three:

1. Identification of the risk that is to be analysed
2. A qualitative description of the problem and the risk – why it might occur, what you can do to reduce the risk, probability of the occurrence, etc. Possible methodologies could be coarse risk analysis, HAZOP[12] analysis, etc.
3. *A quantitative analysis of the risk and the associated risk management options that are available to determine or find an optimal strategy for controlling and hereby solving the risk problem*
4. Implementing the approved risk management strategy
5. Communicating the decision and its basis to various decision-makers.

[12] HAZard and OPerability study which is mainly used within off-shore and oil rig risk analysis

The main structure of a QRA model is somewhat very similar to a deterministic single value rate of return model except that each variable in the QRA model is represented by a probability distribution function (PDF). The resulting single point estimate from the CBA is transformed into an interval estimate illustrated in terms of a probability distribution in the QRA. The technique used in the following work is a Monte Carlo simulation which involves a random sampling method concerning each different probability distribution selected for the actual model set-up. As these distributions are defined, hundreds or even thousands of different scenarios can be produced. In the following, these types of scenarios are referred to as *iterations*[13]. Each probability distribution is sampled in a manner such that it reproduces the original shape of the distribution, meaning that the actual model outcome reflects the probability of occurrence.

Monte Carlo Simulation

The Monte Carlo simulation is a common technique for analyzing complex problems. In the context of modelling uncertainty in transport investment projects, the MCS model is considered stochastic. Stochastic simulation is a statistical sampling method where the procedure collects random numbers from a particular probability distribution, hence the name MCS. Originally, the Monte Carlo method was considered to be a technique using random numbers chosen from a uniform interval [0;1] (Law & Kelton 2000).

Sampling forms the basis for hundreds or thousands of 'what-if' scenarios. With 'enough' iterations from each input distribution the sampled values become distributed in a manner which approximates the known input distribution. Thus, the sampling process collects random values from the input distributions (Vose 2000). It has been found that the Latin[14] Hypercube Sampling (LHS) technique satisfied the MCS process by recreating the input distribution through a stratified sampling without replacement method. Stratification of a sampling area [0;1] means dividing the input probability distribution into intervals on the cumulative curve. The sampling procedure is then forced to represent the values in each interval, thus, recreating the input distribution. One of the main advantages of using LHS is that it economises with the number of iterations used within MCS hence the simulations process is speeded up compared to other sampling methods.

Vose (2000, p. 59) gives a step-wise procedure on how the LHS method performs in a typical risk analysis model combined with the MCS. A schematically

[13] The term iterations are used in the context of runs, e.g. a single iteration depicts a single run in the Monte Carlo simulation

[14] A Latin square is defined where the sample only consists of one value for each row and column hence LHS ensures per definition variation of sampling where the ensemble of random numbers from the input distribution is a "valid" representation.

overview of the process is shown in Figure 7 adapted from Hertz and Thomas (1984). The MCS set-up is applied in the transport area in which six typical effects are treated.

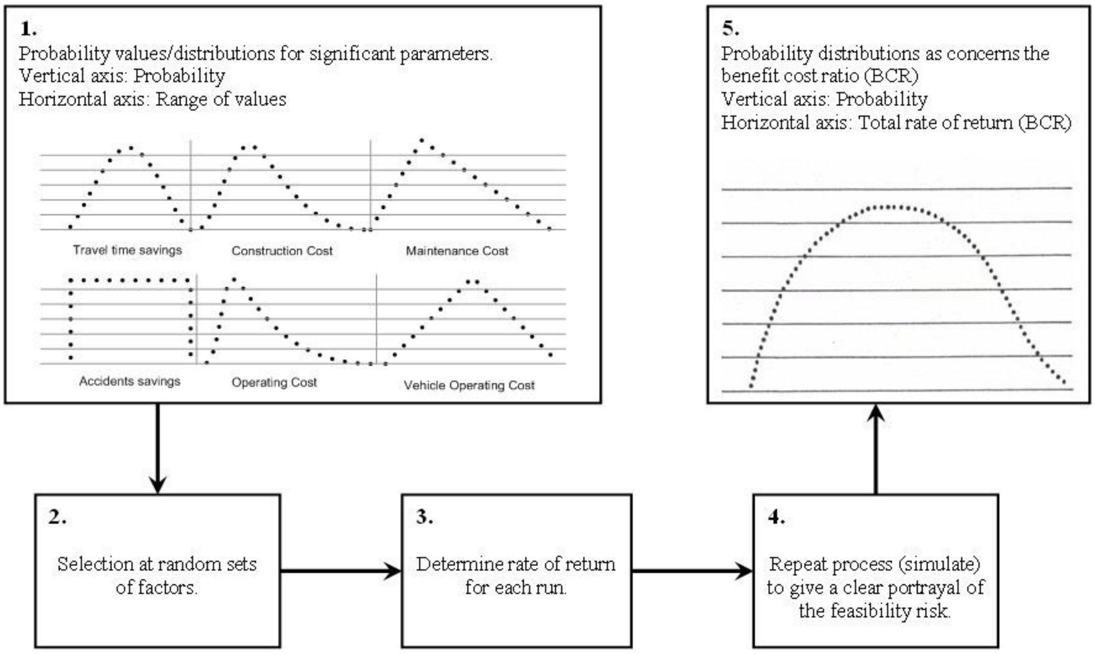

Figure 7. The sampling process applied for Monte Carlo simulation in the CBA-DK modelling framework (adapted from Hertz and Thomas (1984), p. 32).

The final procedure of the QRA is now to assess and define suitable input distributions to describe the uncertain parameters in the modelling framework.

Deriving Suitable Probability Distributions

A common mistake within risk analysis is to apply wrong or inadequate[15] probability distributions. A common bias is the distinction between actual data fit and "expert opinion" in the derivation of distribution functions. Interpreting the level of knowledge (LoK) on the uncertain parameters or variables allows the analysts to define the best and most suitable input distribution. If the uncertain parameter more or less is defined in literature or by data, *parametric distributions* should be applied, e.g. normal, gamma and beta. If, the uncertain parameter relies on experts to judge the uncertainty, *non-parametric distributions* should be assigned, such as triangular and uniform (Vose 2000, p. 273). Care must be taken in applying parametric distributions since they rely on mathematics describing

[15] Inadequate in the sense of mis-representing past data sets in terms of distribution type, input parameters or mean values.

their shape. Vose (2000) proposes only to apply parametric distributions, if and only if, (1) the theory underpinning the chosen distribution applies for the particular problem, (2) general acceptance of the specific problem, where it has been proven useful to apply the specific probability distribution, and (3) the distribution approximately fits the expert opinion being modelled and the required level of accuracy is not too high.

The simulation model made use of in this thesis, @RISK, presents 31 continuous and 8 discrete probability distribution functions (Figure 8).

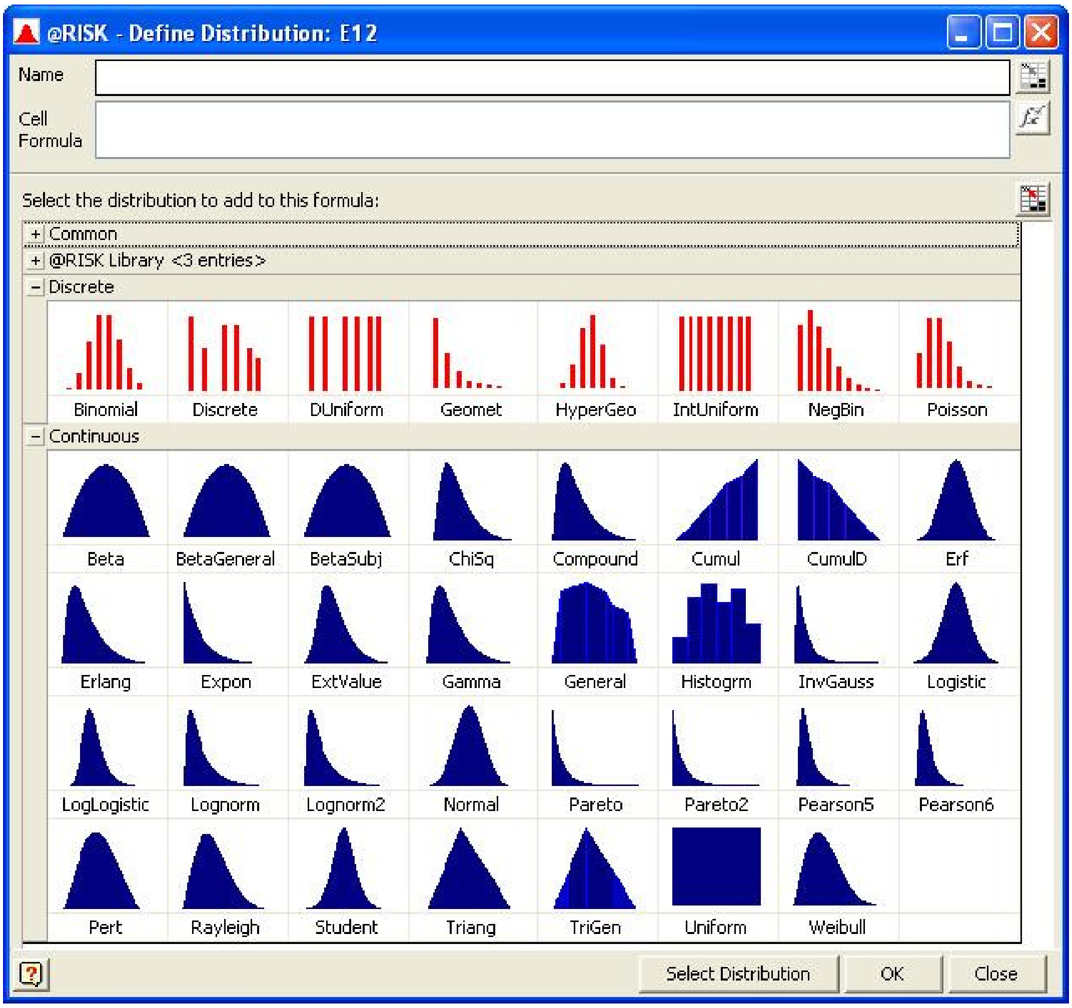

Figure 8. Available probability distributions within the software of @RISK.

These distribution types can be further explored and adapted with regard to their applicability in risk analysis related to transport project assessment, as described in the following sections.

The Uniform Distribution

The simplest applied distribution in this context is the uniform distribution (rectangular distribution). In a uniform distribution, the probability of occurrence is the same for all 'values' chosen in the interval (Figure 9). For example, if a fair dice is thrown, the probability of obtaining any one of the six possible outcomes is 1/6. Since all outcomes are equally "probable", the distribution is uniform as illustrated in Figure 9. The uniform distribution is classified as non-parametric due to its input parameters in which a minimum and maximum value is to be applied.

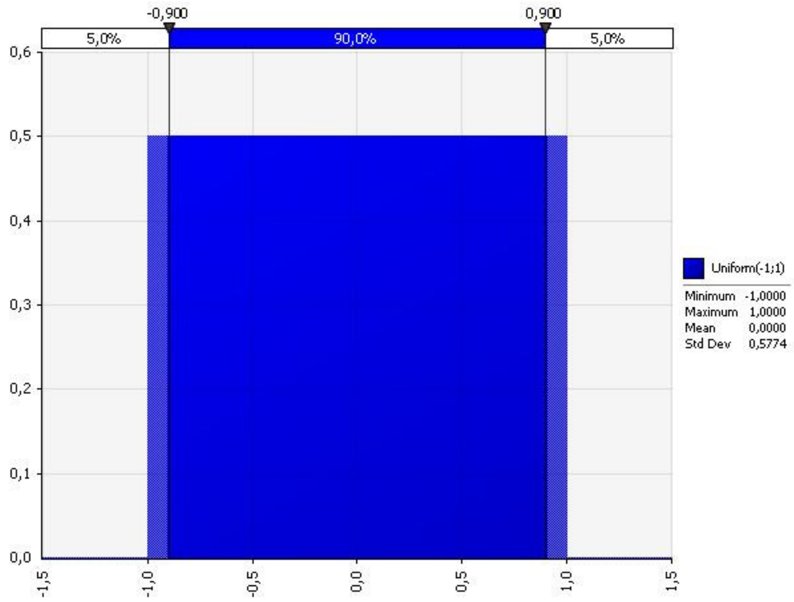

Figure 9. Illustration of a uniform distribution [-1:1] from @RISK.

This distribution function has previously been applied within the modelling of accidents saved for a particular transport infrastructure project. However, since the distribution allows for the same probability of occurrence in the entire interval, the distribution function is henceforward only applied within the modelling of non-monetary impacts treated within a multi-criteria analysis (Goodwin & Wright 2004).

The Triangular Distribution

The triangular distribution is typically used as a subjective description of a population for which there is only limited sample data. It is based on knowledge of the minimum and maximum and an inspired guess (referred to as the Most Likely value – *mode*). Despite being a simplistic description of a population, it is a very useful distribution for modelling processes where the relationship between variables is known, but data is scarce. The triangular distribution or in an enhanced version: the *Trigen*-distribution, allows the upper and lower boundaries to be skewed (Palisade 2002, 2007). The *Trigen*-distribution further offers the analyst the possibility of choosing a confidence interval, where the upper and lower boundaries can be exceeded within a predefined percentage, see Figure 10. This distribution function is also classified as non-parametric due to its inputs as described earlier.

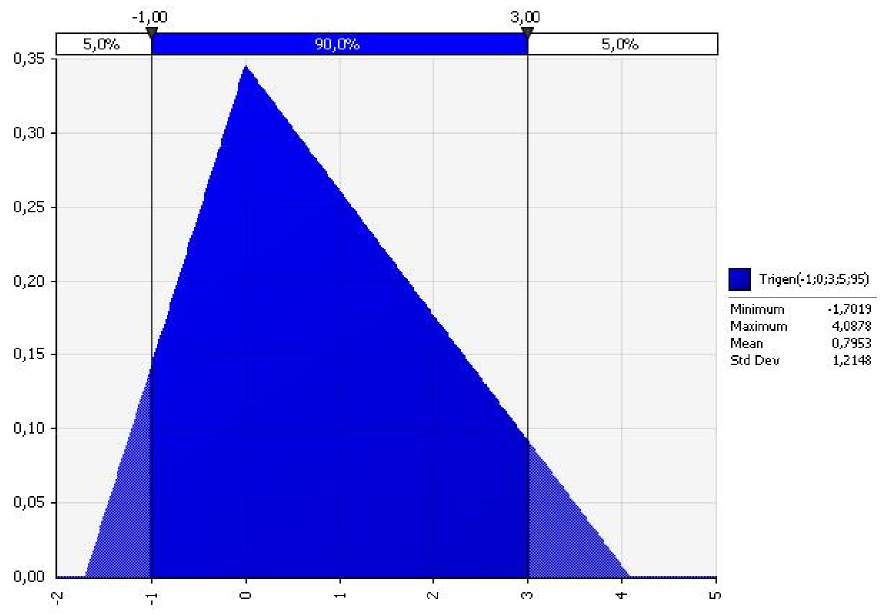

Figure 10. Illustration of a Trigen distribution with [-1;0;3] and open ended boundaries of 5%.

The *Trigen*-distribution has been applied on the accident impact where decision-makers are able to decide of a lower and upper boundary of the effect. This effect is treated in impact models where so-called black spot analyses are performed together with traffic flow analyses. The number of accidents saved is hereby relatively certain, however, this particular impact is of huge importance towards political decision-making. Lower and upper boundaries should be set with that in mind.

The Beta-PERT Distribution

The Beta-PERT distribution (from here on referred to as the PERT distribution) is a useful tool for modelling expert data. PERT (Program Evaluation and Review Technique) originates from 1958 where it was assigned a so-called schedule procedure (Lichtenberg 2000). The PERT distribution is derived from the beta distribution which mathematically is fairly simple and furthermore covers a huge variety of skewness types. When used in a MCS, the PERT distribution can be used to identify risks in project and cost models especially based on the resemblance to the triangular distribution. As with any probability distribution, the usefulness of the PERT distribution is limited by the quality of the inputs: the better your expert estimates, the better results you can derive from a simulation. An illustration of the comparison between the triangular and PERT distributions is given in Figure 11.

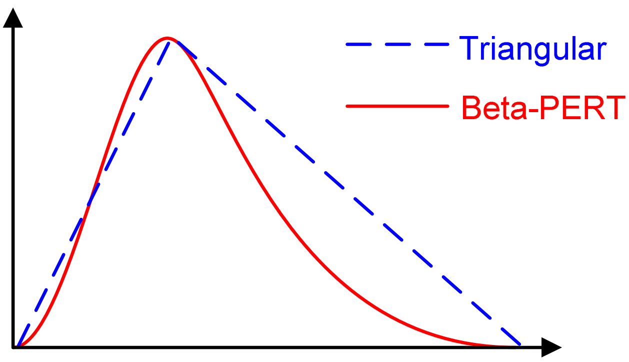

Figure 11. Illustration of the PERT distribution compared with a triangular distribution.

Like the triangular distribution, the PERT distribution *emphasizes* the 'most likely' value over the minimum and maximum estimates, contributing to the non-parametric dimension of the distribution function. However, unlike the triangular distribution the PERT distribution constructs a smooth curve which places progressively more emphasis on values around the most likely value, in favour of values around the edges, i.e.

$$Mean_{Triang} = \frac{Min + Mode + Max}{3} \text{ vs. } Mean_{PERT} = \frac{Min + 4 \cdot Mode + Max}{6}$$

The average of all three parameters in the PERT distribution has four times the weighting on the mode. In real-life problems we are usually capable of giving a more confident guess of the mode rather than of the extreme values, hence the PERT distribution brings a much smoother description of the tales of the impacts to be considered (Vose 2000). In practice, this means that we 'trust' the estimate for the most likely value, and we believe that even if it is not exactly accurate (as estimates seldom are), we have an expectation that the resulting value will be close to that estimate.

Application of the PERT distribution

This distribution, given the extra emphasis on the mode value, makes it ideal for modelling expert opinions of a variable. This distribution type has been applied to the maintenance unit costs as well as the travel time savings. Thus, newly suggested use of the PERT distribution has been implemented and fitted against historical data derived from Flyvbjerg et al. (2003).

Demand forecasts[16] in the transport sector make up a substantial part of any socio-economic analysis. Traffic prognosis, being a part of this, lays the basis for calculating travel time savings stemming from transport infrastructure projects. The embedded uncertainty in deriving these forecasts depends on the time and effort put into data collection and traffic modelling. It is important to distinguish between the uncertainty involved in predicting future traffic flows and the embedded modelling uncertainty corresponding to traffic models as illustrated in Figure 5 depicting the different sources of uncertainty.

The literature and data study performed by Flyvbjerg et al. (2003) was based upon hundreds of large-scale infrastructure projects with regard to traffic demand forecasts. This comparative study relied upon reference class forecasting in collecting ex-ante based and ex-post based data sets from different transport-related projects covering rail, road and fixed link projects (Flyvbjerg 2007). This study concluded that generally, traffic forecasts within road projects are within a threshold of ±40% accuracy. It also concluded that generally, traffic forecasts with respect to road type projects are underestimated with an average of 9%, however with a relatively high standard deviation on 44%. Secondly, 27 rail project forecasts with respect to the inaccuracy for traffic demand forecasts was compared with an average of 39% lower traffic than predicted (Flyvbjerg et al. 2003, p. 26). The approximated range of demand forecast bias is set between -92% and 144% which results in a relatively high standard deviation of 52%.

Figure 12 illustrates a sample of 183 road projects depicting respectively under- and overestimations of the traffic demand forecasts. The inaccuracy of the traffic demand forecasts is clearly skewed to the right which means that distribution functions that allow skewness are needed to represent this data set. Unfortunately, the exact data material used is confidential due to copyrights. Thus, the data

[16] In this thesis, demand forecasts acts as traffic prognosis which among others lays the foundation for traffic model calculations, i.e. travel time savings

depicted in Figure 12 are found by interpolation of data points from Flyvbjerg et al. (2003).

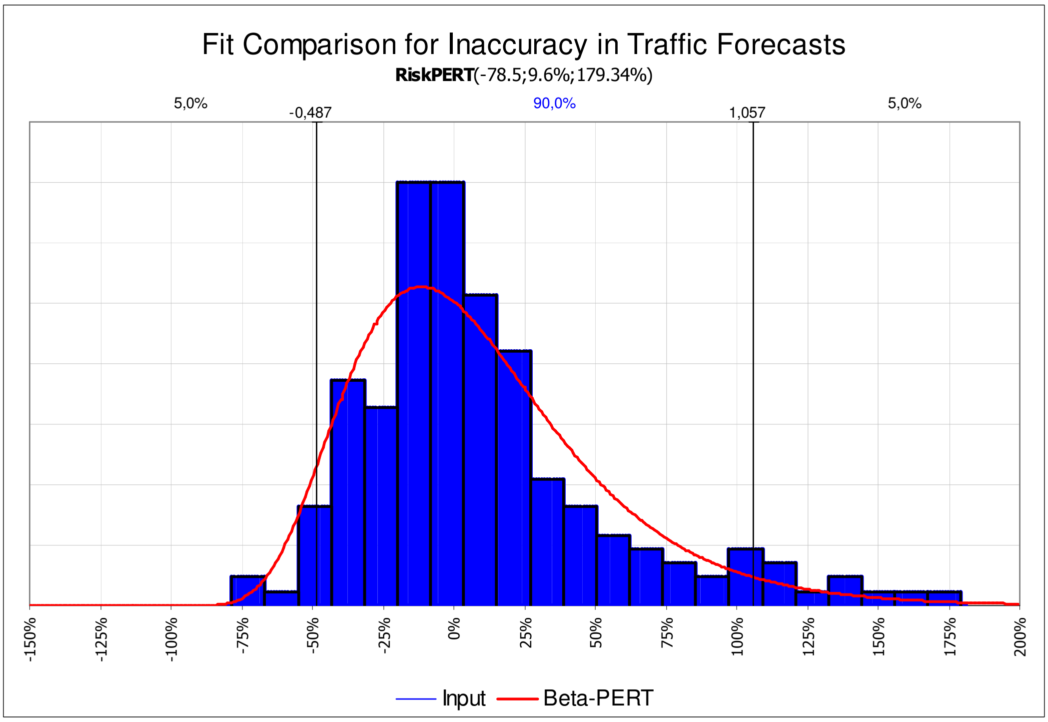

Figure 12. Inaccuracies of traffic forecasts in 183 road projects, calculated in percentage between ex-ante and ex-post analyses (adapted from Flyvbjerg et al. (2003) p. 27).

The blue bars depict the inaccuracy of traffic demand forecasts of 183 road type projects. The inaccuracy is defined as traffic demand counted in the first year of operation compared with the forecasted traffic determined before operation. Hence the forecasted traffic estimate for the first year of operations is estimated at the time of decision to build. The red curve has been fitted in @RISK version 4.5 from Palisade (2002). The data points fitted are shown in the top as:

RiskPERT(-78.5%; 9.6%; 179.34%)

The second fit comparison for inaccuracies in traffic demand forecasts is shown in Figure 13. This diagram illustrates overestimations for rail type projects occurring in 85% of the cases. Herein, nearly one third of the projects lie within a threshold of -70% and 30% of overestimations. A negative sign corresponds to overestimation of demand forecasts whereas a positive sign corresponds to underestimations.

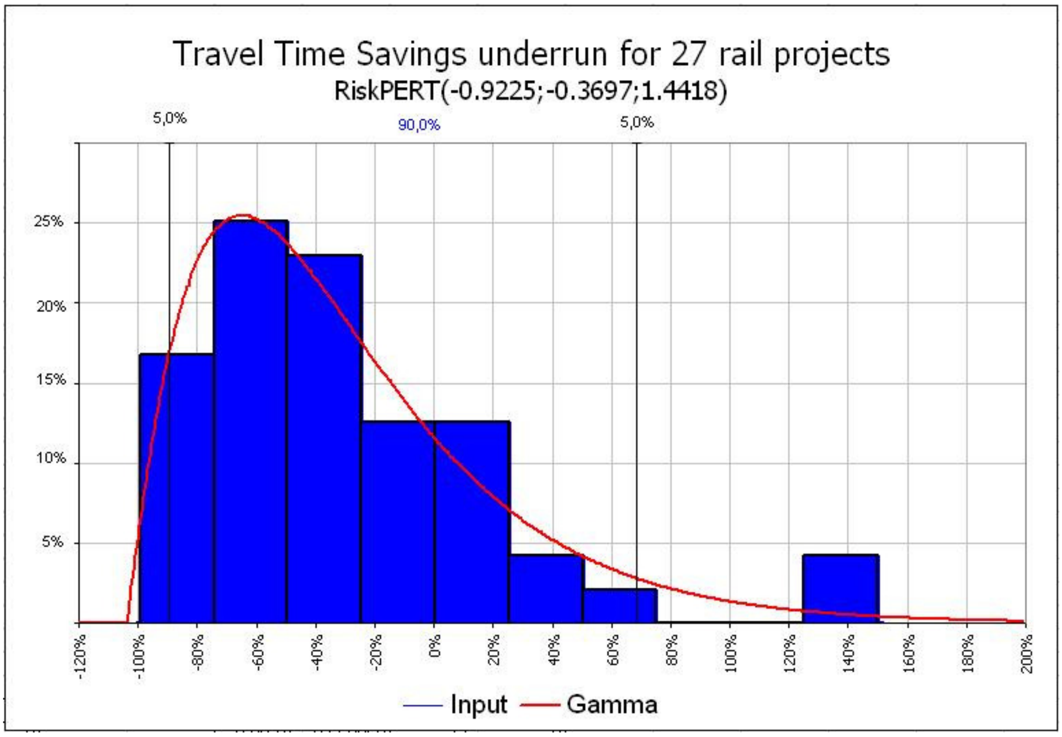

Figure 13. Inaccuracies of traffic forecasts in 27 rail projects calculated in percentage between ex-ante and ex-post analyses (adapted from Flyvbjerg et al. (2003) p. 27).

The data samples illustrated in Figure 12-13 show the inaccuracy in traffic forecasts skewed to the right. Even though the distribution is clearly skewed to the right, most emphasis must be placed on the central probability mass. A prior acknowledgement from David Vose[17] and David Kelton[18] proposes the use of a PERT distribution for cases with a relatively high degree of skewness. From both Figure 12 and 13 it is clear that the data fit from a PERT distribution is valid. The data points fitted are shown in the top as:

RiskPERT(-92.3%; -37%; 144.2%)

The Normal Distribution

The normal distribution is an extremely important probability distribution in many fields. The normal distribution is a family of different distributions of the same general form, however, differing in their *location* and *scale* parameters: the mean and standard deviation, respectively. The standard normal distribution is the normal distribution with a mean of zero and a standard deviation of one (Figure 14). Some of the most notable qualities of a normal distribution are that it is

[17] Discussion at the 2nd European Palisade User Conference (2007) – London, UK
[18] Discussion at the 40th Winter Simulation Conference (2007) – Washington DC

symmetric around the mean and the mean is also both the mode and median value. The normal distribution is considered parametric due to its mathematical description.

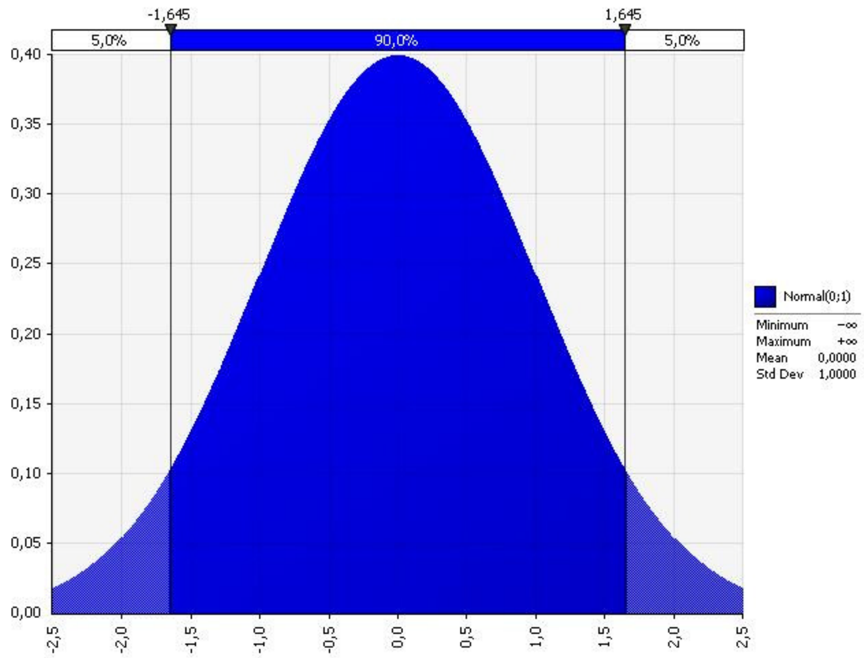

Figure 14. Illustration of a standard normal distribution from @RISK.

Application of the distribution

The normal distribution has been applied the travel time savings (TTS) effect where studies have been conducted, e.g. de Jong et al. (2005) and Knudsen (2006). De Jong et al. (2005) and Knudsen (2006) focus upon the actual traffic model uncertainties whereas Flyvbjerg et al. (2003) focus on the inputs to the latter. In the previous section, a PERT distribution has been fitted towards the uncertainty of deriving demand forecasts. This type of distribution has been found suitable in interpreting uncertainties in the actual traffic models. Thus, the PERT and normal distributions are used to classify the same type of uncertainties, however, in different situations.

Knudsen (2006) investigates the uncertainty in a 4-step traffic model by the use of a comparative study between various standard deviations. She concluded that even a small analysis area creates substantial variations of standard deviations with respect to various model assumptions. De Jong et al. (2005) give an elaborate description of various modelling errors in the determination of TTS from substantial literature reviews. Furthermore it was concluded that general standard errors stemming from traffic models are impossible to determine (de Jong et al.

2005, pp. 8-10). Hence it has been found that the use of the normal distribution should be limited. Specifically, the conditional definition of the distribution with open ended tales causes difficulties in the implementation due to cases where large negative parameters can be selected and inserted in the MCS.

The Erlang Distribution (Gamma)

The Erlang distribution is a probability distribution with wide applicability primarily due to its relationship with the exponential and gamma distributions. The Erlang distribution was developed by A. K. Erlang[19] to examine the number of telephone calls which might be made at the same time to the operators of the switching stations. This work on telephone traffic engineering has been expanded to consider waiting times in queuing systems in general. The distribution is now used in the field of stochastic processes.

The Erlang distribution has a positive value for all the numbers greater than zero, and is parameterized by two parameters: the shape *k*, which is an integer, and the rate λ, which is real. The distribution is sometimes defined using the inverse of the rate parameter, the scale *θ*, applicable within the software program @RISK. The Erlang distribution has been found useful in combination with the so-called Lichtenberg principle in obtaining a mean and a standard deviation from successive calculation (Lichtenberg 2000). Succesive calculation is derived in the context of determining construction cost estimates and especially usefull in interpreting the uncertainties involved.

The mean value (μ) is determined on basis of the shape parameter. For $k = 1$ the Erlang distribution is similar to the exponential distribution and if *k* increases the Erlang distribution is similar to the normal distribution. The mean is hence forward k/λ or $k \cdot \theta$ and the mode is defined by (k-λ)/λ only for $k \geq 1$. The applicability of the Erlang distribution is widespread especially in the context of production processes and the uncertainty of production cut-offs. The uncertainties as concerns production processes relate to unforeseen production stops, e.g. by human interventions or mechanical shut downs. Herein the process “dies” and “revives” after a certain period of time where the number of revivals can be described by the *k* value (Vose 2000).

The cause-effect is then describing the procedure of shut downs, for instance if only one cause exists the *k* value is set to 1 and the distribution functions can be described by an exponential distribution. In practice unforeseen shut downs are not caused by only one source, but by several, hence the applicability of the Erlang distribution, where $k > 1$. Lichtenberg (2000) makes use of an analogy

[19] Agner Krarup Erlang (1878-1929) was a Danish mathematician, statistician and engineer who was active in the fields of tele-traffic engineering and queuing theory.

described by the 9 lives of a cat. The interpretation of a cat's life span can be described by $k = 9$ where each "death" and "revival" depicts the 9. A set of Erlang distributions is illustrated in Figure 15 where various shape parameters are tested.

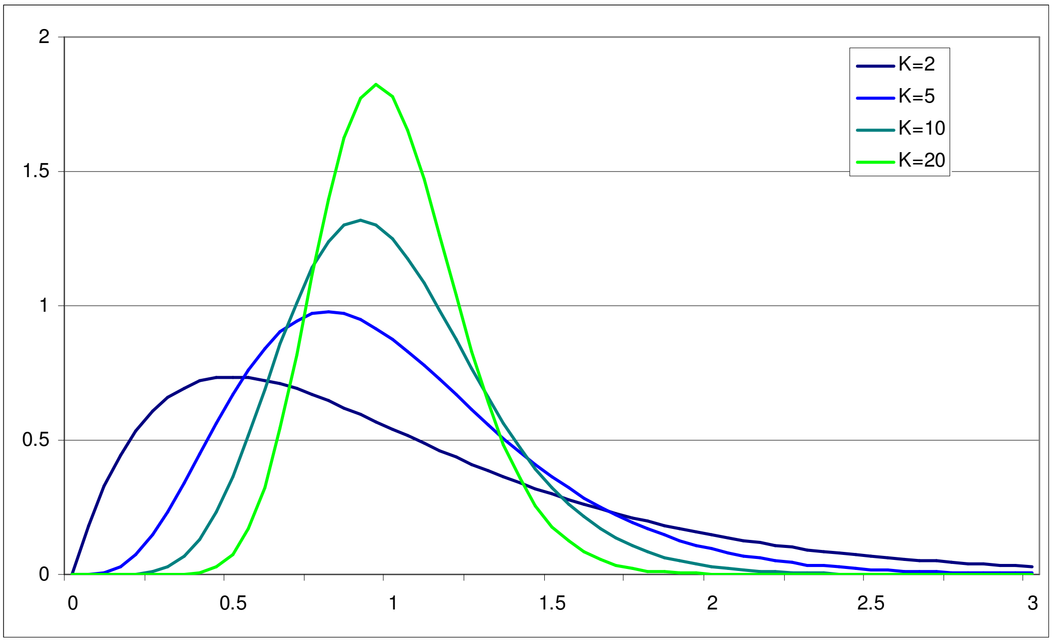

Figure 15. Illustration of the Erlang distribution for various shape parameters.

Input parameters to the Erlang distribution are calculated by use of Lichtenberg's principle taking into account the upper and lower bound together with the most likely (ML) value based upon successive calculation. The strength of applying the principle is that the decision-maker only has to consider a minimum, ML and maximum value. It is, among other things, used for several issues including support, optimizing and estimating budget allowances especially within the construction area (Lichtenberg 2000, pp. 151-168). Some other key areas where the principle has been applied are strategic planning and risk analysis. Then by use of a so-called triple estimation approach, the mean (Equation 7) and the standard deviation (Equation 8) is calculated by the two following formulas (Lichtenberg 2000, p. 125):

$$\mu = \frac{(\min. + 2.9 \cdot ML + \max.)}{4.9} \tag{7}$$

$$s = \frac{|\max. - \min.|}{4.65} \tag{8}$$

The properties of the Erlang distribution requires a shape (k) and a scale (θ) parameter. The relationship to the scale parameter is found by the equation (9):

$$\theta = \frac{\mu}{k} \tag{9}$$

The applicability of the Erlang distribution is then related to the variation of the scale and shape parameter as illustrated in Figure 15.

Application of the distribution

Construction costs for large public procurements tend to be underestimated meaning that appraisals seem to be over-optimistic with regard to the costs of the project. Mis-interpretation of ex-ante based costs, deliberately or otherwise, results in budget overruns. By use of literature studies it has become clear that estimating construction costs involves a relatively high degree of uncertainty. Studies conducted in the US, UK and Denmark all contribute to the interpretation and in some cases measurement of the uncertainty within ex-ante based construction cost derivation, see MacDonald (2002), Flyvbjerg et al. (2003), Flyvbjerg & COWI (2004), Back et al. (2000) and Lichtenberg (2000).

Flyvbjerg et al. (2003) has investigated cost overruns for 167 large-scale road and 58 rail infrastructure projects. The tendency is clearly right skewed where cost overruns are commonly occurring. In fact an average of 20% cost overrun among the 167 road projects and an average of 45% overrun for rail projects are derived. Figure 16 and Figure 17 have been interpolated through the data sets from Flyvbjerg et al. (2003) p. 17 and fitted against an Erlang distribution. A more detailed analysis of the data has been given in Salling & Banister (2008).

The inaccuracy in this context is defined as construction costs counted in the first year of operation compared with the ex-ante based construction costs in the planning phase of the project. For instance a positive sign in the two diagrams depicts cost overruns whereas a negative sign depicts cost under runs.

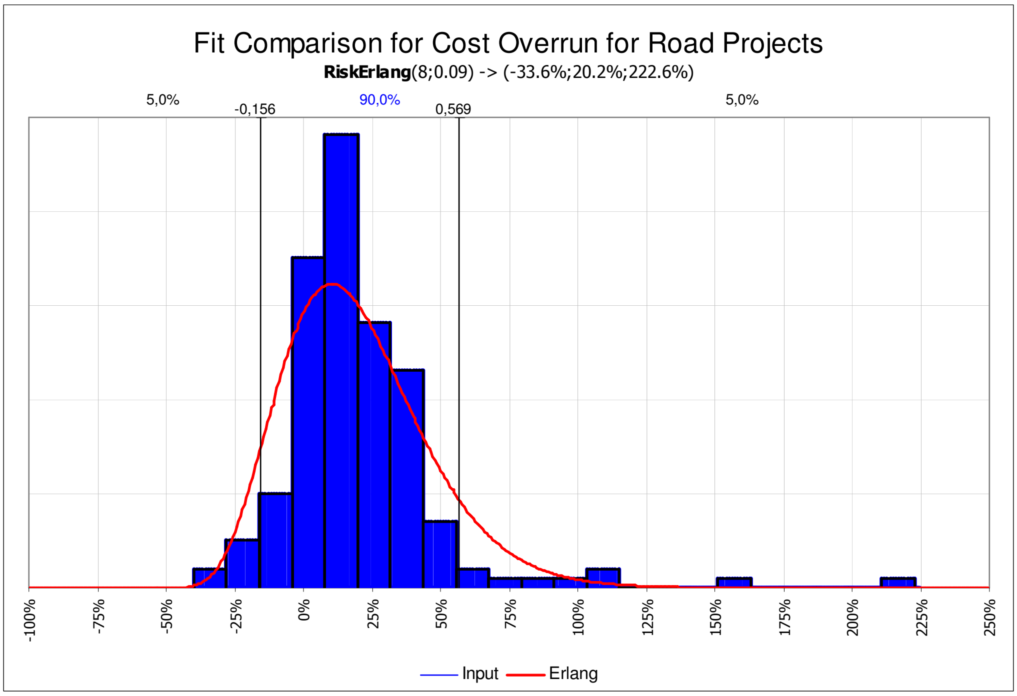

Figure 16. Inaccuracies of construction cost estimates of 167 road infrastructure projects (adapted from Flyvbjerg et al. (2003) p. 17).

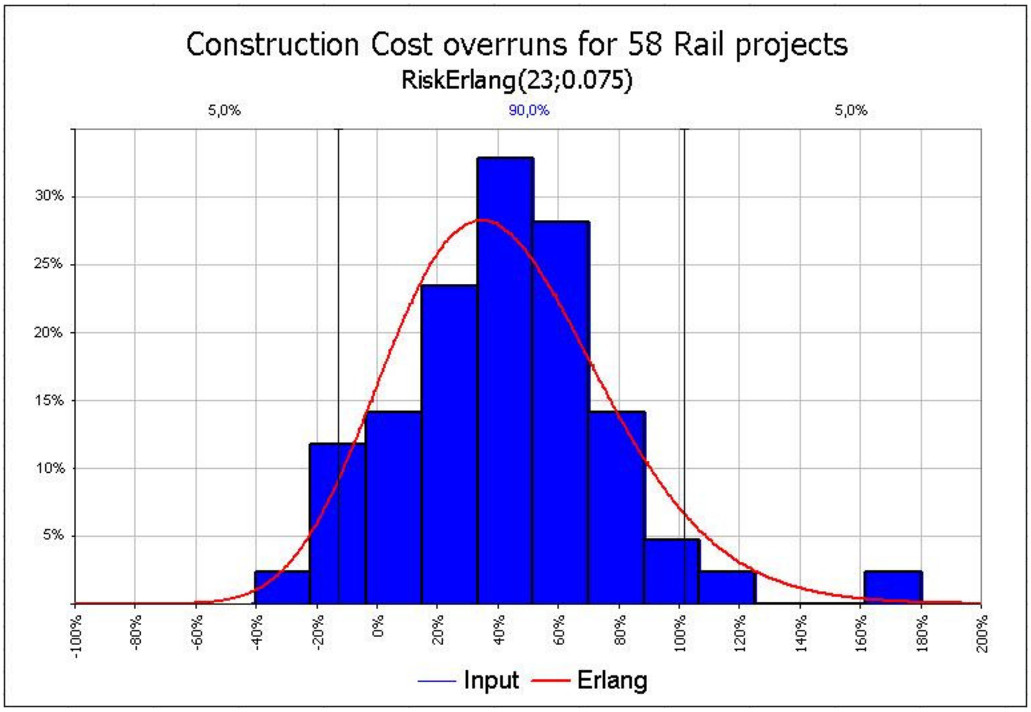

Figure 17. Inaccuracies of construction cost estimates of 58 rail infrastructure projects (adapted from Flyvbjerg et al. (2003) p. 17).

Figure 16 and 17 illustrates the fit by using the Erlang distribution on the data from the previous road type projects (Flyvbjerg et al. 2003, p. 17). The data fits are conducted by the use of maximum likelihood estimators in which distribution parameters are estimated. The goodness of fit is interpreted by using Chi-squared statistics (Vose 2000; Palisade 2007). The distribution function towards road projects is fitted with a shape parameter of $k = 8$ and a scale parameter of $\theta = 0.09$ whereas the rail project is fitted with $k = 23$ and $\theta = 0.075$.

The implementation of an Erlang distribution relies upon the shape parameter depicting how much skewness the distribution is assigned. It has been found that a shape parameter in the range of $k = 4$-9 matches the distribution of the uncertainty involved in determining the construction cost (Rosenstand 2007). The resulting standard error of k for relatively small fluctuations is, however, found to be insignificant compared with normal practical uncertainties (Lichtenberg 2000, p. 128). Currently, a shape parameter of 5 is used for road type projects in the decision support model described later. Clearly, a higher shape parameter should be applied in rail infrastructure projects.

Summary

The two types of distributions applicable within CBA-DK, parametric and non-parametric distributions are summarized in Table 2 together with their sources of uncertainty, level of knowledge (LoK) and the transportation impacts, where they can be useful to apply.

Distribution	Category	LoK	Impact	Source
Uniform	Non-parametric	Low	Non-monetary	Multi-criteria analysis
Triangular	Non-parametric	Low	Accident savings	Pricing strategies
Beta (PERT)	(Non)-parametric	Medium & High	Maintenance costs & Travel time savings	Pricing strategies & Model uncertainties
Normal	Parametric	High	Travel time savings	Model uncertainties
Gamma (Erlang)	Parametric	High	Construction costs	Model uncertainties

Table 2. List of applied probability distributions and their level of knowledge.

Substantial effort has been placed upon the selection process from the 30 available probability distributions from @RISK to the five presented distributions above. The five distributions have all been tested and validated trough case study applications varying from air to rail and road transport projects. Obviously, it is preferable to assign distributions as a result of a data fit, however, since data are sparse this is often not possible. Thus, the listed distributions from Table 2 assist analysts and decision-makers in choosing the most suitable ones.

1.3 Feasibility Risk Assessment (FRA)

Complementing cost-benefit with quantitative risk analysis enables a more comprehensive type of assessment. This wider type of analysis has been determined as feasibility risk assessment (FRA). A main question in this Ph.D. study is *whether the FRA suggested for evaluation of transport infrastructure projects can lead to more "useful" decision support (by moving from single point estimates to interval results)?*

The FRA is connected by the CBA and QRA approaches as shown in Figure 18.

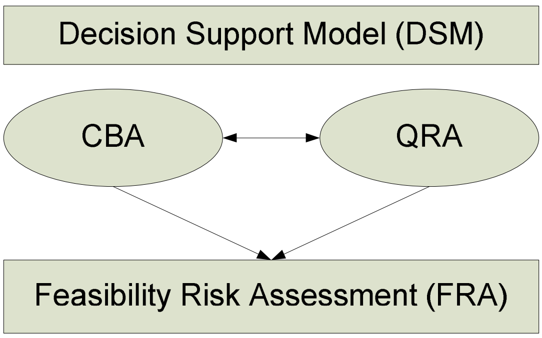

Figure 18. The feasibility risk assessment procedure.

The procedure outlined in Figure 18 form the basis of feasibility risk assessment. The conventional cost-benefit analysis, although it tends to be a "black-box" with respect to the aggregation of benefits and costs into one single point evaluation criterion, is particular appealing due to its flexibility and adaptability. However, the resulting single point result in CBA calls for a more elaborate review due to the "false sense of security". These results often lead to wrong decisions where uncertainties of the underlying models somehow are forgotten. The QRA can handle this issue by making use of various relevant probability distributions on the most uncertain elements within the CBA. A main purpose is to make the risk analysis transparent and practical in use, e.g. by decision-maker involvement at an early stage of the process.

A main communication mean in FRA is the accumulated descending graph (ADG) as seen in Figure 19. The intersection between the vertical line *A* and horizontal line *B* is where the BCR equals 1.0. The 90% interval shown below the x-axis becomes a main concern for the decision-makers (Salling & Leleur 2006).

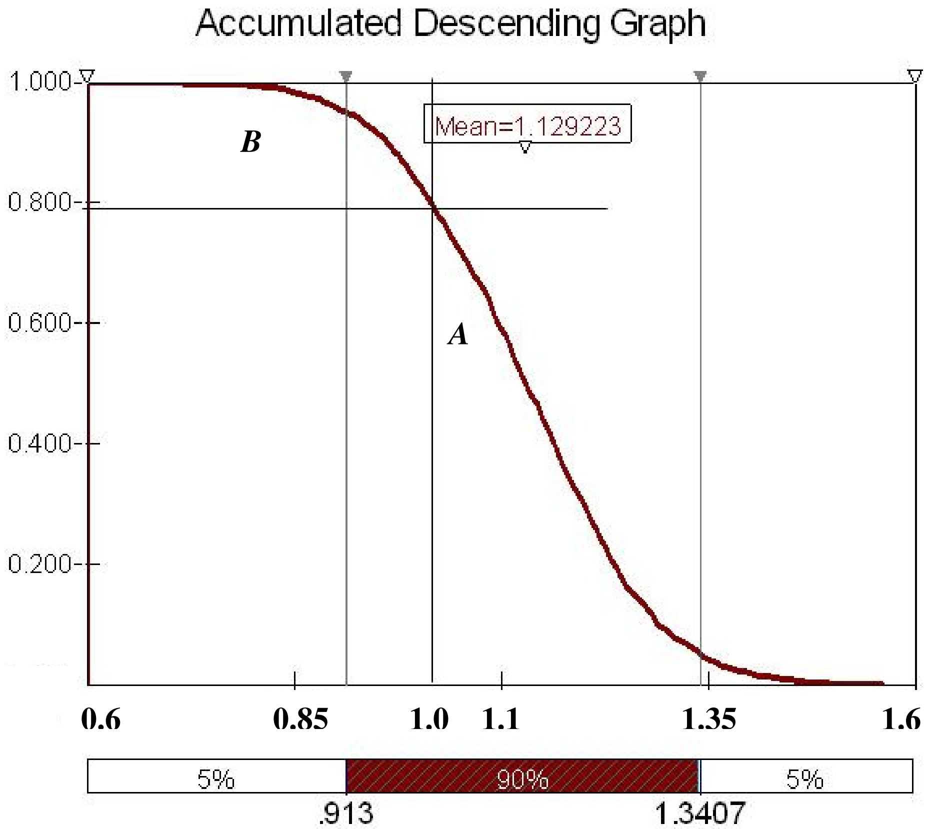

Figure 19. Accumulated descending graph illustrating the variation in probability of the BCR. The y-axis indicates the probability of the project having a BCR greater than or equal to the x-axis value.

The content of FRA can be illustrated in the following way. By moving the horizontal line of *B* upwards the risk aversion lowers. Hereby, the intersection with the vertical line *A* decreases with respect to the BCR, which means that if decision-makers allow high risks the rate of return will be higher and vice versa. Hereby the FRA in the actual case makes the decision-makers debate the specific risk conditions they want to adopt to frame the decision.

Pros and Cons of QRA and FRA

It is increasingly demanded from stakeholders and decision-makers to make comprehensive decision support models. Even though cost-benefit analysis is a very standardized method in performing appraisal studies on transport projects the handling of uncertainties is required. QRA converts the single point estimate into interval results depicting cumulative probability curves of the outcome from CBA. The application of decision support results can assist the decision-makers in making more informed decisions. Furthermore, the decision-makers have the possibility of viewing different project alternatives in one single graph. Special risk aversions towards choosing the most optimal solution are depicted by the intersections of alternatives, where preferences and agendas can be assessed.

Valid information about input distributions is, however, vital in making the decision support model comprehensive. Theoretical contributions to the QRA area are extensive when it comes to financial and off-shore analyses, however, QRA within the transportation area in general still lacks a general implementation. The five chosen input distribution functions are all continuous and widely applicable in any field of risk analysis. Two distributions have, however, proven to be very useful in the interpretation and handling of uncertainties within transport infrastructure assessment, namely the PERT and Erlang distributions.

The build-up and investigation of QRA within decision support with respect to transport projects is a rather new area of research. Few very specialized studies exist where, particularly, the choice of input distributions is narrow and unambiguous. In the present study, substantial effort has been put in testing and implementing the various probability distributions whereby decision-makers achieve the best informed decision support available. In this context new research such as Optimism Bias and practical RCF has recently been implemented in the UK (Flyvbjerg & COWI 2004).

The UK Department for Transport uses a set of Optimism Bias uplifts towards the estimated construction costs. This can be explained as an advanced type of sensitivity analysis producing new decision criteria in which the uncertainty of cost overruns is embedded. Decision-makers are now presented with an interval on which to base their decisions instead of point estimates. Performing a set of sensitivity tests copes with some of the uncertainties within transport infrastructure assessment. However, the problem concerning the number of “what if” scenarios remain, as there are situations where combinations of one or more uncertain impacts produce a large number of scenarios. The present study proposes to apply probability distributions with MCS to handle the complexity of combinations where two or more uncertain impacts can be included. This method uses combinatorial evaluations to perform uncertainty analysis on travel time savings and construction costs. The simulation approach differs from the Optimism Bias that is heavily dependent on detailed empirical analyses to determine the values to be used.

2. The CBA-DK Model

The CBA-DK decision support model is comprised by two modules respectively a deterministic and a stochastic module as shown in Figure 20. A more detailed description of CBA-DK, which also can serve as a documentation report, is presented in Appendix 1. Among other things it contains an overview description of the @RISK software program version 4.5 and 5.0[20]. Each of the following boxes in Figure 20 denotes a separate worksheet within Microsoft Excel that forms the basis of the cost benefit analysis calculation procedure. The CBA part is based solely on the issued guidelines by the Danish Ministry of Transport in 2003 (DMT 2003). These guidelines concentrate on the use only of cost-benefit methods, where future investments are calculated and assessed by the use of single point estimates. As described an important aim of this study is to examine whether the introduced feasibility risk assessment concept may be useful. The risk analysis is carried out by add-on software from Palisade named @RISK that implements a Monte Carlo simulation (Palisade 2002; 2007).

One of the key advantages of the CBA-DK framework model is the operability and flexibility of the system. The papers 1-6 in chapter 3 show six different implementation schemes ranging from road to rail to airfield appraisals. For each implementation, a customized decision support model is created and the worksheets are altered in an automated process. New users of the software will be able to conduct stand-alone analyses in their field of interests ultimately resulting in a feasibility risk assessment.

[20] @RISK version 5.0 was published December 2007 and purchased March 2008. Most of the case calculations have been made by the use of @RISK version 4.5, see Appendix 1

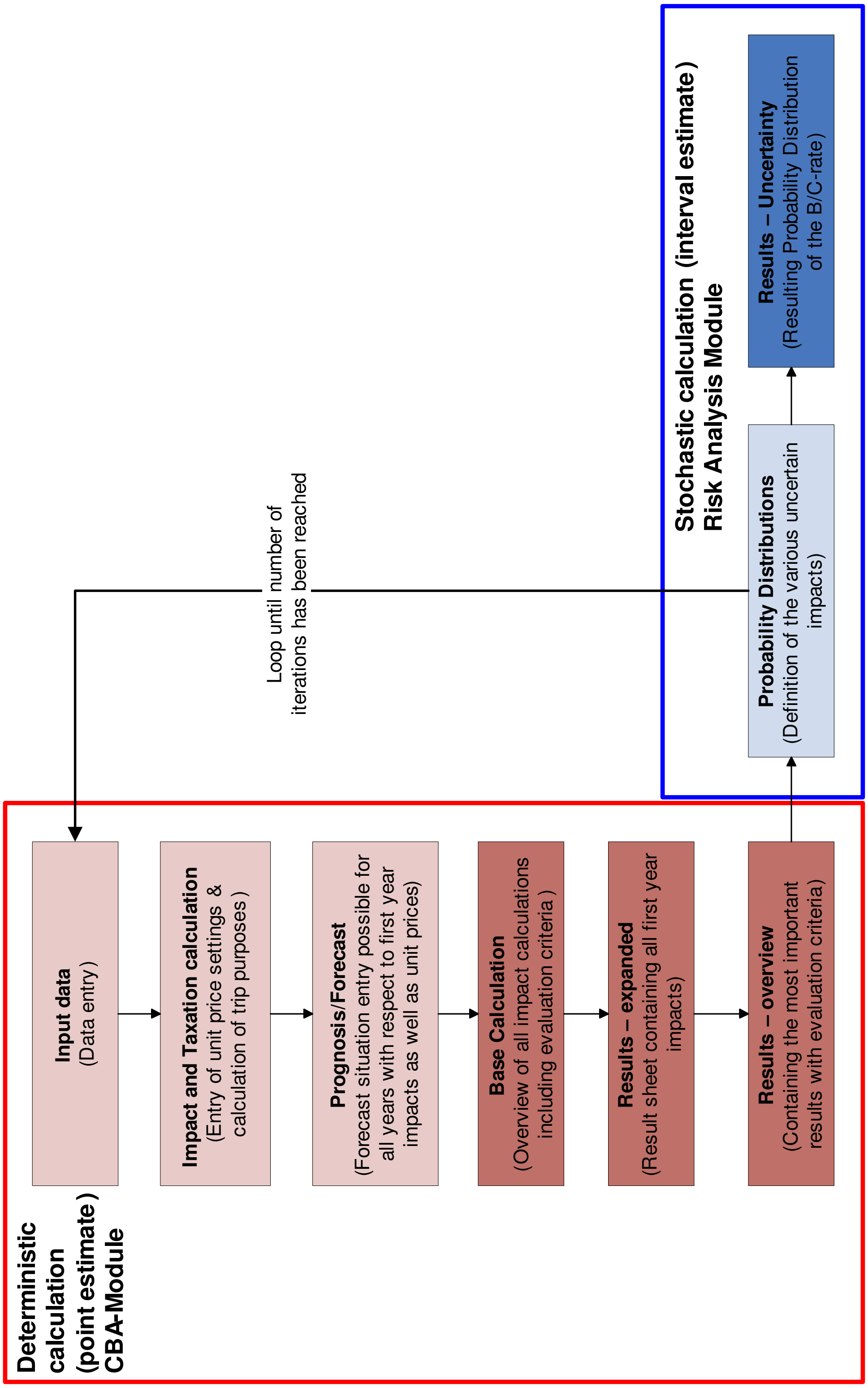

Figure 20. The module structure of CBA-DK for a more elaborate description see Appendix 1.

2.1 The CBA Module

The deterministic calculation consists of 6 worksheets set out as a top-down approach. The entry or input sheet currently consists of four possible input categories subject to change. The input sheet allows 27 entries or first year impacts. Additional entries are construction costs (investment costs), sequentially divided operating and maintenance costs, evaluation period and key parameters such as discount rate, growth in the economy, etc. (Figure 21).

The CBA module presented in Figure 21 consists of: Passenger Cars, Vans, Lorries and External Effects. Input to these groups is all modelled in traffic and impact models comparing the before and after project situation. It should be noted that the induced traffic (i.e. changing traffic) is assessed by making use of the rule-of-a-half principle as described in equation (1).

The '*yellow'* entry fields denote user input. '*Red'* fields depict catalogue figures, e.g. key figure catalogue prices (DMT 2006). These numbers are possible to change, but as default they are pre-determined. Finally, the '*blue'* fields illustrate a sub-calculation field in which the user is not allowed to edit. Currently, only one sub-calculation field exists in the entry sheet, namely in relation to the air pollution entry. A more elaborate review of the entry sheet is given in Appendix 1.

From the entry sheet the user has the possibility of making a calculation directly in the top bar. Otherwise, he can choose to proceed to the next step namely the impact and taxation calculations (Figure 20). This sheet provides the modeller to make sub-calculations, e.g. the air pollution scheme where various types of pollutants are induced. Additionally, the terminal value of the project is calculated in this sheet.

A sub-feature of the modelling framework is to introduce the taxation and distortion impacts. These rules applied generate a net yield towards the public purse in terms of duties and taxes of, e.g. petrol and other energy expenditures. If the general public for instance receives a travel length reduction, the consumption of petrol will decrease resulting in fewer petrol dependent taxes. If the transport investment is funded through tax money (which currently is the case for the majority of transport investments in Denmark), the government has to collect the 'missing' taxes somewhere else (DMT 2003).

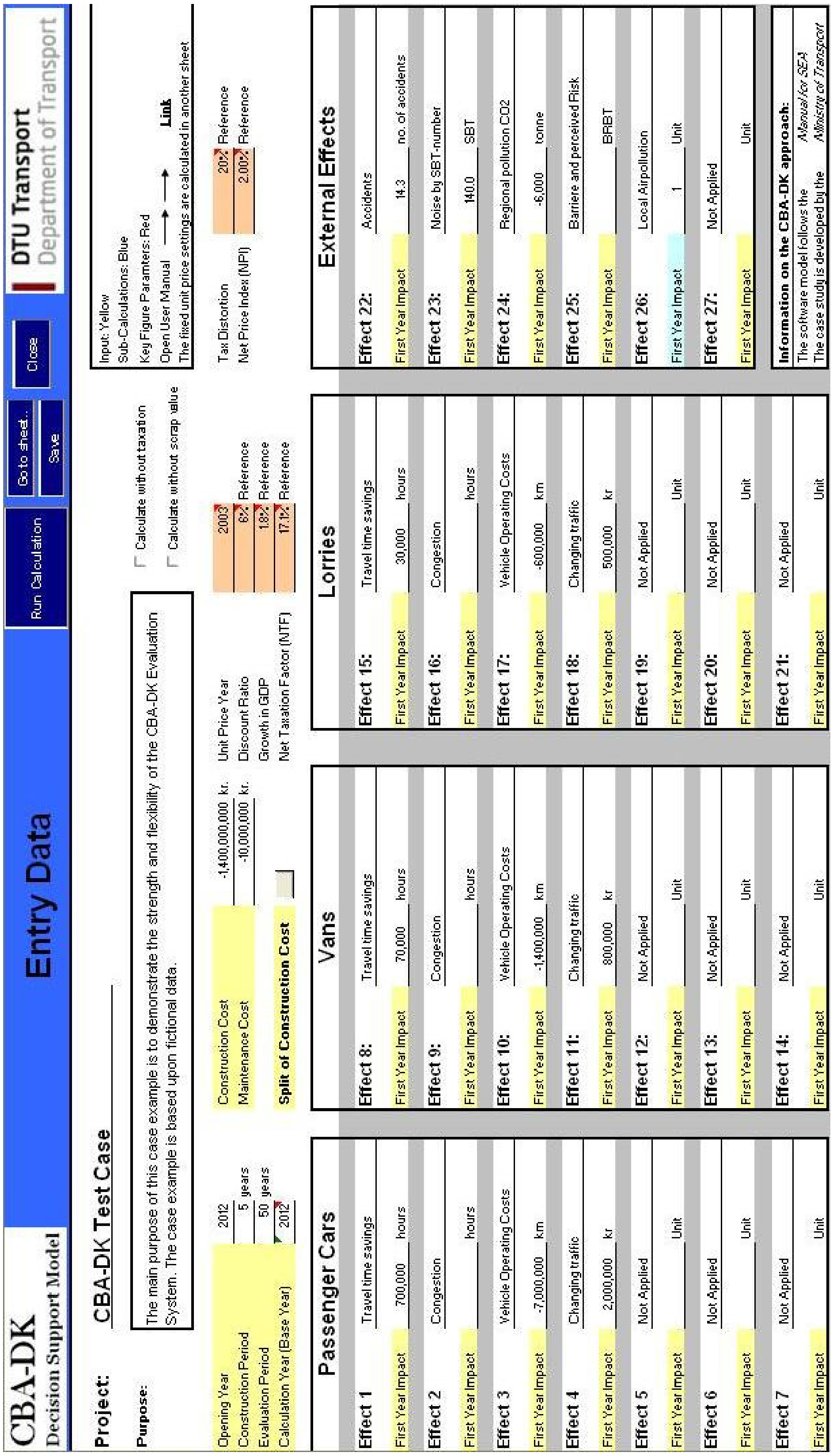

Figure 21. Illustration of the entry sheet of CBA-DK (Appendix 1).

The following step in the CBA-DK model is to assign the key figure parameters and prognosis factors on future traffic scenario. It has been a common agreement within transportation planning to assign a forecast factor for the first 20 years from the opening where after the factor remains constant until evaluation ends (Leleur 2000). As default values in the CBA-DK model, this assumption has been applied for travel related impacts such as travel time savings, vehicle operating costs, etc. The growth (or forecasted value) of the first year impacts is set to the net price index determined by the Ministry of Finance (DMT 2006).

The growth in fixed price levels is as default set to a zero growth for all years, except for the travel time savings. A commonality within transport assessment is to allow for growth in the first 20 years of evaluation. Hereafter, the travel time savings effect is assumed to be set to a zero growth in the remaining evaluation period. The 20 years of growth is assumed to follow the growth in the Gross Domestic Product (DMT 2006).

A model run of CBA-DK produces a result sheet consisting of the previously described evaluation criteria and combined net benefits and costs (Figure 22). Additionally, two bars depict respectively the costs and the benefits presented in the same absolute scale. By comparing the decision criteria from different runs on different projects or objectives a prioritisation can be made.

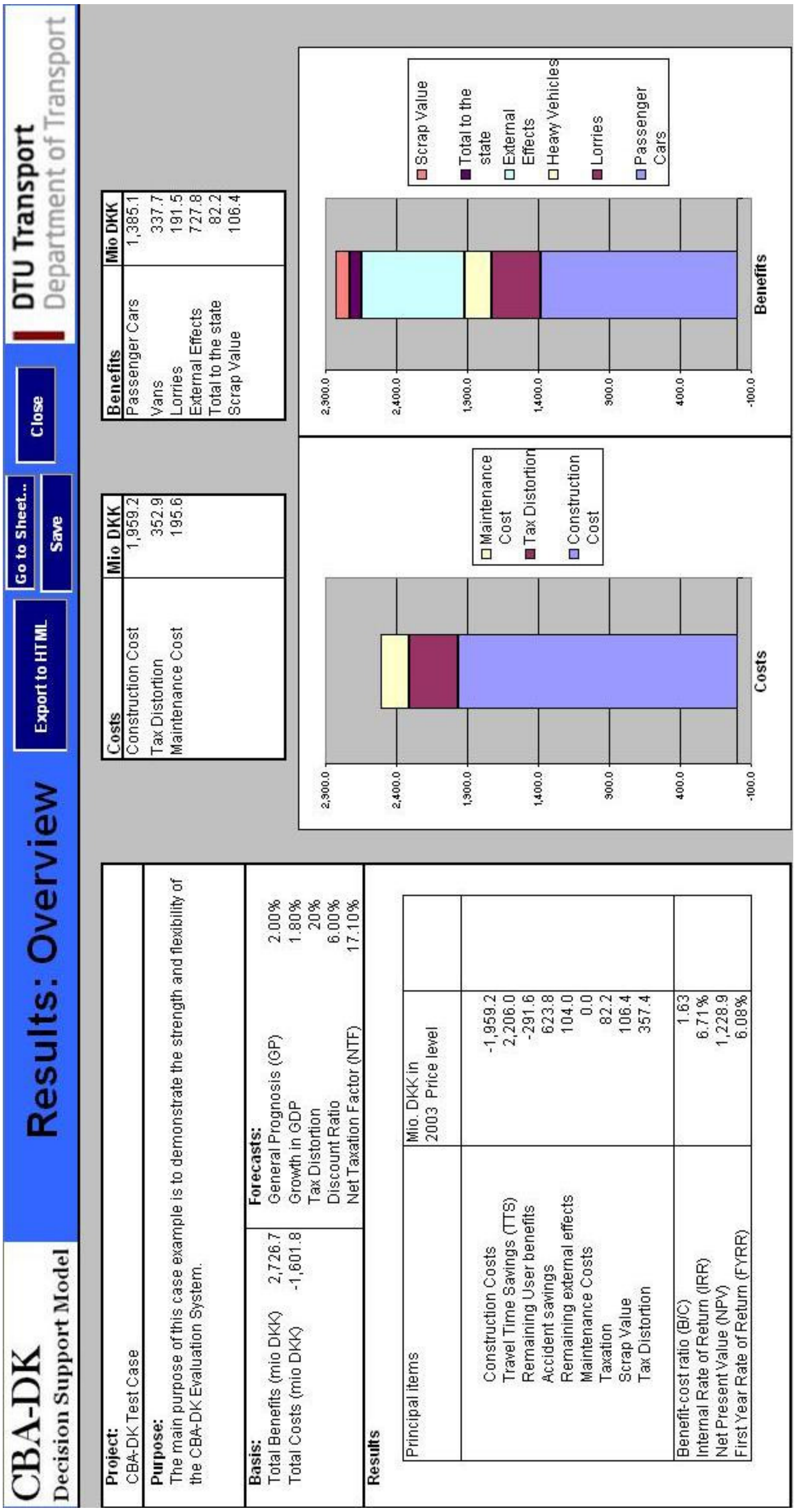

Figure 22. Overview of the results-overview sheet containing the most important case results (Appendix 1).

2.2 The QRA Module

The distinction between single point estimates as illustrated in Figure 22 and interval results given as probability distributions is most important. The Risk Analysis (RA)-module of CBA-DK enables the analyst or modeller to enhance the results in which decision-makers receive a broader decision base. The main scope of the stochastic calculation has been to incorporate risk and uncertainty within transport appraisal in a straightforward and comprehensive way. Currently, the BCR is treated as the uncertain output parameter subjected to Monte Carlo simulation.

Figure 22 gives a clear indication of the impacts with the highest overall contribution to the BCR: construction costs, travel time savings, accident savings, and maintenance costs. The two impacts concerning tax distortion and taxation rely heavily on the construction costs, meaning that dependencies are present. Unfortunately, the CBA-DK model is not able to separate or make use of the correlations between impacts at the moment. However, a future development of the model is to incorporate the use of dependencies between impacts. Figure 23 shows the entry to the quantitative risk analysis sheet, where all implied impacts are outlined.

By choosing a distribution from the pool described in section 1.2 the CBA-DK model performs a MCS. The default settings are currently 2000 iterations by the use of the LHS method. The resulting RA sheet is shown in Figure 24 where three reports are presented. A thorough description of the two RA sheets appears in Appendix 1.

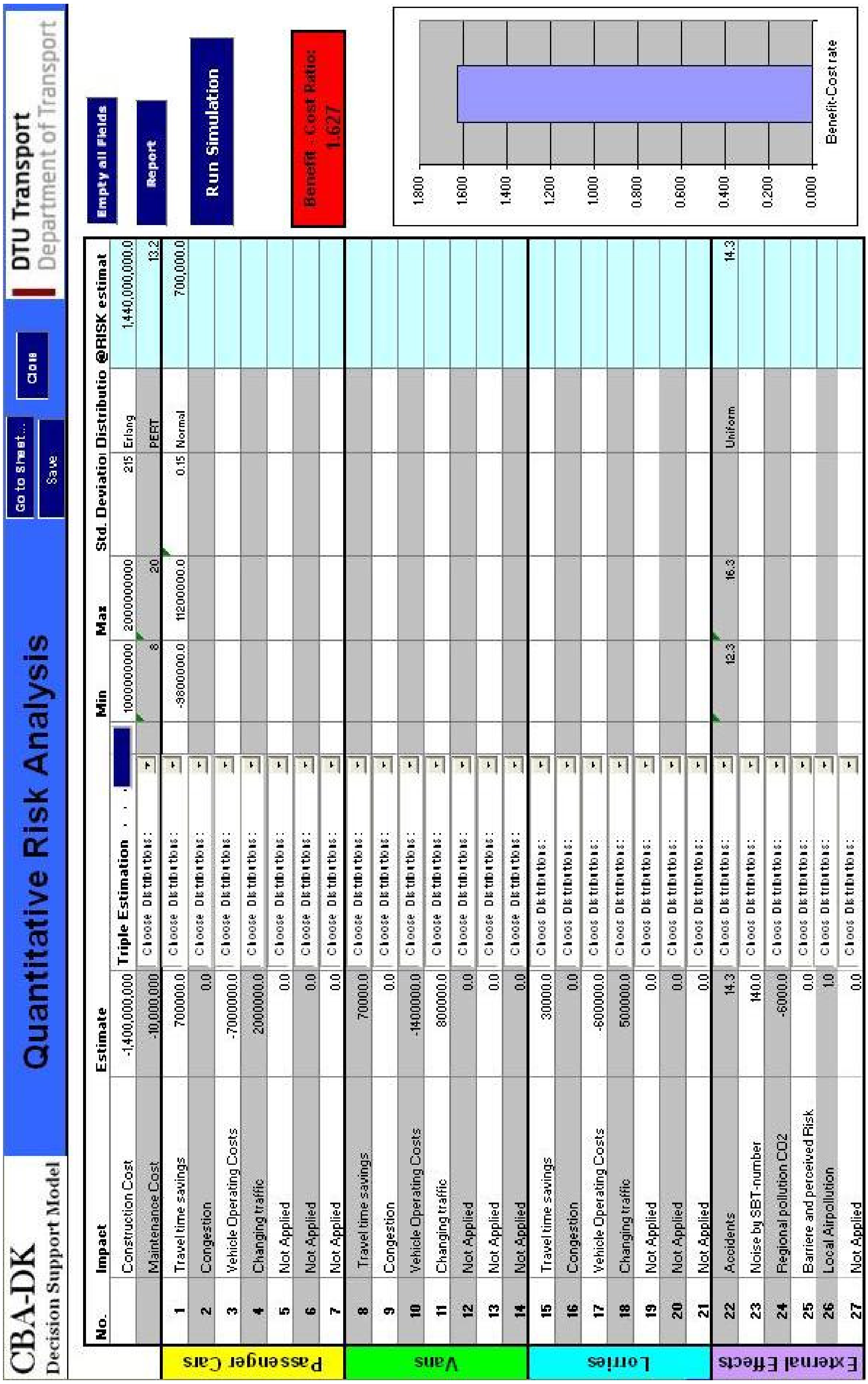

Figure 23. The entry sheet as concerns the risk analysis in CBA-DK (Appendix 1).

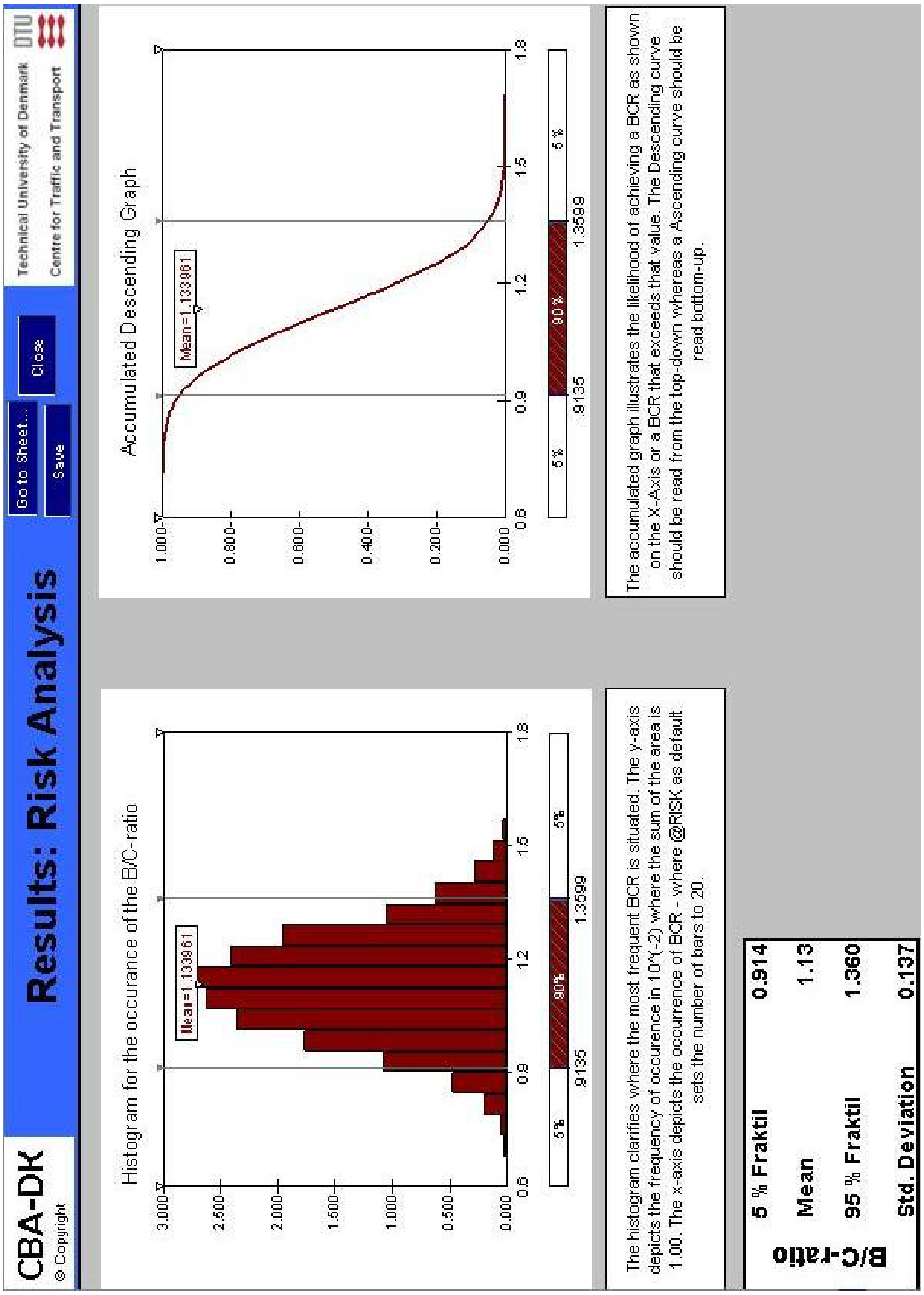

Figure 24. Screen-dump of the resulting sheet from a Monte Carlo Simulation in CBA-DK (Appendix 1).

First, a histogram or the relative frequency is given where the most frequent (mode) BCR can be determined. Currently, the CBA-DK model plots the frequency of occurrence without the scaling parameter on the y-axis of 10^{-2}. However, as described in the text box below the illustration the sum of the area is 1. The number of bars is as default set to 20. There should be a balance between the number of bars in the histogram claiming that too few bars derives a lack of detail and too many an overwhelming random noise (Vose 2000, p. 381).

Secondly, the ADG is illustrated depicting the likelihood of achieving a BCR as shown on the vertical axis or a BCR that exceeds that value. The bullet point indicates a BCR of 1.0 with 80% probability of having a BCR greater than or equal to 1.0, which is the theoretical cut-off value for a societal reasonable project. A higher degree of certainty corresponds to a lower BCR and vice versa. A cumulative frequency plot is traditionally used in project planning to determine, e.g. contract bid prices and project budgets which makes is useful in our context. The major strength of this way of communicating the results is the possibility of adding a risk contingency to the budget or appraisal scheme. The risk contingency is typically the amount or aversion the decision-maker allows exceeding the budget (Vose 2000). Several other outcome reports from the modelling framework are available, e.g. regressions, ascending curves, mode/median values (Appendix 1).

3. Case Examination and Discussion

The following chapter is a review of my work conducted in the field of quantitative risk analysis and decision support ultimately resulting in six accepted peer-reviewed papers in international journal or conference proceedings. The chapter comprises different aspects of my work where the emphasis in my early work is on the application of cost-benefit approaches and the build-up of the CBA-DK modelling framework. Furthermore, some considerations in the early papers (paper 1-3) also include non-monetary aspects to improve decision support. These impacts are handled by so-called multi-criteria analysis which can be further elaborated in Banister & Berechman (2000), Leleur et al. (2004), Kronbak (1998) and Hansen (2003).

The more recent papers (paper 4-5) discuss the uncertainties embedded within the modelling framework and conclude with different ways of handling or interpreting those. These prospects are discussed particularly in papers 4 and 5. The key references in these two papers rely mainly on Law & Kelton (2000), Rubinstein (1981), Vose (2000), and Hertz and Thomas (1984). The final and most recent paper (paper 6) combines the feasibility risk assessment approach with Optimism Bias uplifts within a concrete case.

The following papers are all case specific where different infrastructure proposals are investigated using the CBA-DK modelling framework. The sequence in which the papers appear is based on the progress of the CBA-DK model development and the level of knowledge. Some assumptions and model set-ups have been subject to change. The case pool can be divided into three types of travel modes road, rail and air. A more specified description of the 6 cases can be divided respectively into a fixed link, inter-urban road, rail, urban road, and finally two airfield project investigations. A schematic overview of the papers together with their main purposes is listed in Table 3. In each of the following sections, a small description of the case is given followed by the specific findings from the associated paper. The full papers are all included in the end of this thesis.

1. Modelling Decision Support and Uncertainty for Large Transport Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link (2004). This paper gives an ex-post analysis of the Øresund Fixed Link by the use of the following methodologies: Cost-benefit analysis, multi-criteria analysis, scenario analysis and quantitative risk analysis.
2. Modelling Decision Support and Uncertainty using @RISK: The COSIMA-ROAD Model (2006). This paper appraises four urban road alternatives surrounding the city of Allerød in the Northern part of Sjælland[21] by the use of the following methodologies: Cost-benefit analysis and quantitative risk analysis.
3. Composite Appraisal of the Railway Line between Copenhagen and Ringsted by the use of a Decision Support Model named COSIMA-DSS (2006). This paper investigates two railway track alternatives connecting Copenhagen with Ringsted by the use of the following methodologies: Cost-benefit analysis, multi-criteria analysis and quantitative risk analysis.
4. Transport Appraisal and Monte Carlo Simulation by the use of the CBA-DK Model (2006). This paper gives an ex-post appraisal of the enlargement of an inter-urban road project in the northern part of Sjælland by the use of the following methodologies: Cost-benefit analysis and quantitative risk analysis.
5. Appraisal of Airport Alternatives in Greenland by the use of Risk Analysis and Monte Carlo Simulation (2007). This paper appraises three possible runway alternatives in the capital of Greenland (Nuuk), by the use of the following methodologies: Cost-benefit analysis and quantitative risk analysis.
6. Assessment of Large Transport Infrastructure Projects: the CBA-DK Model (2008). This paper seeks to exploit the Optimism Bias approach proposed by the British Department for Transport. The case study relies on the Greenlandic data set from paper 5 and the following methodologies are applied: Cost-benefit analysis, quantitative risk analysis and Optimism Bias.

Table 3. Chronological overview of the six paper contributions to this thesis.

[21] The English terminology is Zealand

3.1 Paper 1

Modelling Decision Support and Uncertainty for Large Transport Infrastructure Projects: The CLG-DSS Model of the Oresund Fixed Link

Author(s): Salling, K.B., Leleur, S. and Jensen, A.V.

Presented at the 15th Mini-EURO Conference on Managing Uncertainty in Decision Support Models (MUDSM), Coimbra, Portugal, August 2004

Published in Decision Support System 43, Issue 4, pp. 1539-1547, Elsevier 2007

Case Description

This paper presents a preliminary version of the decision support model, CLG-DSS, which mainly was comprised of a cost-benefit and multi-criteria analysis. The paper is based on an ex-post case calculation for the Øresund Fixed Link illuminating different aspects of appraisal uncertainties, i.e. scenario building and risk analysis. Special emphasis is directed towards the tribute of decision-maker preferences with respectively low, middle and high integration in the Øresund region. Furthermore, various regimes, i.e. political agendas were defined ranging from deregulation over regulation towards stagnation.

Finally, a stochastic implementation of the modelling task proposed by assigning three types of probability distribution functions, namely a normal, triangular and uniform. It is particularly found, that the CLG-DSS model demonstrates a high flexibility and operability towards complex decision tasks. Moreover concrete and useful decision support is provided both in terms of deterministic as well as stochastic results. The CLG-DSS is a special hybrid version of the CBA-DK that performs a multi-criteria analysis (MCA). A special emphasis was given to the composite modelling assessment (COSIMA) approach in which the CBA and MCA results are combined, also reoccurring in paper 3. The CLG-DSS model is developed within the Danish Centre for Logistics and Freight Transport (CLG) for which reason the name CLG-DSS model.

Case Findings

The first major outcome from the paper is that narrow CBA-based impacts – in many European countries described in a national manual – need to be supplemented with wider impacts to appraise whether the project is feasible or not seen from a societal point of view. Four strategic (non-monetary) effects are determined in the process namely, (1) network and mobility, (2) global emission, i.e. CO_2, (3) employment and (4) logistics and goods (LG-effects).

The main result from this paper is the stochastic examination of nine different scenarios of the Øresund Fixed Link case. The risk analysis conducted is shown in Figure 25 where all different scenarios are depicted.

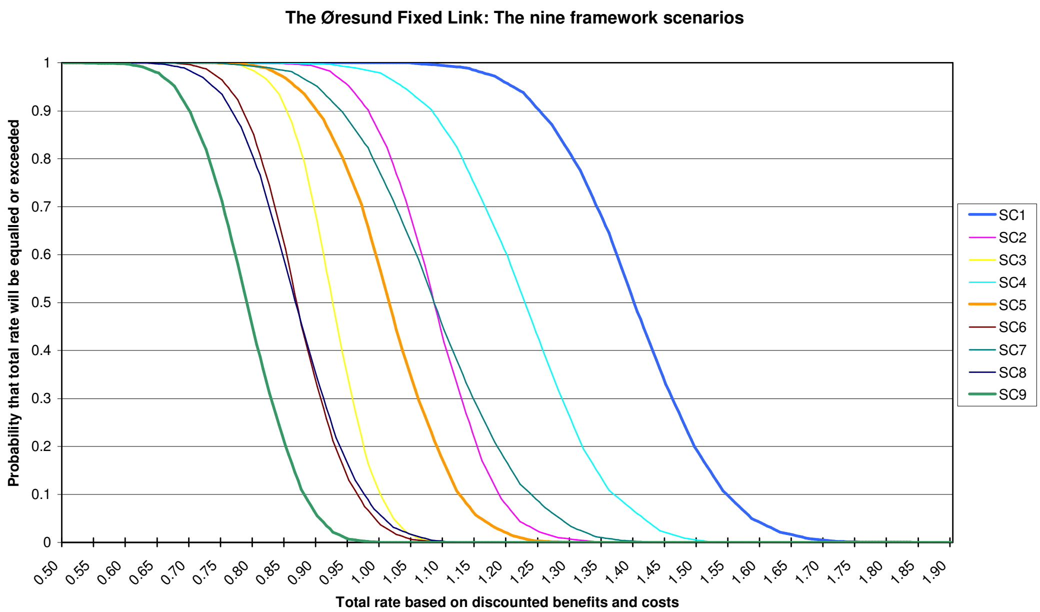

Figure 25. Combination of the nine scenarios within the CLG-DSS framework model depicting their respective accumulated descending graphs (ADG).

The risk analysis performed in paper 1 makes the first attempt in clarifying the need for feasibility risk assessment within transport infrastructure projects. A special emphasis is to be placed on the steepness of the curves indicating the decision-makers risk aversion towards a given project alternative. Additionally, the SC2 and SC7 together with SC6 and SC8 crosses each other, which illustrates points where a different scenario could result in higher rate of returns given more risk in the decision making process.

3.2 Paper 2

Modelling Decision Support and Uncertainty using @ RISK: the COSIMA-ROAD Model

Author(s): Salling, K.B. and Leleur, S.

Presented at the 1st Palisade User Conference – Europe, London, UK May 2006

Published in Proceedings at the Palisade Corporations website (www.palisade.com)

Case Description

Paper 2 should primarily be seen as a consultancy project application in which the main focus was to develop the decision support model into a functional system for the Danish Road Directorate. The new software model was named COSIMA-ROAD for project evaluation in the Danish road sector. The appraisal tool developed contributed to consistent and flexible assessment of road infrastructure projects according to the set of guidelines presented in the Manual for socio-economic analysis (DMT 2003).

The paper was invited for an hourly session at the first Palisade European User Conference, hence the main purpose of the paper was to describe how @RISK functions within the COSIMA-ROAD model. The paper sets out to investigate an urban road proposal within the town limits of Allerød in the Northern part of Sjælland. Four different by-pass alternatives were proposed in which both the town centre would be relieved for traffic and a newly constructed housing area could be connected with the main road. Extensive preliminary appraisal studies were made by the municipality, and the purpose of the COSIMA-ROAD analysis was to support the decision-makers of Allerød.

Case Findings

The main objective of building a functional and dynamic model, in which road infrastructure assessment was possible to conduct, was fulfilled. COSIMA-ROAD relies upon CBA in which three road vehicle groups are defined: cars, vans and lorries together with a set of external effects, all quantifiable. Secondly, a QRA was adapted within the modelling framework of COSIMA-ROAD. A special concern in this paper was the methodological approach of dividing four types of probability distributions into knowledge levels ranging from low to high (Figure 26).

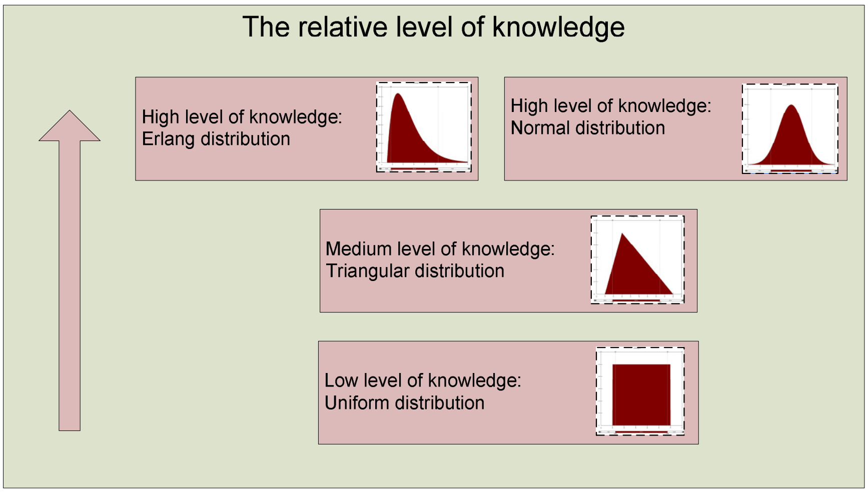

Figure 26. The relative level of knowledge as concerns various probability distribution functions.

A preliminary investigation is made, concerning the division of ontological and epistemic uncertainty. Construction costs and travel time savings are considered ontological whereas the maintenance and safety effects are treated as epistemic (Vose 2000; Walker et al. 2003).

The outcome is presented as ADG with respect to all four alternative projects. The key finding of this paper was the definition and description of the LoK concept in which four distributions were determined. This paper introduced the Erlang distribution which together with the Lichtenberg principle was used to appraise the uncertainty of determining the projects construction costs.

3.3 Paper 3

Composite Appraisal of the Railway Line between Copenhagen and Ringsted by the use of a Decision Support Model named COSIMA-DSS

Author(s): Salling, K.B., Landex, A. and Barfod, M.B.

Presented at the 10th International Conference on Computer System Design and Operation in the Railway and other Transit Systems (COMPRAIL), Prague, Czech Republic, July 2006

Accepted for publication in Journal for Advanced Transportation, March 2008

Case Description

This paper presents an extension of the CBA-DK model re-implementing the COSIMA principle from paper 1. This approach is considered state-of-the-art within transport appraisal incorporating both monetary and non-monetary impacts. A special emphasis in the paper has been the interpretation and description of non-monetary railway impacts such as scheduled waiting time, network effects, and timetabling.

The case study involves the main railway line between Copenhagen and Ringsted which currently acts as a ‘bottle-neck’. Two different alternatives are proposed: an extension of the current line or a new line. The case study is made up by combining the cost-benefit approach with the wider multi-criteria approach where the decision-makers are able to perform a more informative and thorough decision. Finally, a quantitative risk analysis is performed upon the two CBA impacts of construction costs and travel time savings.

Currently, extensive debate of the Copenhagen-Ringsted line is made both in the news media and at government level. It currently looks like the extension proposal of the existing alignment will be chosen which is contradicting the results of the evaluation of the two alignment proposals.

Case Findings

The main scope of this paper was to adapt and implement the CBA-DK model towards a different transportation mode, namely railway operations. The presented version of CBA-DK was altered to incorporate the various impacts and actors within railway operations. Hereby the model was re-named to COSIMA-DSS as a consequence of the implementation of non-monetary aspects as it was the case in paper 1. The model build-up was comprised of three modules respectively a monetary, non-monetary and stochastic module relying on the mathematical principles of COSIMA (Figure 27).

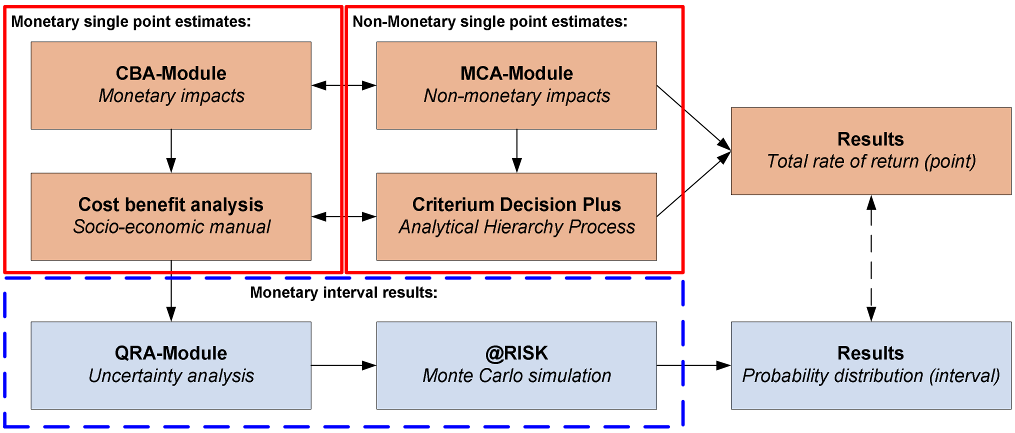

Figure 27. Module set-up of the COSIMA-DSS framework model for assessment of railway infrastructure projects.

The results of this paper concern the adaptation of the CBA-DK model into covering both monetary and non-monetary aspects of a decision task. Particularly, the handling of converting so-called point scores from the Analytical Hierarchy Process (Saaty 2001) into total rate of return widens the decision-maker perspective.

The main outcome of this paper was the implementation and validation of a railway case in which the CBA-DK model clearly proved its usefulness as relates to transport infrastructure assessment. A secondary objective of the paper was to investigate the possibility of only treating the two main impacts of any transport infrastructure assessment scheme, namely the construction costs and travel time savings, within the quantitative risk analysis. This analysis presented the beta-PERT distribution for the first time with respect to the travel time savings effect.

3.4 Paper 4

Transport Appraisal and Monte Carlo Simulation by the use of the CBA-DK Model

Author(s): Salling, K.B. and Leleur, S.

Presented at the 39th Winter Simulation Conference (WSC '06) Monterey California, December 2006

Submitted for publication in Transport Policy, January 2008 (currently under review)

Case Description

Paper 4 comprises the current module flow of CBA-DK in which the model is divided into a deterministic and stochastic module (Figure 20). The applied case concerns an inter-urban motorway enlargement scheme in the northern part of Sjælland, Denmark. The study was conducted as an ex-post analysis, where the enlargement has been accepted by the decision-makers. Hereby only one alternative was investigated with the research objective of testing the risk analysis module of CBA-DK. Furthermore, since the project has undergone extensive research, large amounts of data material exist in a verified and validated manner.

A special emphasis in this paper was the separation between inherent randomness in the modelling system and lack of knowledge. These two types of uncertainties, defined in terms of variability (ontological uncertainty) and uncertainty (epistemic uncertainty) were used to determine the outcome uncertainties and whether improvement of the traffic models would improve the overall model results.

The paper depicts the various probability distributions available in the @RISK software, as shown in Figure 8, and it classifies four valid distribution functions to be applied within the CBA-DK framework.

Case Findings

The case study examines the need for stochastic modelling within decision support models. The feasibility risk assessment study showed that accepting a risk aversion around 80% would lead to a profitable rate of return. Point estimates on the other hand showed generally a profitable project seen from societal point of view. The strength of FRA is to include interval based results in terms of accumulated descending graphs indicating a feasibility of rejection somewhere on the curve.

The particular interest within this paper was put on the application and validation of the various input probability distributions. The CBA-DK modelling framework relies heavily on valid and communicable distribution functions, a short summary of the case findings is shown in Table 4.

Distribution	LoK	Source of uncertainty	Framework
Uniform: Safety unit costs	Low	Pricing strategies	Equal possibility of under- and overestimating the most likely value with ± 10%
Beta (PERT): Maintenance unit costs	Medium	Pricing strategies	Possibility of respectively under-estimation of ML is [-10% ; ML ; +50%]
Normal: Travel time savings	High	Model uncertainties	Most likely value is set to first year impact, std. dev. is set to 15%
Gamma (Erlang): Construction costs	High	Model uncertainties	k-value is set to 5 and θ is calculated on basis of the mean from Lichtenberg [-25% ; ML ; +100%]

Table 4. Resulting distributions applied for the framework model of CBA-DK.

The set of probability distributions ranges from open ended distributions to close ended distributions applied where needed. The level of knowledge is applied on the uncertain input parameter as concerns detailing level and determination from, e.g. traffic or impact modelling. The two types of uncertainty sources embedded in Table 4 depict how each input impact is classified. Pricing strategies relates to embedded uncertainties of unit price settings whereas the model uncertainties relate to prior or existing modelling work.

Paper 4 treats the number of possible input distribution functions and narrows the possible number of input probability distributions within CBA-DK. Especially, the two impacts of travel time savings and constructions costs are found of special interest within appraisal studies.

3.5 Paper 5

Appraisal of Airport Alternatives in Greenland by the use of Risk Analysis and Monte Carlo Simulation

Author(s): Salling, K.B. and Leleur, S.

Presented at the 40th Winter Simulation Conference (WSC '07), Washington DC, December 2007

Submitted for publication in Journal of Air Transport Management (JATM), January 2008 (currently under review)

Case Description

This paper presents the fully developed version of the CBA-DK model adapted to airfield assessments in Greenland. The Greenlandic Home Rule, Department of Housing needed an assessment of possible airfield constructions in Greenland as a consequence to a newly developed transportation plan (TGB[22]). This plan focused among others on moving the major international airport from Kangerlussuaq to the capital of Nuuk. The modelling framework has been modified in terms of dealing with air transport related issues, herein the CBA-DK has been renamed to CBA-TGB.

This paper is based upon the assessment of three different airport alternatives in Nuuk. This third type of transportation mode clearly strengthens the validity and flexibility of the modelling framework. A special emphasis in this study was to introduce a new type of travel mode in order to increase the adaptability of the model. This large-scale study was made in co-operation with the traffic modelling group and the logistics group at the Department of Transport, in which a large concern was the interaction between respectively traffic, schedule and evaluation models. The case study is based upon a temporary set of study results (Leleur et al. 2008).

[22] TGB is abbreviated from Danish: "Trafikplan i Grønland: Beslutningsredskab"

Case Findings

The Greenlandic airfield study described in this paper was composed of three different runway length alternatives, respectively 1799 and 2200 meters runway increases and a 3000 meter brand new runway construction. The cost-benefit analysis proved the fact that only the two short alternatives were viable seen from a societal point of view. However, the two alternatives of 1799 and 2200 almost performed alike contributing to the need of performing quantitative risk analysis. The two impacts of construction costs and travel time savings have been chosen in which the selection of probability distributions was of greatest importance for the outcome.

The Erlang distribution was selected and tested with respect to the construction costs whereas both a normal and a PERT distribution was tested as input distribution for the travel time savings. A special emphasis was given on separating the various input distributions in terms of output results hence four scenarios were created. 1. simulation only applying the Erlang distribution, 2. simulation only applying a normal distribution, 3. simulation only applying the PERT distribution, and finally, 4. simulation applying the Erlang and PERT distributions combined. The combined result of a fixed model run in CBA-TGB is shown in Figure 28.

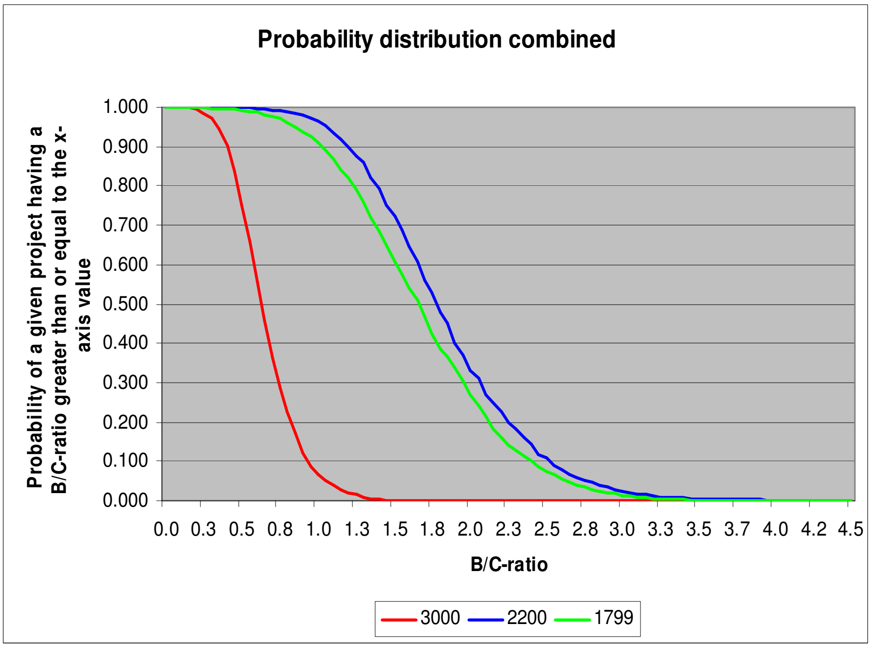

Figure 28. Resulting output of a simulation in CBA-TGB combining the Erlang and PERT distribution.

3.6 Paper 6

Assessment of Large Transport Infrastructure Projects: the CBA-DK Model

Author(s): Salling, K.B. and Banister, D.

Accepted for presentation at the International Conference on Infrastructure Systems (NGInfra), Rotterdam, the Netherlands, November 2008

Invited to submit paper in the European Journal of Transport and Infrastructure Research (EJTIR), 2009.

Case Description

Paper 6 depicts the fully developed version of the CBA-DK modelling tool for transport project assessment. On basis of the guidelines issued by the British Department for Transport with respect to procedures for dealing with Optimism Bias in transport planning, June 2004, the CBA-DK model has been adapted in this context (Flyvbjerg & COWI 2004). The Optimism Bias approach deals with the uncertainty aspect of transport assessment in terms of a general tendency when making socio-economic analyses. The historical tendency has been to underestimate ex-ante based investment costs and overestimate the time benefits (i.e. demand forecasts) of the new infrastructure project. The guidance document ultimately results in a series of uplift factors to be applied the estimated investment costs of transport infrastructure projects.

The modelling framework is again illustrated by the use of a case study appraising airport and runway alternatives in the capital of Greenland – Nuuk. The main focus of this case application is to illustrate the capabilities of CBA-DK in terms of applying probability distributions compared with the proposed Optimism Bias uplifts. The data material in the case study relies on preliminary calculations based upon a master thesis conducted at the DTU Transport. Currently, the Home Rule of Greenland is discussing the results produced by DTU Transport. A final decision on which type of runway enlargement to choose is to be made ultimo 2008.

Case Findings

The CBA-DK model has demonstrated that a combination of conventional cost-benefit analysis and quantitative risk analysis examination can increase the decision-makers opportunities to make informed decisions. The two proposed ways of handling uncertainties have been shown to complement each other. The Optimism Bias approach provides uplift estimates with a 50% and 80% threshold, see Table 5, and the quantitative risk analysis has been applied with a PERT and an Erlang distribution to create a mean in which the underlying uncertainty has been addressed (Figure 29).

Distribution	Nuuk 1799	Nuuk 2200	Nuuk 3000
BCR (estimated)	2.46	2.52	0.83
BCR (50-percentile)	1.74	1.79	0.60
BCR (80-percentile)	1.54	1.59	0.53

Table 5. Resulting BCRs when applying Optimism Bias uplifts.

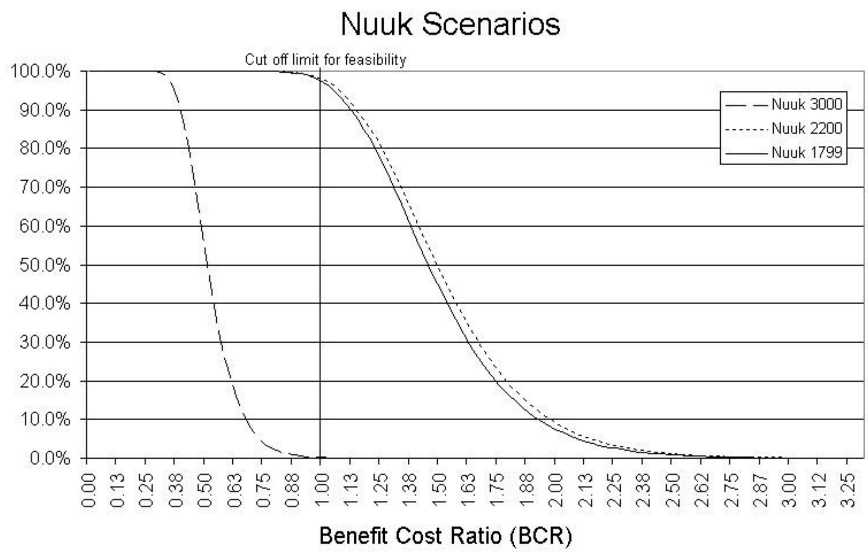

Figure 29. Modelling results from CBA-DK illustrating the Monte Carlo simulation output.

One may argue that the Optimism Bias uplift produces probabilistic output in terms of decision-maker preferences. However, the same decision-makers are still left with single point estimates. Herein lies the advantage of applying the CBA-DK model where feasibility risk assessment are produced in terms of accumulated descending graphs as depicted in Figure 29.

3.7 Impact of the six papers

As all six papers address feasibility risk assessment it is appropriate to discuss how they differ and what their combined contribution is. The papers all serve the purpose of validating and testing the decision support model of CBA-DK. Concerning the time frame of the study three phases has been scrutinised in which the decision support model has undergone substantial changes.

Paper 1, even though published in 2007, was originally presented in 2004. Herein the focus was to assess wider economic impacts (non-monetary) of the Øresund fixed link. Several methodologies were introduced and implemented within the framework model in which the model was entitled the CLG-DSS model. Paper 2 and 3 were case-oriented papers treating road and rail cases. The perspective of those was to implement and refine the CBA-module of the model. The model developed for the two cases in Paper 2 and 3 was still in the development stage for which reason it was entitled COSIMA (composite model for assessment). Paper 4-6 present the finalised decision support model of CBA-DK. The model makes use of feasibility risk assessment in which a set of interval results are produced based upon Monte Carlo simulation. In particular the concern of assigning appropriate probability distributions has been of major interest. Research in the field of Optimism Bias and Reference Class Forecasting (RCF) has produced new and better distribution fits. Especially the two impacts of construction cost and travel time savings have been investigated and found suitable within the field of quantitative risk analysis for transport infrastructure projects.

The main focus of this Ph.D. study has been first to develop a valid, flexible and functional decision support tool in which risk oriented aspects of project evaluation could be implemented. Hereby a major concern within the work of developing the CBA-DK model was secondly to bring informed decision support to the decision-makers in terms of accumulated descending graphs and thirdly to specify relevant probability distribution functions to feed into the Monte Carlo simulation - the technique behind the quantitative risk analysis of CBA-DK. Fourth, emphasis has been given to the fact that especially two impacts stand out in transport project assessment, namely, travel time savings and construction costs. The final concern of the study has been the fitting of distribution functions, e.g. by the use of data from major databases developed in which Optimism Bias and RCF are associated. Table 6 depicts the way each research outcome has been handled through each paper. This table forms the basis for the concluding remarks of this Ph.D. dissertation.

Research Outcomes	**Paper 1**	**Paper 2**	**Paper 3**	**Paper 4**	**Paper 5**	**Paper 6**
1. Development of the CBA-DK model as a flexible tool applicable for wider risk oriented assessment for transport projects across difference modes.	**(x)**	**(x)**	**(x)**	**x**	**x**	**x**
2. The developed type of graph referred to as the accumulated descending graph (ADG) is found to be useful to inform about uncertainty relating to assessment of transport projects. The ADG makes it possible for decision-maker(s) to work and come to terms in a straight-forward and understandable way with their risk aversion when confronted with a specific decision task.	**x**	**x**	**x**	**x**	**x**	**x**
3. Dependent on the information available parameter-based or parameter-free probability density functions (PDFs) should be applied. The most common impact types are associated with the PDFs as shown in Table 2.				**x**	**x**	**x**
4. It is possible to accommodate the recent results stemming from Optimism Bias theory and Reference Class Forecasting to produce relevant PDFs for travel time savings and construction costs.					**(x)**	**x**

Table 6. Research outcomes from the six papers.

4 Conclusions & Perspectives

This Ph.D. study has its focus on the treatment of uncertainty as it relates to assessment of transport projects. In this way a major concern has been how the conventional cost-benefit analysis (CBA) could be extended to include risk analysis, while at the same time it should maintain its purpose of providing decision support in a straight-forward manner.

A characteristic feature of CBA is that it communicates its result by an economic index value, for example the benefit-cost ratio (BCR), which has been made use of in this study to represent the calculation result of CBA. This index, BCR, can be seen as a point result as it communicates one value to represent the result of the assessment. Including risk considerations in transport project assessment in general replaces the point result of the CBA with an interval result stemming from a wider analysis which combines CBA and risk analysis techniques.

Technically, this Ph.D. study has proceeded both by undertaking a theoretical literature study and by technical modelling. As concerns the latter, the CBA-DK model has been developed. It appears from the six papers included in this thesis that the development of CBA-DK has been going on for the whole study period (2004-2008). In this concluding section CBA-DK will refer to the fully developed version behind the papers 4-6.

CBA-DK makes it possible to carry out CBA calculations in accordance with the Danish Ministry of Transport 2003 manual for socio-economic analysis and hereby let the BCR point result undergo a quantitative risk analysis (QRA). The CBA-DK has been developed as a flexible tool, which has made it possible to apply CBA-DK in different application contexts across different transport modes (new infrastructure for road, rail and air transportation) and thereby useful for different scopes of examination relating to the study. Claiming this study has produced a number of valid outcomes and findings – generally seen as the conclusions – the first major outcome is the developed CBA-DK model.

1. *Development of the CBA-DK model as a flexible assessment tool applicable for wider risk oriented assessment for transport projects across different modes.*

A major concern has been that replacing point results with interval results stemming from QRA should be made in a way so that these results would appear as easy to communicate to the decision-makers as is the case with the conventional point results. Therefore, relatively early in the study, the feasibility risk assessment (FRA) approach was conceived to be presented by use of the accumulated descending graph (ADG). The initial idea behind this graph has been tested in various papers, hence, the second major outcome to be claimed on the basis of this study concerns ADG.

2. *The developed type of graph referred to as ADG for accumulated descending graph is found to be useful to inform about uncertainty relating to assessment of transport projects. The ADG makes it possible for decision-maker(s) to work and come to terms in a straight-forward and understandable way with their risk aversion when confronted with a specific decision task.*

Evidently, the two outcomes above are based on a number of study results that are tied to the theoretical work behind CBA-DK. Early in the study it was realised that statistical and theoretical studies with regard to transport assessment and risk were sparse. This showed up in a practical way when searching the literature for the probability distribution function (PDF) to make use of as being the most theoretically and practically relevant ones in a successive examination of the individual CBA components. Hence, the next major study outcome is the identification of a set of relevant PDFs to feed into the Monte Carlo simulation.

3. *Dependent on the information available parameter-based or parameter-free PDFs should be applied. For the most common impact types the following specific results have been obtained, see Table 7.*

Distribution	Category	LoK	Impact	Source
Uniform	Non-parametric	Low	Accident Savings	Pricing strategies
Triangular	Non-parametric	Low	Accident Savings & Maintenance costs	Pricing strategies
Beta (PERT)	(Non)-parametric	Medium & High	Maintenance costs & Travel time savings	Pricing strategies & Model uncertainties
Normal	Parametric	High	Travel time savings	Model uncertainties
Gamma (Erlang)	Parametric	High	Construction costs	Model uncertainties

Table 7. PDFs applied for the most common impact types within transport assessment.

Two impacts stand out in transport project assessment, namely travel time savings (TTS) and construction costs (CC). As appearing from Table 7 TTS can be modelled with either a normal or Beta-PERT distribution, while CC can be modelled with an Erlang distribution. The final major outcome concerns the fitting of parameters for these distributions by the use of data from a major database developed laying behind the Optimism Bias and the associated Reference Class Forecasting (RCF) technique.

4. *It is possible to accommodate the recent results stemming from Optimism Bias theory and Reference Class Forecasting to produce relevant PDFs for travel time savings and construction costs.*

One of the issues dealt with in the study is to come to terms with the number of CBA elements to explore by using risk analysis. A tentative finding early in the study was that only a 'limited' number of 'most important' impacts should be examined. Hereby, among other things, the correlation issue could be dealt with. Including only TTS and CC, which are surely uncorrelated, and which are by all means the most important impacts in most major transport infrastructure investments studies, a practical FRA approach can be implemented based solely on these.

The perspective to be outlined on the basis of the present Ph.D. study is related to the application of CBA-DK and the FRA approach on a number of practical studies. No doubt, this will lead to new insights, which will concern both the practical handling of project assessment and risk but surely also will point to additional theoretical considerations. The latter may concern digging deeper into the categorising of uncertainty (here treated as epistemic and ontological types of uncertainty) and into the question about correlation when applying Monte Carlo simulation on a range of CBA elements.

References (main text)

Back, W. E., Boles, W. W. & Fry, G. T. (2000). Defining Triangular Probability Distributions from Historical Cost Data. *Journal of Construction Engineering and Management*, Vol. 126, No. 1: 29-37.

Banister D. and Berechman J. (2000). *Transport Investment and Economic Development*. UCL Press, London, United Kingdom.

Barfod, M.B., Salling, K.B. & Leleur, S. (2007). A Composite Modelling Approach to Decision Support based on Cost-benefit Analysis and Multi-criteria Analysis: The Hornsherred case. Proceedings of the Mini-EURO XXII 2007, Prague, Czech Republic, submitted for publication in *Transport Policy*.

DMT, Danish Ministry of Transport (2003). *Manual for Socio-Economic Analysis – Applied Methodology in the Transport Sector*. Copenhagen, Denmark (In Danish).

DMT, Danish Ministry of Transport (2004). The socio-economic analysis – case studies, illustration of the procedure in a socio-economic analysis. *Technical Report*, Copenhagen, Denmark (in Danish).

DMT, Danish Ministry of Transport (2006). *Key Figure Catalog for use in socio-economic analysis on the transport area*. Revised June 2006, Copenhagen, Denmark (In Danish).

Dasgupta, A.K. & Pearce, D.W. (1978). *Cost-Benefit Analysis – Theory and Practice*. The Macmillan Press Ltd., London, UK.

De Jong, G., Pieters, M., Miller, S., Daly, A., Plasmeijer R., Graafland, I., Lierens, A., Baak, J., Walker, W. & Kroes, E. (2005). Uncertainty in traffic forecasts: literature review and new results for the Netherlands. *Working Paper* prepared for AVV Transport Research Centre - RAND Europe.

Flyvbjerg, B. and COWI (2004). Procedures for Dealing with Optimism Bias in Transport Planning. *Guidance Document prepared for the British Department for Transport*, UK.

Flyvbjerg, B., Bruzelius, N. & Rothengatter, W. 2003. *Megaprojects and Risk – An anatomy of Ambition*. Cambridge University Press, United Kingdom.

Flyvbjerg, B. (2007). Megaproject Policy and Planning: Problems, Causes, Cures," *Doctoral Dissertation*, Faculty of Engineering, Science and Medicine, Aalborg University.

Friis-Hansen, P. (2005). Risk Analysis of Marine Structures. *Technical Report*, Department of Mechanical Engineering – Maritime Engineering, Technical University of Denmark.

Gissel, S. (1999). Decision aid methods in rail infrastructure planning. *PhD Thesis*, Department of Planning, Transport Studies, Technical University of Denmark.

Gissel, S. G. (2002). Cost-Benefit Analysis. *Teaching note*, Centre for Traffic and Transport, Technical University of Denmark, Spring 2002 (Internal Report).

Goodwin, P. and Wright, G. (2004). *Decision Analysis for Management Judgment*. 3rd Edition, John Wiley & Sons Ltd., United Kingdom.

Hansen, S. (2003). Large Transport Infrastructure Investments and their Strategic Impacts with a Special Focus on Enterprises. *PhD Thesis*, Centre for Traffic and Transport – Technical University of Denmark.

Hertz, D.B. & Thomas, H. (1984). *Risk Analysis and its applications*. John Wiley & Sons., London, United Kingdom.

Knudsen, M. A. (2006). Evaluation of uncertainty in traffic models – a theoretical and practical analysis of the Naestved model, *Master Thesis*, Technical University of Denmark, Lyngby (In Danish).

Kronbak, J. (1998). Traffic Planning and GIS-based Impact Assessment. *PhD Thesis*, Department of Planning, Technical University of Denmark.

Lahrmann H & Leleur S. (1997). Road Traffic: *Traffic Engineering & Traffic Planning*. 2nd edition, Lyngby: Polyteknisk Press, Denmark (In Danish).

Law, A.M. & Kelton, D.W. (2000). *Simulation Modelling and Analysis*. 3rd edition, McGraw-Hill International Series, USA.

Leleur, S. (2000). *Road Infrastructure Planning – A Decision-Oriented Approach*. 2nd Edition, Lyngby: Polyteknisk Press, Denmark.

Leleur, S., Holvad, T., Salling, K.B. and Jensen, A.V. (2004). Development of the CLG-DSS Model. *Midterm Report presenting the CTT contribution to TASK 9*. Centre for Logistics and Freight Transportation, Denmark.

Leleur, S., Salling, K.B. and Jensen, A.V. (2007). Documentation and Validation of the TGB Evaluation model in Greenland. *Technical Report prepared for the Home Rule Authorities in Greenland*, Centre for Traffic and Transport, Technical University of Denmark, Copenhagen (in Danish).

Lichtenberg, S. (2000). *Proactive Management of Uncertainty using the Successive Principle – a practical way to manage opportunities and risks*. Polyteknisk Press, Copenhagen, Denmark.

Lyk-Jensen, S. V. (2007). Appraisal Methods in the Nordic Countries – Transport Infrastructure Assessment. *Technical Report 3*, Danish Transport Research Institute, Copenhagen, Denmark.

MacDonald M. (2002). Review of Large Public Procurement in the UK. *Report prepared for the HM Treasury*, London, UK.

Mackie, P. J., Fowkes, A.S., Wardman, M., Whelan, G. & Nellthorp, J. (2003). Value of Travel Time Savings in the UK – Summary Report. *ITS Working Paper*, University of Leeds to the Department of Transport, London, January 2003.

Palisade Corporation (2002). @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel. Version 4.5, *User Manual*, Newfield, USA.

Palisade Corporation (2007). @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel. Version 5.0, *User Manual*, Newfield, USA.

Rosenstand, K. (2007). A socio-economic analysis of the road connection between Sisimiut and Kangerlussuaq with a special emphasis on construction cost and uncertainty. *Master Thesis*, Technical University of Denmark (in Danish).

Rubinstein, R.Y. (1981). *Simulation and the Monte Carlo Method*. John Wiley & Sons, Technion, Israel Institute of Technology.

Rubinstein, R.Y. and Melamed, B. (1998). *Modern Simulation and Modeling*. John Wiley & Sons Ltd., USA.

Saaty, T.L. 2001. *Decision Making for Leaders: The Analytical Hierarchy Process for Decisions in a Complex World*. The Analytical Hierarchy Process Series, USA.

Salling, K.B. (2003). The socio-economic consequences of the Øresund Fixed Link – an ex-post study. *Master Thesis*, Centre for Traffic and Transport, Technical University of Denmark (in Danish).

Salling, K.B. (2008). CBA-DK – Software for Project Appraisal and Risk Analysis in the Transportation Sector. *Documentation Report*, Centre for Traffic and Transport, Technical University of Denmark.

Salling, K.B. & Leleur, S. (2006a). Transport Appraisal and Monte Carlo Simulation by use of the CBA-DK Model. Proceedings of the WSC '06, Monterey, CA-USA, submitted for publication in *Journal of Risk Research.*

Salling, K.B. & Leleur, S. (2006b). Modelling Decision Support and Uncertainty using @RISK: The COSIMA-ROAD Model. *Invited speaker* at the 1st Palisade User Conferece, London, UK.

Salling, K.B. & Landex, A. (2006). Composite Appraisal of the Railway Line between Copenhagen and Ringsted by the use of a Decision Support System named COSIMA-DSS. Proceedings of the 10th COMPRAIL, Prague, Czech Republic, submitted for publication in *Journal of Advanced Transportation.*

Salling, K.B., Leleur, S. & Jensen, A.V. (2007). Modelling Decision Support and Uncertainty for Large Transport Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link. *Decision Support Systems*, Vol. 43, issue 4, 1539-1547, Elsevier.

Salling, K.B. & Leleur, S. (2007). Appraisal of Airport Alternatives in Greenland by the use of Risk Analysis and Monte Carlo Simulation. Proceedings of the WSC '07, Washington DC, USA, submitted for publication in *Journal of Air Transport Management.*

Salling, K.B., Vestergaard, A.V., Rehfeld-Moshøj, C. & Leleur, S. (2008). Decision-Oriented Project Ranking for the Danish Railway Asset Management

System: The AMS-PM Model. Proceedings of the 10th AATT, Athens, Greece, submitted for publication in *Decision Support Systems*.

Salling, K.B. & Banister, D. (2008). Assessment of large transport infrastructure projects: the CBA-DK model. *Accepted for presentation* at the International Conference on Infrastructure Systems (NGInfra), Rotterdam, the Netherlands, November 2008.

The Benchmark Centre for the Danish Construction Sector (2007). Budget deviations on Cultural Constructions in Denmark. *Technical Report (Byggeriets Evaluerings Center - BEC)*, March 2007 (in Danish).

Vose, D. (1996). *Quantitative Risk Analysis – A Guide to Monte Carlo Simulation Modelling*. John Wiley & Sons, Chichester, UK.

Vose, D. (2000). *Risk Analysis – A Quantitative Guide*. 2nd Edition, England: John Wiley and Sons Ltd.

Walker, W.E., Harremöes, P, Rotmans, J., Van Der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P. and Krayer Von Krauss, M.P. (2003). Defining Uncertainty – A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Journal of Integrated Assessment*, Vol. 4, No. 1 pp. 5-17, Swets & Zeitlinger.

Wilmot, C. G. & Cheng, G. (2003). Estimating Future Highway Construction Costs. *Journal of Construction Engineering and Management*, Vol. 129, Issue 3, pp 272-279.

Paper 1

Modelling Decision Support and Uncertainty for Large Transport Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link

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Abstract

This paper presents a decision support system, named the CLG-DSS model, which makes it possible for decision makers to assess various uncertainties in project appraisal in a systematic and explicit way. This model, a decision support system (DSS) developed within the Danish Centre for Logistics and Freight Transport (CLG), the CLG-DSS model, is based on cost-benefit analysis (CBA) embedded in a wider multi-criteria analysis (MCA) by some principles for composite modelling assessment (COSIMA). The CLG-DSS model is set-up to make use of scenario analysis (SA) and Monte Carlo simulation (MCS). A particular concern in the model is the handling of varying information across the assessment criteria and the application of SA to inform the MCS parameter setting. After the presentation of the modelling principles some ex-post case calculations for the Øresund Fixed Link are illuminating different aspects of appraisal uncertainty and thereby, at the same time, demonstrate the features of the CLG-DSS model as a useful decision support tool. It is finally concluded that appraisal of large infrastructure projects can be effectively supported by dealing with uncertainty issues in accordance with the principles described.

1. Introduction

The purpose of this paper is to present the CLG-DSS model with emphasis on its potential for dealing with uncertainty issues relating to the appraisal of major transport infrastructure projects. The model is developed as a decision support system (DSS) and as one of several research tasks in the Danish Centre for Logistics and Freight Transport (CLG). It has been used to make an ex-post appraisal study of the Øresund Fixed Link which opened in July 2000. The Øresund Fixed Link is a 20 km long bridge connecting Copenhagen with the southern part of Sweden - Skåne. It is, however, foreseen that the CLG-DSS modelling principles can be used for other purposes such as, for example, upcoming ex-ante appraisal studies for other European major transport infrastructure projects and even for assessment tasks in other societal sectors due to the generality and flexibility of the model.

The paper is organized as follows: After this introduction section 2 presents some principles for composite modelling assessment (COSIMA) while section 3 gives an overall description of the CLG-DSS model together with a presentation and discussion of the different model components and the methodological principles and theories that underpin them. The model basically consists of a cost-benefit analysis (CBA) embedded in a multi-criteria analysis (MCA) where the latter is calibrated by making use of weights made up similar to the standard prices of the

CBA. A computable general equilibrium (CGE) model for the Øresund Region is applied to calibrate the MCA model.

An important feature described in section 4 is the linking of scenario analysis (SA) with Monte Carlo simulation (MCS). A particular concern has been to apply available assessment information in the best possible way, as collection of extra data and estimation of more precise parameters in many cases turn out to be relatively expensive study costs. By approaching the uncertainty issues involved in transport infrastructure appraisal, it becomes possible for the decision-makers assisted by the model to follow in an explicit and straightforward way how uncertainty issues can be dealt with. This is demonstrated in section 5 by a number of different model runs. The results are discussed and interpreted to give an indication of how decision-makers can be supported by making use of the different aspects of uncertainty handling.

Finally, section 6 presents some conclusions and gives a perspective on the further work on the development of the model.

2. Principles for Composite Modelling Assessment (COSIMA)

CBA into a more comprehensive type of analysis – as often demanded by decision-makers – by including “missing” decision criteria of relevance for the actual assessment task. The missing criteria often address issues that have been difficult to assess by the conventional CBA but hold a potential of improving actual decision support from the assessment if treated properly. This is the purpose of COSIMA where the added criteria will be referred to as the MCA part of the COSIMA analysis.

In brief, COSIMA consists of a CBA part and a MCA part and the result of a COSIMA examination is expressed as a total value (TV) based on both parts. This model set-up emphasizes that the MCA part should be truly additive to the CBA part for which reason an activity, project or initiative A_k, is better represented for a decision support purpose by TV(A_k) than by the net present value of benefits (NPV) from the CBA, here referred to as CBA(A_k). Thus the basic principle behind COSIMA can be set out by (1) below:

$$\mathrm{TV}(A_k) = \mathrm{CBA}(A_k) + \mathrm{MCA}(A_k) \tag{1}$$

The formulation of COSIMA introduced by (1) thus resembles cost-benefit analysis but the assessment principles made use of in the MCA part - generally based on decision-maker involvement which is not made use of in CBA - justifies the denomination as multi-criteria analysis. It can be noted on the basis of (1) that in a situation where the investment in A_k equal to the investment cost C_k is not feasible seen from CBA, i.e. CBA(A_k) < C_k, then the investment can be justified by the wider COSIMA examination if TV(A_k) > C_k. If examined as a total rate of return (TRR), the latter can be expressed as TRR(A_k) > 1.

In a COSIMA analysis applied in the CLG-DSS model, where A_k denominates the implemented infrastructure alternative k for the Øresund Fixed Link, it has in fact been convenient to express the feasibility by the total rate of return TRR(A_k) from the investment C_k which leads to (2) below:

$$TRR(A_k)\cdot C_k = TV(A_k) = \sum_{i=1}^{I} V_{CBA}(X_{ik}) + \alpha \cdot \left[\sum_{j=1}^{J} w(j)\cdot V_{MCA}(X_{jk}) \right] \quad (2)$$

where

V_{CBA} (X_{ik}): Value in monetary units for the CBA effect i for alternative k for altogether I CBA effects.

V_{MCA} (X_{jk}): Value function for MCA criterion j for alternative k for altogether J MCA criteria.

α: Calibration factor that expresses the specific model set-up´s trade-off between the CBA and the MCA part.

$w(j)$: A weight expressing the importance of criterion j.

The general COSIMA principles are presented by (1) and (2). It can be realized that with sufficient information about the MCA part, (2) can be specified into a CBA. This will be the situation when, for example, a conventional CBA is carried out and is afterwards supplemented with some extra criteria. This can be specified fully by impact models that lead to net effects which can be given satisfactory unit prices similar to the assessment in the CBA part. Most often this will, however, not be possible as in general the MCA part will be “less known” than the CBA part. In fact the purpose of COSIMA is to handle such a situation. In modelling terms this is done by the determination of appropriate values for α and $w(j)$ for the J MCA criteria and by the determination of appropriate value functions V_{MCA} (X_{jk}). The latter supplement the determination of V_{CBA} (X_{ik}) that, however, can be derived from a CBA manual relevant for the actual assessment case.

In the CLG-DSS model – one specific application of COSIMA - the following specifications are applied for the CBA part (Leleur et al. 2004):

$$V_{CBA}(X_{ik}) = \sum_{t=0}^{T} D(t)\cdot UP_i(t)\cdot e_{ik}(t) \quad (3)$$

where,

$e_{ik}(t)$: Net change for CBA effect i in year t with $t = 0,1,\dots,T$.

$UP_i(t)$: Unit price in year t (estimated growth in fixed price level can be accounted for).

$D(t)$: Discounting factor $(1+r)^{-t}$ with r as discount rate.

Due to the availability of suitable effect models for strategic impacts, it has been chosen to formulate the MCA part of the CLG-DSS model in a way similar to (3) so the following specifications are applied:

$$\alpha \cdot w(j) \cdot V_{MCA}(X_{jk}) = \sum_{t=0}^{T} D(t) \cdot WP_j(t) \cdot e_{jk}(t) \tag{4}$$

where
$e_{jk}(t)$: Net change for MCA effect j in year t with $t = 0,1,\ldots,T$.

$WP_j(t)$: Weight price in year t (estimated growth in fixed price level can be accounted for).

$D(t)$: As in (3)

α and $w(j)$: As in (2)

It should be noted that in the CLG-DSS application of COSIMA, (3) and (4) differs principally by the prices they adopt, namely the standard unit prices and the weight prices. The latter are dependent on the actual values of α and w(j), see (2), and the idea of the CLG-DSS model is that appropriate weight prices can be determined by making use of computable general equilibrium (CGE) modelling for the actual examination case. Technically the set of weight prices in the CLG-DSS model is determined by the CGE - CBA difference treated by making use of different runs of the CGE calculation model (Leleur et al. 2004).

3. Description of the CLG-DSS Model

The Danish Centre for Logistics and Freight Transport – Decision Support System (CLG-DSS) model concerns the development of a new evaluation methodology to be applicable within the area of logistics and transport. Given the complexity of this particular research task it has been decided to concentrate the model study on the Øresund Fixed Link as base case, i.e. as a kind of evaluation research laboratory.

The CLG-DSS model consists of two modules, a COSIMA-module (Leleur 2000) which is a module combining a CBA and a MCA, and a GAMS-module (General Algebraic Modelling System) using a CGE model. The interaction between the two modules shown in Figure 1 makes it possible to combine a conventional CBA and CGE models which proves to be particularly useful to study the overall effects of transport projects (covering both the direct and indirect effects). Among other things, this makes it possible to provide assessment information for decision-makers in a straightforward and comprehensible manner. First, the decision-maker will get information about the impacts usually included in a CBA such as time savings, accidents, and vehicle operating costs together with the construction and operating costs. Second, CGE model results will identify the changes in welfare at an aggregated level and for the individual groups involved. This will identify the welfare changes for consumers and producers (from different economic sectors). In particular, the structure of CGE models is well-suited to address the impacts associated with enlargement of markets (effects on competition and productivity) and relocation of firms. It should be noted that the CBA outcome is likely to be different from the CGE outcome (unless perfect competition in the economy can be assumed).

The CLG-DSS model

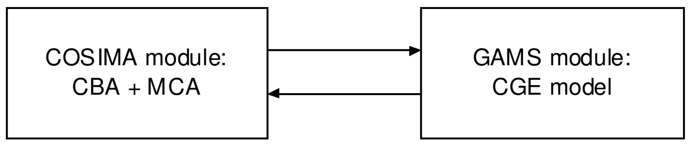

Figure 1. The CLG-DSS model.

The basic structure of the CGE model used for the specific Øresund Region is as follows. The economy is divided into four regions: The Greater Copenhagen area, the rest of Denmark, the Skåne region and the rest of Sweden. In addition, there is an external region to describe the trade between the four regions and the rest of the world. Each region includes a set of households, a bundle of labour, and capital used by regional firms for producing goods and services. Apart from production factor services, the firms are using intermediate goods in the production process. The firms can belong to one of three tradable goods sectors or to one non-tradable (local) goods sector.

Furthermore, the sectors can be described via a number of different product types and services: agriculture, forestry and fishery products; manufactured products; market services and non-market services. Firms are free to compete in the market for a tradable product which already exists or to sell a new one not yet in the market. The optimal choice for the firm is to choose the latter option which means that only one firm will monopolistically supply each product. In this context the firm will set the price as a mark-up on costs. If the firm has a positive profit, new firms are attracted to the industry supplying new variants of the product such that the demand for each single product decline until profits is driven back to zero. Households are assumed to be utility maximizing in the spending of their total disposable income. Disposable income is assumed to come from returns on regional production factors (all production factors are assumed to be owned by regional households) and a net transfer payment from the rest of the world. Households can expend their income on goods (local and tradable) as well as on travel. Households gain utility from a set of activities connected with travel and suffer from disutility for spending travel time. This model set-up allows calculation of the welfare changes as a result of the Øresund Fixed Link. The welfare changes can be calculated at an aggregated level as well as at disaggregated levels for Denmark and Sweden respectively.

The CGE model work is in line with the research findings within the SACTRA work (Banister & Berechman 2000) and (SACTRA 1999). In particular, the model focuses on effects on the product market taking into account the possibility of imperfect competition within a multiregional economic system. In the COSIMA module, CBA is supplemented with MCA so that the MCA basically "interprets" the overall CGE-CBA difference[2]. Due to the theoretical difference between CBA and CGE the decomposition of the CGE-CBA difference at this stage of the work is sometimes referred to as "pedagogical". Wider economic effects are included as the following MCA criteria: (I) Network and mobility, (II) Global emissions (CO_2), (III) Employment, and (IV) Logistics and goods effects (Banister & Berechman 2000). In this way it becomes possible to obtain an estimate of the socio-economic value of the wider economic effects as part of the modelling results. The general structure of the model work carried out in the CLG has been split into six different stages combining the various research results.

First, the principles behind the composite CBA & MCA modelling were determined. In the CLG-DSS model this is addressed by the COSIMA module. Some specifications were discussed in section 2.

The second stage was a determination of the planning principles for the appraisal of large infrastructure projects such as the previously mentioned case for the Øresund Fixed Link and the Øresund Region.

In the third stage a determination of the so-called logistics and goods (LG) effects was treated on an aggregated level by consideration of four defined effects (frequency of shipments, changes in regularity, enlargement of the market, and relocation of production and/or warehouses). The LG-effects differ from the traditional CBA effects due to their nature as defined on company level. It is maintained that the CBA is well-determined both in literature and in practice whilst the wider economic impacts concerning companies are not similarly well-defined (Leleur 2000).

In the fourth stage the scenario work was developed. This stage is described more explicitly in the following section 4.

The fifth stage concerns the model results based on both deterministic and stochastic model runs. The results are also discussed in the following sections with some illustrating examples.

The last stage of the CLG-DSS model work concerns the growth effects giving the interlinking of the COSIMA and the GAMS module for the Øresund Fixed Link case. Available theoretical and empirical findings support the hypothesis that wider economic impacts can be rather substantial, e.g. the English SACTRA work (SACTRA 1999) has suggested that the true benefits (with inclusion of direct and indirect impacts) could be between 30% and 50% greater than the benefits calculated in a standard cost benefit analysis (Venables & Gasiorek 1999). The problem, however, is that the magnitude of these (potentially) additional impacts can be determined only on a case-by-case basis. The modelling and the case relations give valuable information as concerns the level and composition of the socio-economic project value.

Aiming at working more closely with alternative development patterns, it has proven relevant to create a number of framework scenarios to interpret the economic growth in the region as well as at a European level.

4. Scenario Analysis and Monte Carlo Simulation

The technical modelling work carried out in the CLG-DSS model aims also at demonstrating that scenarios - in addition to their basic function showing alternative development patterns - can be made use of to influence the parameter settings in related model simulations.

The CLG-DSS model consists of 10 scenarios divided into 9 framework scenarios and 1 trend scenario.

All of the produced scenarios in the CLG-DSS work can be categorized as exploratory. Within these there are two sub-types of scenarios: framework- and tendential scenarios. The framework scenarios expand the possible range of outcome and try to elaborate various (extreme) scenarios while the tendential or – as also called – trend scenarios try to elaborate a scenario which is affected by some particular development trend (Hall 1977).

The scenarios in the study have been elaborated with respect to two regimes: A Regional/Local regime and a National/European regime. The Regional/Local regime describes how the integration within the Øresund Region is progressing and varies with high, middle and low integration, while the National/European regime deals with the more overall development in the remaining part of Denmark and elsewhere in Europe. This regime varies between a situation with deregulation, regulation & sustainable development and a situation with stagnation & crisis. By combining these two regimes a total of 9 different framework scenarios can be produced as shown in Table 1.

Øresund Region Integration	Deregulation	Regulation & sustainable dev.	Stagnation & crisis
High	1	4	7
Middle	2	5	8
Low	3	6	9

Table 1. The 9 different framework scenarios.

The Deregulation regime (Scenarios 1, 2 and 3) is a situation where the market mechanism is in control. The European Union is here expanding with new member nations. Consequently, Europe has developed into a flexible and competitive region without trade barriers. The transport area has traditionally been a much regulated area but has through the 1990’s undergone a shift towards more deregulation, e.g. road haulage, airlines, railways, and inland waterways. This trend is assumed to continue. The successful economy allows substantial investment in the European infrastructure. Furthermore, the development of technology is also making progress, which means that a possible lack of fossil fuels can gradually be remedied by new technology that allows the use of fuel cells and electrically driven cars.

The Regulation regime (Scenarios 4, 5 and 6) also implies an expansion of the European Union, but the market is more regulated and moves towards a more sustainable direction. In Europe agreements have been made regarding standards for speed limits, noise, emissions and land use planning. Road tax, fuel duties and road pricing contribute to a sustainable development. However, the introduction of new agreements is not achieved without problems and makes only slow progress. The environmental agreements imply that infrastructure investment has not been made to the same extent as is the case in the Deregulation regime. Furthermore, an adjustment of the tax system from taxing the income to taxing the use of natural resources, results also in more sustainable development.

The Stagnation regime (Scenarios 7, 8 and 9) assumes that the previous years' tendency of a weak economy will continue. The enlargement of the European Union is not working out in a smooth way. Unemployment continues to grow implying increased pressure on public resources. In general Europe experiences stagnation and therefore few infrastructure investments are made. The high demand on public expenditures implies that there are few resources left to deal with environmental problems. This is reflected in environmental policies that continue mainly based on already existing agreements, etc.

An additional scenario - Scenario 10 - is produced to make possible the modelling of an oil crisis. The tenth Scenario is referred to as a trend scenario based on Scenario 7, in which an oil crisis is modelled to take place around year 2015.

To incorporate the different scenarios in the CLG-DSS model it is necessary to estimate a scenario modelling parameter (the scenario factor S) for each effect. These S-estimates are made on the basis of the different development patterns that are embedded in each scenario. The scenario factor used in the COSIMA module varies around 1.00 where a value of 1.00 implies that the effect is not affected by the actual scenario. A value below 1.00 corresponds to the S-factor reduces the impact on the effect and a value above 1.00 increases the impact. Values varying from 0.67 to 1.15 have been used in the calculations presented in this paper. However, most of the effects vary from 0.85 to 1.15 with regard to the S-factor.

One of the main influences of the Regional/Local regime is the growth in traffic. Different growth rates have been estimated for both the car and train traffic. The growth in car traffic is illustrated on Figure 2. In this case the growth has a big effect on the total evaluation of the project because the main benefits stems from the reduction in travel time. However, other impacts are also affected by the difference in the two regimes and these are explained in the following description of Scenario 1.

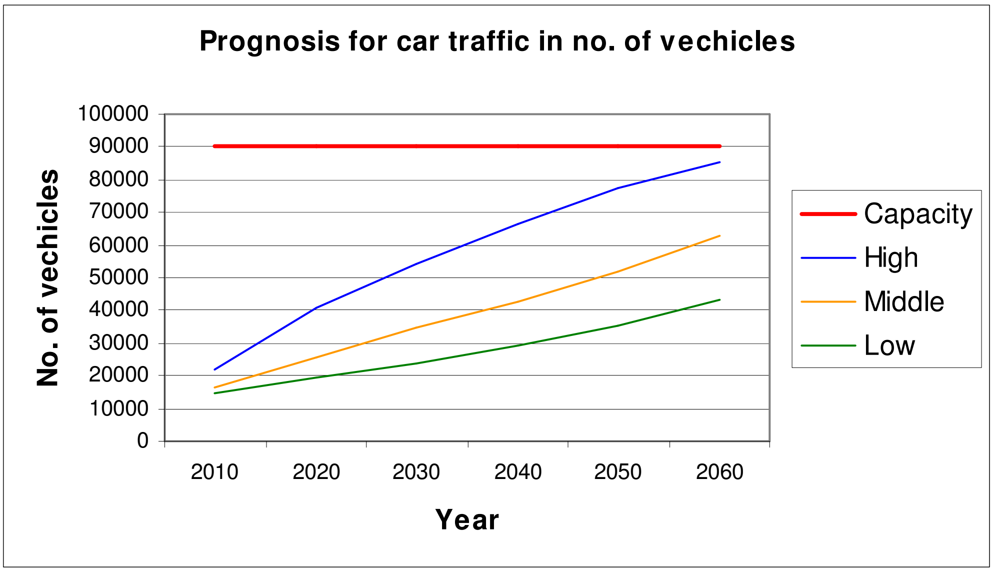

Figure 2. The traffic growth for car traffic for the three Regional/Local regimes.

Scenario 1 is the most optimistic one. The economy in Europe and Denmark is generally in a good state. Within the Øresund Region the economy has developed towards a very strong economy. The integration between The Greater Copenhagen Region in Denmark and Skåne in Sweden has undergone a progressive development. This has resulted in the creation of an integrated region where people move across the border between Denmark and Sweden daily without noticing the differences. The region is highly competitive compared with other regions within the European Union.

The effect is a perceived higher value of time for the travellers (both car and train travellers). This is due to the level of activity in the region. The value will increase after 2004 with a steady rate until year 2020 where the scenario factor (S) ends up with a value of 1.15. After 2020 the value of S is constant at 1.15. A progressive technology development results in a reduction of the number of accidents on the Øresund Fixed Link. This reduction is modelled with a fall in the scenario factor after 2004 until 2020 to a value of 0.95. Then the factor is set to 0.95 throughout the evaluation period.

The value of carbon dioxide (CO_2) is reduced due to the expectation towards the emission which fail to appear and the technological development has also reduced the emission of CO_2. The price per ton CO_2 emission is reduced rapidly after 2004 until a value of 200 DKK per tonne is reached in 2007. This is modelled with a scenario factor that takes on the value of 0.67 in 2007. The CO_2 price reflects

USA and UK estimates, where CO_2 emissions are not considered as important as in continental European countries today.

Employment issues are affected such that the value of a new workplace is reduced. A new workplace value is based on a report from the former West Germany calculating the resources associated with creating a new workplace for the government (Goodwin & Persson 2001). The value is reduced because the economy produces many new workplaces and therefore the expenses associated with forming a new workplace are reduced. The value is reduced with the scenario factor that takes on the value of 0.95 in 2020. The high integration between Denmark and Sweden results in 3300 new workplaces. Because of the progressive development in the rest of Denmark and Europe there are further 100 new workplaces because of the Øresund Fixed Link. This gives a total of 3400 new work places (Leleur et al. 2004).

The number of scenarios reflects the overall uncertainty. To handle the uncertainty involved within each scenario in the CLG-DSS model, Monte Carlo simulation (MCS) has been used including software @RISK applied as an add-on to the Excel-based CLG-DSS software (Palisade 2002) and (Vose 2000).

The CLG-DSS model in its present version categorises information about study data and parameters into three levels of knowledge:

1. A relatively high level of knowledge is modelled by a normal distribution leaving the decision maker with the determination of a mean value and a standard deviation. An example is the use of this distribution for the travel time savings based on traffic flow modelling.

2. The middle level of knowledge is modelled by a triangular probability distribution leaving the user to determine a minimum, a most likely and a maximum value. The triangular distribution is furthermore characterised by higher flexibility as it is possible to work with open distribution tails defined by appropriate fractiles stating that some values exceed the previously defined range with a chosen probability. An example here is the employment effect based on regional economics studies.

3. The low level of knowledge is related to the uniform distribution, which as input only needs a minimum and a maximum value defining an overall range for the parameter value. An example here is the amount of local pollutants.

5. Model Results

The CLG-DSS model results are divided into 2 groups based on the deterministic runs and on the stochastic runs. The results concerning the deterministic runs are presented as single value return rates representing the nine different framework scenarios. As an example Table 2 shows the result of framework scenario 1 representing a high integration in the Øresund Region combined with deregulation from the National/European regime.

Travel time etc.	0.85
Network & mobility	0.11
Global emissions (CO_2)	0.02
Employment	0.32
Logistics & Goods effects	0.05
Total Rate	**1.35**

Table 2. Deterministic results concerning Scenario 1.

The “Travel time etc.” result stems from the basic cost-benefit analysis stating that a benefit-cost rate above 1 is an indication of a socio-economically feasible project. This is, however, not the case in the given study from the Øresund Fixed Link. However, if the employment effect, one of the added MCA-effects is taken into account, a combined CBA & MCA rate is found equal to 1.17, which then makes the project feasible seen from a societal point of view. The conclusion to be drawn from the deterministic runs is therefore that when making a socio-economic analysis it is important not only to look upon the traditional, narrow effects from a CBA but also include wider impacts made up by network & mobility, global emissions (CO_2), employment and logistics & goods effects modelled by the applied MCA in the COSIMA module (Leleur et al. 2004) and (Leleur 2000).

The total level of the allocative externalities – the MCA impacts above – is determined by a CGE sketch model being developed for the Øresund Region (Banister & Berechman 2000) and (SACTRA 1999), see also Figure 1 indicating the iterative procedure applied (Holvad & Leleur 2004). The CGE modelling approach is relevant to assess the wider economic impacts generated from transport projects, i.e. those impacts which are caused by the interaction between the transport sector and the overall economy. One problem, however, is that the magnitude of these (potentially) additional impacts can only be determined on a case-by-case basis (SACTRA 1999) and (Holvad & Leleur 2004).

The results from the deterministic runs are further examined in the CLG-DSS model by setting probability distributions for some of the variables. In this respect it can be mentioned that travel time savings, based on flow estimates from traffic models, are modelled by a normal distribution whereas, for example, employment is modelled by a triangular distribution for the value of one job created and CO_2 emissions by a uniform distribution for the value of one tonne of CO_2. Furthermore, there will appear across the scenarios an increasing uncertainty, reflected in the particular distribution parameters. This uncertainty are modelled so moving from low via medium to high integration and from deregulation via regulation and sustainability to crisis and stagnation is associated with higher uncertainty along each regime axis. Figure 3 gives an overview of the settings and the obtained results.

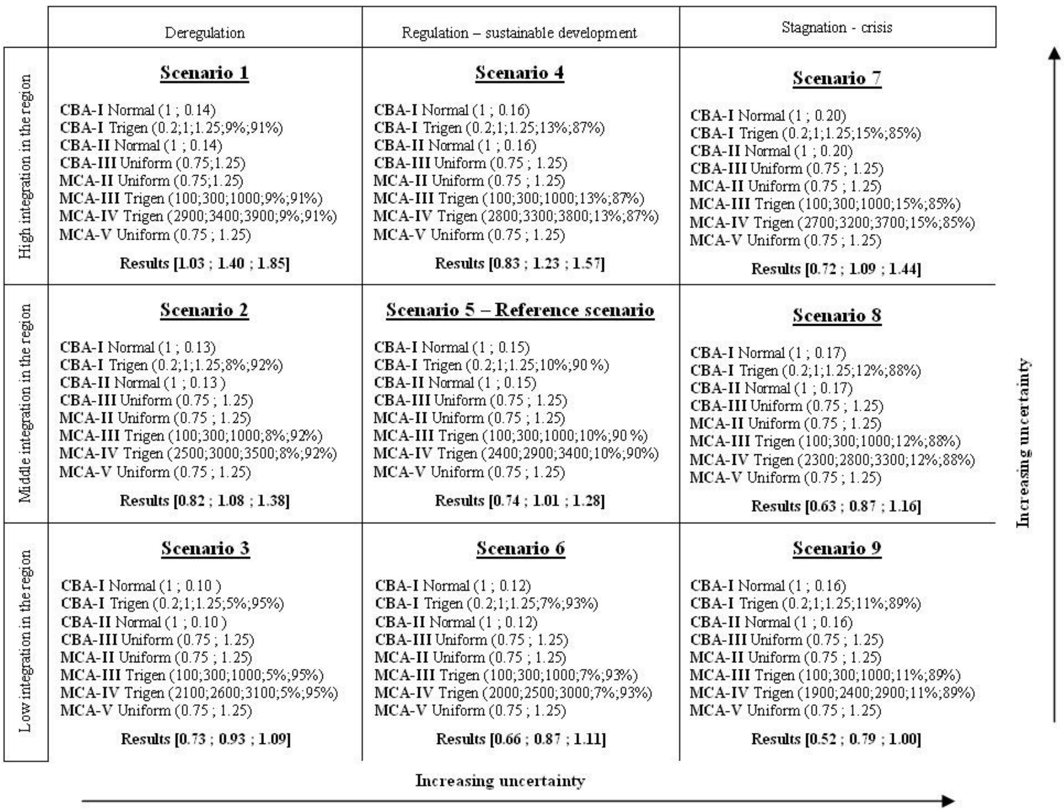

Figure 3. Overview of results for the stochastic runs.

The results from the stochastic runs are presented in Figure 4 by descending cumulative graphs indicating the probability that the overall rate of return will be equalled or exceeded. To exemplify, the Scenario 1 result is the SC 1-curve at the right, showing a total return rate equal to 1.03 at 100% probability and a rate equal to 1.85 at a 1% probability level.

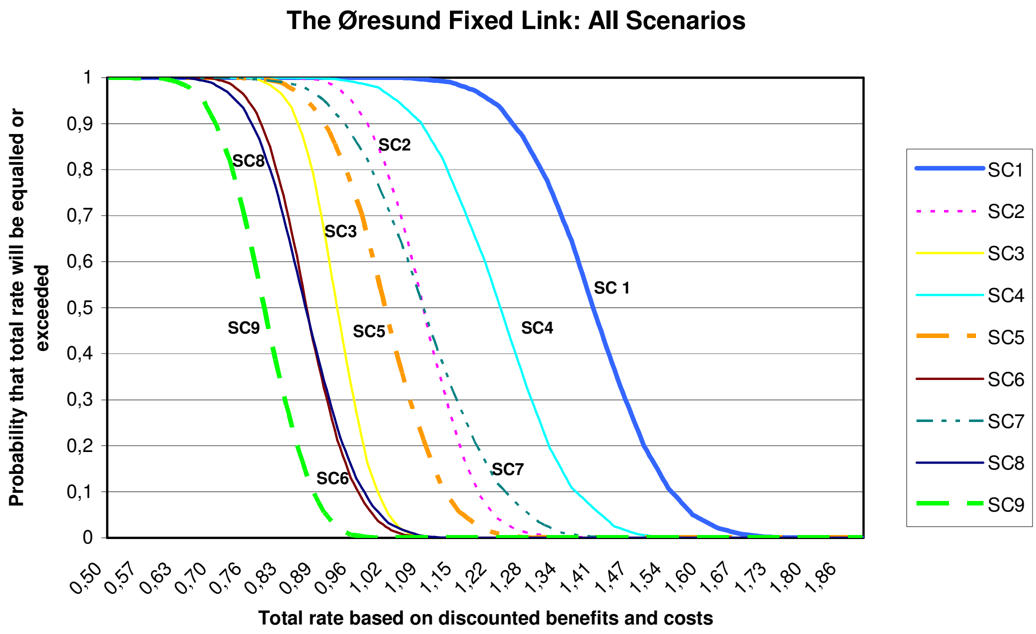

Figure 4. Combination of descending graphs concerning the nine framework scenarios.

Note that for the descending cumulative curves with the probability on the y-axis and the rate of return on the x-axis more reliable data will lead to steeper curves. Note also for Scenarios 2 and 7 results, and to some extent for Scenarios 6 and 8 results, that the curves cross each other. This is to be paid special attention to by the decision-makers with regard to the desired level of rate and their actual risk aversion.

The influence on practical decision-making can be illustrated as follows. Scenario 7 has a total return rate equal to 1.09 at the 50 percentile indicating a feasible project. Most decision makers, however, are not pleased "only" with a 50% level but would prefer, for example, a 90% level here giving a rate below 1 equal to 0.94 indicating that the project is not feasible at this level of probability. The feasibility risk to be adopted in the actual case is of course up to the decision-makers to debate but the features to deal with uncertainty in the CLG-DSS may help support their considerations. Some of these will be to get acquainted with the various assumptions behind the scenarios, probability distributions, and the way the latter have been assessed/estimated and related to the different scenarios.

6. Conclusions and Perspective

This paper has presents a new model to appraise large transport infrastructure projects stemming from research carried out in the Danish Centre for Logistics and Freight Transport (CLG). The model development uses the Øresund Fixed Link and the Øresund region as an evaluation methodology laboratory. One major outcome is that narrow CBA-based impacts – in many European countries described in a national manual – needs to be supplemented with wider impacts to appraise whether the project is feasible or not feasible from a socio-economic viewpoint. Due to the comprehensive and complex project information it will be relevant to deal with uncertainty issues as part of the decision support established by the appraisal study. The approach taken in the CLG-DSS model is to combine scenarios and Monte Carlo simulation to establish a range of results.

Although the total set of model results – here also considering subdivisions of the total rate into CBA and MCA contributions and further into single impact return contributions – may seem quite comprehensive it is the opinion of the team behind the CLG-DSS model that it is possible to communicate the essence to decision-makers. This also includes the extension of deterministic single value results into stochastic result curves and their association with different scenarios.

A current research perspective is to refine the CGE approach and continue the iteration indicated in Figure 1. This will allow better calibration of the impact models applied for the four allocative externalities made use of in the model. Another research perspective is to continue the work on linking scenarios with Monte Carlo simulation (Goodwin & Persson 2001).

At its current stage of development it can be concluded that the CLG-DSS model contains model features that are relevant and effective for the provision of decision support for large transport infrastructure projects with emphasis on assessment of uncertainty. There is, however, ample room for further development when applying it on other case studies.

References

Banister, D. and Berechman, J. (2000). *Transport Investment and Economic Development*, UCL Press.

Goodwin, P. & Persson, S. (2001). Assessing the Benefits of Transport, *Chapter from ECMT*, OECD

Hall, P. (1977), *Europe* 2000, Columbia University Press.

Holvad T. & Leleur S. (2004). Assessment of Wider Economic Benefits: The Case of the Øresund Fixed Link with a Special Emphasis on Regional Economic Development, *The 10th World Conference on Transport Research*, Istanbul, Turkey.

Leleur S. (2000). *Road Infrastructure Planning – A Decision-Oriented Approach*, Second Edition, Polyteknisk Forlag, Lyngby, Denmark.

Leleur S., Holvad T., Salling K.B. and Jensen A.V. (2004), Development of the CLG-DSS Evaluation Model, *Midterm report*, Centre for Logistics and Goods Transport (CLG), February 2004.

Palisade Corporation (2002). @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel, *User Manual*, Version 4.5.

SACTRA (1999). *Transport and the Economy*, Final Report, The Standing Advisory Committee on Trunk Road Assessment, London.

Venables, A.J. and Gasiorek, M. (1999). The welfare implications of transport improvements in the presence of market failure, *report to SACTRA*, UK.

Vose, D. (2000), *Risk Analysis – A Quantitative Guide*, Second edition, John Wiley & Sons.

Paper 2

Modelling Decision Support and Uncertainty using @RISK: The COSIMA-ROAD Model

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The paper forms the basis for interview on the Palisade webpage entitled: *Air, Land & Sea: @RISK used in Transportation Planning in Denmark*: http://www.palisade.com/cases/ctt.asp.

Keywords: Decision Support Model, CBA-DK modelling framework, Quantitative Risk Analysis, Monte Carlo Simulation

Abstract

This paper concerns a newly developed software model called COSIMA-ROAD for project evaluation in the Danish road sector. COSIMA-ROAD is developed as a combined effort in co-operation between the Danish Road Directorate and the Technical University of Denmark. The applied case study is developed by the Danish Road Directorate. The main purpose of this paper is primarily to describe how @RISK is used in COSIMA-ROAD. First the two main modules of COSIMA-ROAD are described as respectively a traditional cost-benefit analysis (deterministic point estimate) and a risk analysis using Monte Carlo Simulation (stochastic interval estimate). Next the actual case example is presented with the obtained results. Finally, conclusions and a perspective of the future modelling work are given.

1. Introduction

A few years ago the Danish Ministry of Transport released a manual for socio-economic analyses on transport issues (DMT 2003). Based on this work and the guidelines presented in this manual the Danish Road Directorate decided to develop a software program COSIMA-ROAD for use in evaluating Danish road investments. In co-operation with the Centre for Traffic and Transport (CTT)[23] at the Technical University of Denmark (DTU) a proto-type model was finished in the spring of 2005. Current research and further development of this model is presented in this paper with emphasis on risk analysis carried out by use of @RISK (Palisade 2002).

Due to limited resources Danish infrastructure proposals are prioritized by use of socio-economic analysis. By use of COSIMA-ROAD this examination is structured to provide decision-makers with support that enables them to make more informed decisions. The main purpose is not to give strict answers but to assist by facilitating the right choice.

COSIMA-ROAD is an Excel based software model for road and infrastructure evaluation consisting of a cost-benefit analysis (CBA) part and risk analysis (RA) part. The software model consists of 9 different worksheets contributing to the CBA component also referred to as the deterministic calculation and 2 worksheets contributing to the RA component referred to as the stochastic calculation, cf. Figure 1.

[23] Until January 1st 2008 the Department of Transport at the Technical University of Denmark was named Centre for Traffic and Transport (CTT)

The case study relies on data from a Master Thesis conducted at the CTT-DTU (Petersen & Andersen 2006). The case concerns several proposed by-pass roads in an inter-urban area. By examining four different alignment proposals each with varying degree of travel time savings and investment costs - investment criteria can be assessed and presented for the decision-makers.

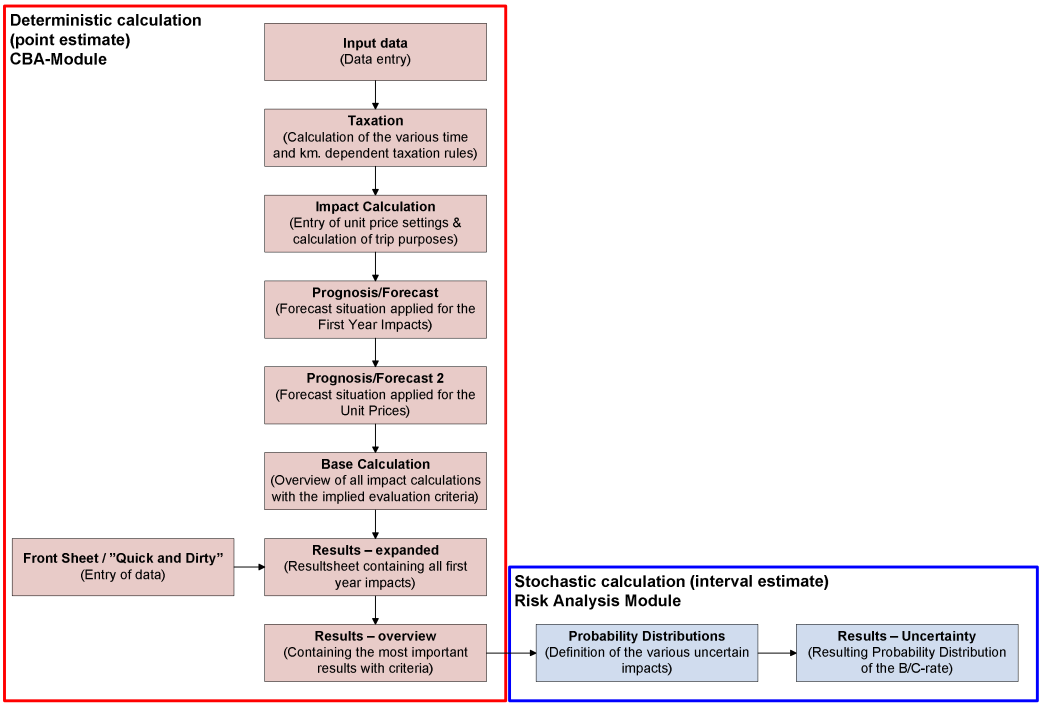

Figure 1. The module structure of COSIMA-ROAD illustrated by the various worksheets.

2. The Deterministic Calculation

The CBA module of COSIMA-ROAD consists of traditional cost-benefit analysis (CBA) split into 4 sub-categories: Passenger Cars, Lorries, Heavy Vehicles and External Effects. The three vehicle groups are further divided into impact groups for each group consisting of travel time savings, vehicle operating costs, congestion and changing traffic. It can be noted that changing traffic is assessed by making use of the so-called rule-of-a-half principle (Leleur 2000, pp. 89-91). The external effects are of different types such as accidents, pollution, barrier and perceived risk and noise. Additional entries in the input sheet are the main data concerning the case project: construction cost (investment cost), operating and maintenance costs, evaluation period and key parameters such as discount rate, growth in the economy, etc. Figure 2 is showing the input data sheet. The Danish methodology is described in (Leleur 2000, pp. 129-134).

By applying the net changes within the user impacts and the external effects as input to a socio-economic analysis, it is possible to obtain decision criteria such as the Benefit-Cost ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR) and First Year Rate of Return (FYRR). A run of COSIMA-ROAD ends up with a result sheet shown in Figure 3. The two bars on the right depict the costs and the benefits presented in the same absolute scale. By comparing the decision criteria from different runs on different projects a prioritisation can be made (Leleur 2000, pp. 99-105).

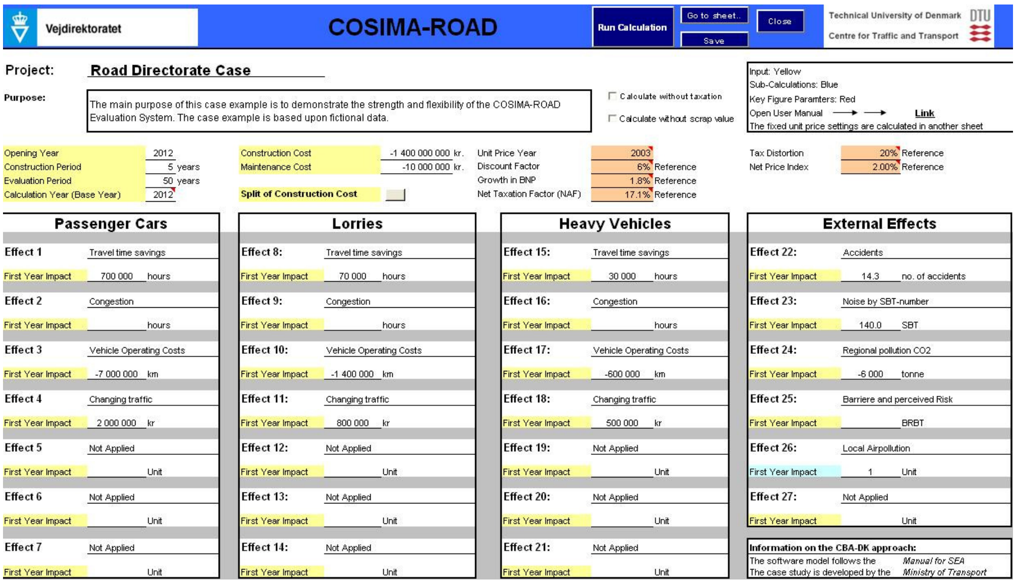

Figure 2. Screen dump of the Input data sheet.

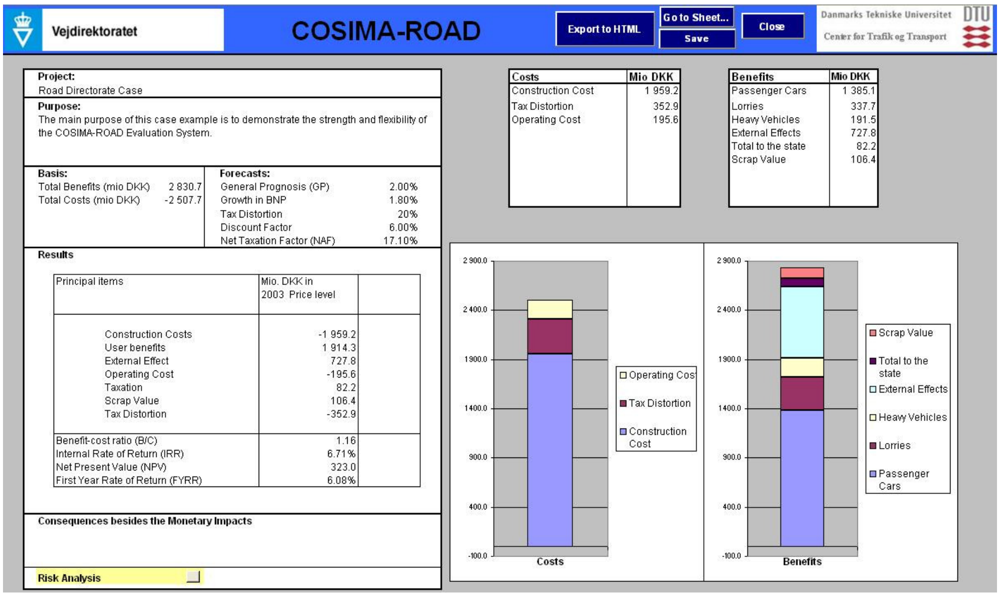

Figure 3. Screen dump of the results overview sheet containing the most important results from this case.

After such deterministic runs it is possible to make risk analyses with BCR intervals as the output. This provides a broader basis for assessing the individual projects.

3. The Stochastic Calculation

To make a CBA, as performed in the COSIMA framework, it is necessary to obtain information from various traffic and impact models. The various types of models combined with varying degrees of effort and resource input for impact modelling result in different degrees of uncertainties. In this respect it is necessary to use different probability distributions in accordance with the variability/uncertainty that characterizes the parameters set focus upon in the risk analysis. The Danish Manual from the Ministry of Transport determines unit prices which in COSIMA-ROAD remain fixed (time unit price, vehicle operating costs a.o.). In the view of this work these parameters are assumed as certain. The COSIMA model examines selected parameters that are considered the most important for RA such as: construction costs, number of hours saved per year for traveling time, maintenance unit costs and safety unit price. The first two are matters of variability and the latter two of uncertainty (Vose 2000, p. 18). Variability and uncertainty reflect ontological and epistemic issues, see Figure 4 from (Walker et al. 2003, p. 13).

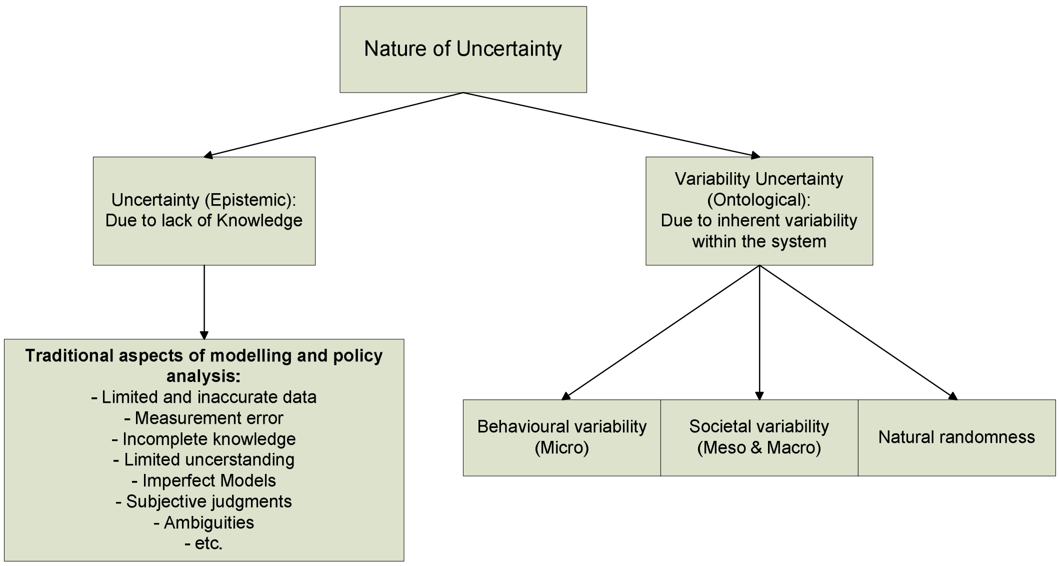

Figure 4. The nature of Uncertainty: Inherent variability or lack of knowledge (adapted from Vose (2002) and Walker et al. (2003)).

The Ph.D. study sought to describe the types of probability distributions suitable for use in the COSIMA-ROAD framework. They follow a level of knowledge typology diagram moving from a relatively "high level" of knowledge to a relatively "low level". The current four types of distributions used within COSIMA from high to low level is: Erlang (Gamma), Normal, Triangular and Uniform distribution. Figure 5 shows how the various distributions are related to the level of knowledge applied on the variable or parameter.

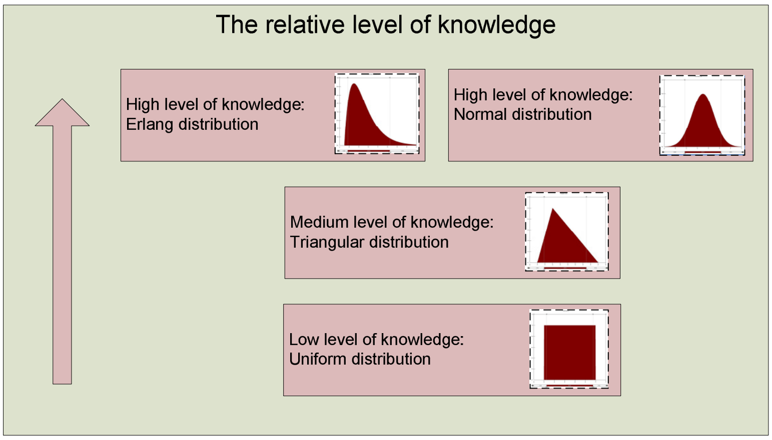

Figure 5. Overview of probability distributions applied in COSIMA-ROAD (adapted from Leleur et al. (2004)).

3.1 Construction Costs

The cost of investing in a project ex-ante is often predicted lower than the actual cost e.g. due to technical problems, delays, etc. A Danish mathematician has developed this experience into a principle based upon successive calculation (Lichtenberg 2000). The strength of applying Lichtenberg's principle is that the decision-maker only has to consider a minimum, most likely (ML) and maximum value. Then by use of a so-called triple estimation approach the mean and standard deviation are calculated by the two following formulas (Lichtenberg 2000, p. 125):

$$\mu = \frac{(\min. + 2.9 \cdot ML + \max.)}{4.9} \tag{1}$$

Due to the properties of the Erlang distribution a scale (k) and shape (θ) parameter is needed. It has been found that a scale parameter of k = 5 matches the distribution of the uncertainty involved in determining the construction cost (Salling & Leleur 2006). From the triple estimation is the mean (μ) calculated by (1). The relationship to the shape parameter is found by the equation: $\theta = \frac{\mu}{k}$. The applicability of the Erlang distribution is related to the variation of the scale parameter, see Figure 6. For k = 1 the distribution is similar to an Exponential distribution, whereas with increasing *k* the distribution will begin to resemble a Normal distribution.

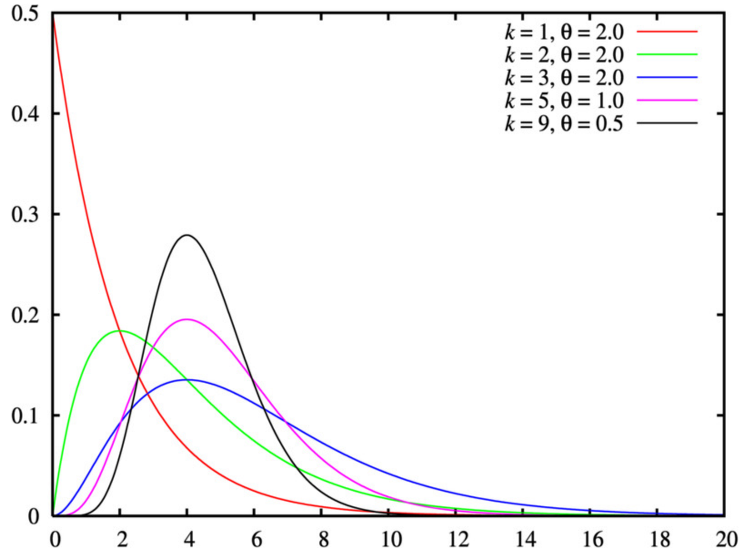

Figure 6. Illustration of an Erlang distribution with various shape and scale parameters.

3.2 Travel Time Savings

The travel time savings have been found to follow a Normal distribution where the mean is based upon the first year effect entry determined as the net change in hours spent on traveling in the influence area of the road project. Standard deviations relating to traffic models applied in Denmark have been found to be around 10-20% (Knudsen 2006). By testing a traffic model in several scenarios it has been proven that the standard error within this model is around 11% for the transport mode and 16% for the traffic loads. Further investigations show that a standard deviation in the area of 10% for smaller projects and 20% for large projects are not unlikely (Knudsen 2006, p. 105).

3.3 Maintenance Costs

The maintenance costs (MC) are developed based on empirical accounting formulas considering different cost factors (Leleur 2000, p. 158). It has been found suitable to use a Triangular distribution (Salling & Leleur 2006). Specifically, the uncertainty assigned to this parameter using the Triangular distribution is defined by 10% possibility of achieving a lower MC and 50% possibility of achieving a higher value at the tales. It should be noted that this effect is a disbenefit towards society.

3.4 Accident Unit Price

The accident benefits are determined by their value to society stemming from multiplying the expected number of accidents saved with a societal unit price. The Uniform distribution shows the assumed uncertainty included in the price-setting where information on a high and low range is estimated. In the actual case run a rather conservative estimate with ± 10% to the standard unit price has been applied.

3.5 The Risk Analysis and its Results

The actual Monte Carlo Simulation shown in Figure 7 is based upon the previous parameters and distributions. The purpose of the COSIMA-ROAD RA result sheet is to give the decision-makers a mean to widen their assessment of the possible BCR (Hertz & Thomas 1984). Specifically, Figure 7 shows three COSIMA reports based on @RISK: Histogram showing the most frequent BCR, a descending accumulated graph that shows the "certainty" of achieving a certain BCR or better and finally a correlation tornado graph that illustrates the impact (correlation) of each variable or parameter to the overall BCR.

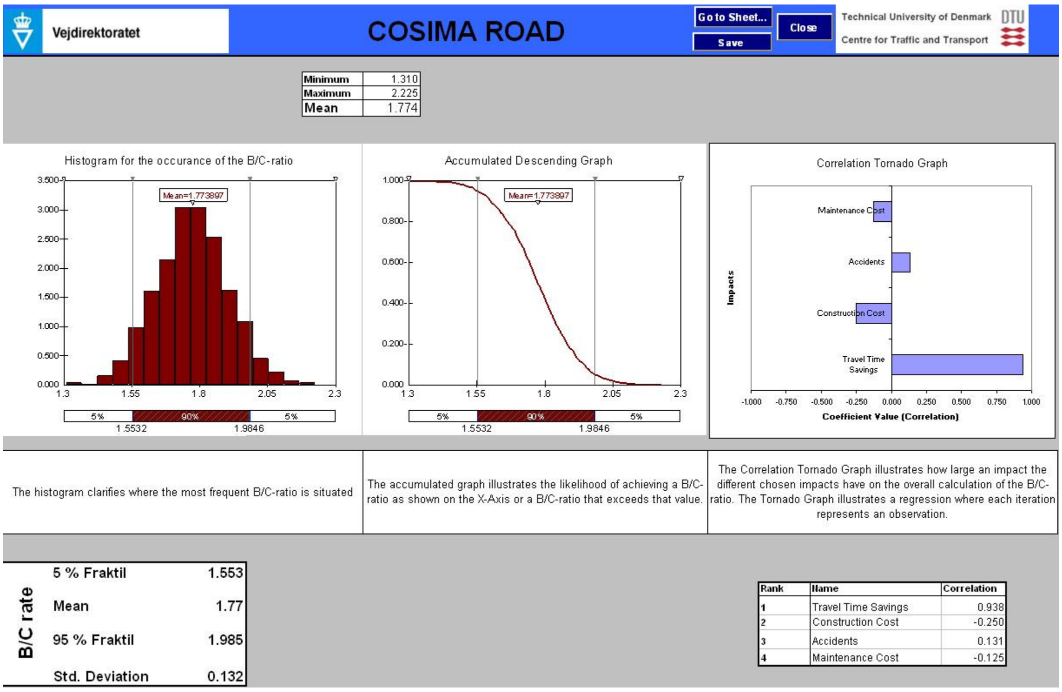

Figure 7. Screen dump of the resulting sheet from a Monte Carlo Simulation in COSIMA-ROAD.

4. Conclusions and Perspective

With COSIMA-ROAD it is possible to carry out a Danish project appraisal study according to the principles determined in the manual developed by the Danish Ministry of Transport (DMT 2003). The software model has been designed as a combined approach in determining the feasibility of a road infrastructure project by use of both a deterministic and a stochastic approach based on @RISK. Thus a deterministic point estimate and a stochastic interval measure make it possible to assist the decision-makers by an accumulated graph whereby risk aversion can be taken into consideration.

The decision support model will be further developed in future studies. Thus it can be mentioned that a new COSIMA model is applied in a large transport study on Greenland with focus upon appraisal of airfields. In this study the work with applying @RISK for Danish transport project appraisal will be continued in a more comprehensive study.

References

Danish Ministry of Transport (2003). *Manual concerning socio economic analysis – applied methodology in the transport sector*, June 2003 (in Danish).

Hertz, D.B. & Thomas, H. (1984). *Risk Analysis and its Applications*. John Wiley and Sons Ltd. England

Knudsen, Mette A. (2006). Evaluation of uncertainty in traffic models – a theoretical and practical analysis of the Naestved model (in Danish), *Master Thesis*, Centre for Traffic and Transport – Technical University of Denmark.

Leleur, S. (2000). *Road Infrastructure Planning – A decision-Oriented Approach*. 2nd edition, Polyteknisk Press, Lyngby, Denmark.

Leleur, S., Holvad, T., Salling, K.B. & Jensen, A.V. (2004). Development of the CLG-DSS Evaluation Model. *Midterm Report*, Centre for Logistics and Freight Transport, Denmark

Lichtenberg, S. (2000). *Proactive Management of Uncertainty using the Successive Principle*. Polyteknisk Press, Lyngby, Denmark.

Palisade Corporation (2002). *@RISK – Risk Analysis and Simulation Add-In for Microsoft Excel*, Version 4.5, Newfield USA.

Petersen, N.B. & Andersen, M.K. (2006). A comparative study of four approaches to Transport Decision-Making. *Master Thesis*, Centre for Traffic and Transport, Technical University of Denmark.

Salling, K.B. & Leleur, S. (2006). Transport Appraisal and Monte Carlo Simulation by use of the CBA-DK Model. Proceedings of the WSC '06, Monterey, CA-USA, submitted for publication in *Journal of Risk Research*

Vose, D. (2002). *Risk Analysis - A Quantitative Guide*. 2nd Edition, John Wiley & Sons Ltd., England

Walker, W.E. et al. (2003). Defining Uncertainty – A Conceptual Basis for Uncertainty management in Model-Based Decision Support. *Journal of Integrated Assessment* Vol. 4, No. 1, pp. 5-17.

Paper 3

Multi-Criteria Evaluation of the Railway Line between Copenhagen and Ringsted by the use of a Decision Support System named COSIMA-DSS

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Keywords: Decision Support System, Cost-benefit analysis, Multi-criteria Analysis, Analytic Hierarchy Process, Quantitative Risk Analysis

Abstract

This article presents a composite appraisal study concerning the extension of the main railway line between Copenhagen and Ringsted by use of a decision support system named COSIMA-DSS. The modelling system is based upon a multi-methodological approach combining cost-benefit analysis with multi-criteria analysis and quantitative risk analysis. The COSIMA-DSS model is used to evaluate the impacts of traditional monetary character together with the non-monetary impacts of scheduled waiting time, network effects and timetabling that cannot be evaluated by traditional cost-benefit analysis. This composite approach is considered state-of-art within transport appraisal studies. The uncertainty concerning the resulting deterministic point results are treated with Monte Carlo simulation bringing informed decision support towards decision-makers. The combined methodological approach depicted, results in the composite model for assessment towards Danish transport infrastructure projects.

1. Introduction

The idea of supporting decisions regarding new transport infrastructure projects by use of cost-benefit analysis (CBA) is well established in Europe. In Denmark the foundation of such analyses is made up by the manual for socio-economic analysis published by the Danish Ministry of Transport in 2003 (DMT 2003). The current challenge is now to develop a method to describe and measure the effects and criteria, not embedded within the manual comprised by non-monetary impacts. The methodology used is made up by a composite analysis in which a rational and trustworthy method is introduced comparing and assessing the latter set of impacts.

The fundamental idea behind COSIMA (COmpoSIte Model of Assessment) is to extend the conventional CBA into a more comprehensive type of analysis – as often demanded by decision-makers – by including "missing" decision criteria of relevance for the actual appraisal task. Thus, the missing criteria are often not possible to assess by conventional CBA but still holds a potential of improving the actual decision support from the appraisal, if treated properly. This is the purpose of COSIMA, where the added criteria will be referred to as the multi-criteria analysis (MCA).

COSIMA also contains a quantitative risk analysis (QRA) module using Monte Carlo simulation (MCS) to assess the varying degree of uncertainty embedded within the model. The uncertain parameters and variables can then be evaluated by assigning probability distributions on the first year effects. Instead of resulting point estimates from e.g. net present values (NPV), internal rate of returns (IRR) or benefit cost ratios (BCR) new resulting interval results based upon the output BCRs can be derived. In this way COSIMA can be seen as an advanced tool for decision support for various kinds of projects – including all transport modes such as road, air and railway.

The framework methodology is used for an ex-ante evaluation of the extension for the main railway line between Copenhagen central station (København H) and Ringsted in mid-Zealand. The capacity of the railway line has since the beginning of the 1990s been planned to be increased by either of two different proposals or main strategies namely (1) two extra tracks along the existing railway line or (2) a new railway line with a new layout. A sketch of the current situation together with the new proposals is depicted in Figure 1.

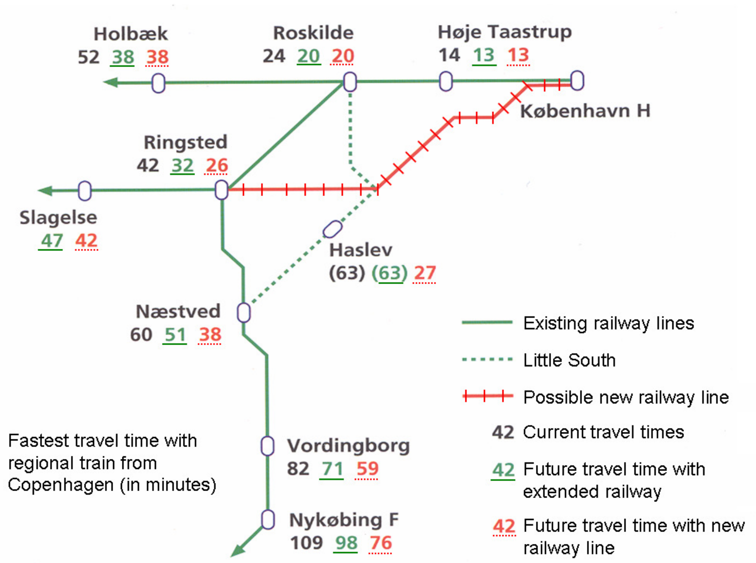


Figure 1. Fastest travel time with regional train from Copenhagen based on (DMT 1997).

The traffic between Copenhagen and Ringsted has increased dramatically over the recent couple of years. To operate more trains and hereby carry more passengers and freight it has become necessary to reduce the speed of the fastest trains to homogenize the operation. The running times of the trains have therefore been prolonged, thus, the trains have got extra stops. This increase in time for the fastest trains is significant as depicted in Figure 1, by which on some travel relations the increase in time (denoted as the *scheduled waiting time*) can be up to 20% of the actual running time (DMT 1997).

The decision to implement the extension or the new railway line is off course up to the decision-makers, in this case the Danish Government. However, by using a decision support system (DSS) like COSIMA-DSS, decision-makers can get "assistance" in making the best and most profitable choice seen from a societal point of view. It is necessary to stress that a DSS is not the "correct" and final answer to the problem but merely assistance to the decision-makers.

2. Time Benefits

When evaluating infrastructure projects using the Danish manual (DMT 2003), the main impact is the time benefits. In schedule-based public transport systems, the time benefits can be divided into several elements – e.g. waiting time, transfer times, time spent in the vehicle and delayed time (Ortuzár & Willumsen 2002). Passengers consider each of these time elements differently and several studies have therefore been carried out to evaluate these e.g. (Mackie et al. 2001). For instance it feels worse to be delayed than travelling in a vehicle – therefore, delayed time has a higher value of time than ordinary travel time in the CBA (DMT 2006).

2.1 Scheduled Waiting Time (SWT)

The scheduled waiting time (SWT) is a time element in the appraisal study worth noticing. It occurs on railway lines when the traffic intensity is close to the maximum capacity level due to mixed operations (e.g. slow and fast trains). Then, the operation speed of the fast trains must adapt to the slower trains as the fast trains otherwise will catch up with the slower trains. This increases the travel time for the fast trains that under free conditions could run at higher speeds.

The time scheduled is clearly highly dependent on available capacity and capacity consumption. If the consumption is high, as in the Copenhagen-Ringsted case, the SWT is correspondingly high. Traditionally, SWT is calculated as ordinary travel time for the passengers, thus included in the travel time savings effect determining hours saved in train. However, it can be argued that the travel time savings should be divided into minimum travel time (the shortest possible running time including relevant time supplements to catch up minor delays) and SWT. Furthermore, the SWT should be assessed as a delay since the train (and thereby the passengers and freight) are delayed due to other trains, although it is a "scheduled delay". Whether the SWT is calculated as ordinary travel time or delayed time, the impact on the result is high since normally delayed time are weighted twice as much as the ordinary travel time (for commuters 59 DKK/hour vs. 118 DKK/hour (DMT 2006)). The SWT is classified as non-monetary within the COSIMA approach since no real recommendation for the impact has been decided yet.

Calculating the time benefits only using the traditional CBA can result in the paradox that a well-planned timetable (in the basis scenario) results in a worse societal impact than a sloppily planned timetable (also in the basis scenario), when e.g. an extension of a railway line is proposed. This paradox is due to the lower socio-economic cost of travelling when the SWT is considered as ordinary travel time (Scenario 1) instead of delayed time (Scenario 2), which will occur when the SWT is not taken into account. A small standardized example is shown in Table 1, where a comparison between a well-planned and sloppy timetable is performed.

	Scenario 1 (Well planned)	Scenario 2 (“Sloppy”)	Scenario 3 (Future)
Minimum running time (minutes)	32	32	32
Scheduled waiting time (minutes)	10	0	0
Travel time (minutes)	42	32	32
Delay (minutes)	0	10	0
Time costs per commuter (DKK)	41.30	51.13	31.47
Difference future vs. basis	**9.83**	**19.66**	**-**

Table 1. Calculation of socio-economic time costs.

Table 1 show that a well planned timetable taking the SWT into account results in a benefit of 9.83 DKK/passenger whilst a sloppy planned timetable results in 19.66 DKK/passenger. Introducing the new schemes of e.g. (1) two extra tracks or (2) a brand new line actually means that the sloppy planned timetable results in a higher benefit of the project towards society. This is due to the fact that socio-economic evaluation is based upon net changes given an infrastructural change. The difficulties and challenges illustrated in Table 1 clearly show that the so-called timetabling impact should be taken into consideration in a socio-economic analysis.

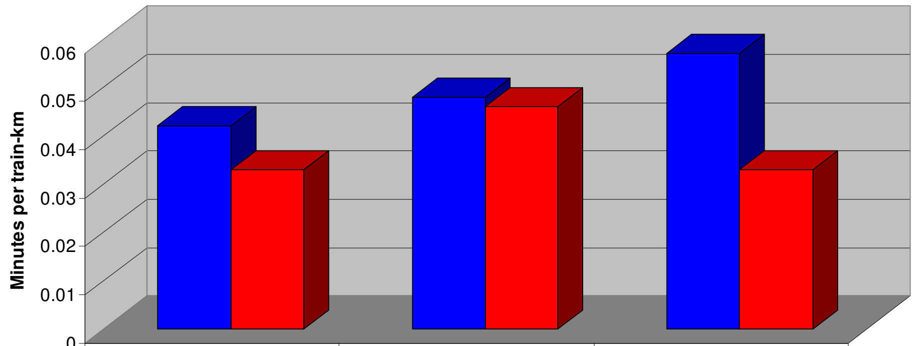
2.2 Timetabling

The existing timetable is most often adjusted and improved over time achieving the best and most optimal situation. In this respect, it is difficult – or even impossible – to plan a brand new optimal timetable for the infrastructural change. Therefore, the timetabling benefits of a new infrastructure are most often underestimated in terms of scheduling optimal timetables. Furthermore, improved railway infrastructure will result in new possibilities to adapt the timetable to future situations. This advantage is not included in a traditional CBA as the future is uncertain. Thus, including this underestimation of benefits and adaptation of future situations should be included in the MCA in terms of the timetabling effect.

2.3 Network Effects

The SWT and timetabling effects are relatively straightforward to determine for the current infrastructure. However, it is extremely time consuming to create new and detailed timetables, thus, often the latter are only worked out for a small analysis area in the preliminary stages of new railway infrastructure proposals. Only looking on a small bisection of the railway system limits the decision to be made in which adjacent lines and connections must be taken into account. This impact is referred to as network effects and should be implemented in any socio-economic appraisal of railway projects covering large-scale networks, e.g. regional, national and global (Hansen 2004).

If a timetable proposal is only worked out for the analysis area it is not possible to calculate the time benefits precisely. Previous studies (Hansen 2004) have shown that the influence of the network effects can be significant for the SWT. This is further illustrated in Figure 2 where the SWT for the eastern part of Denmark and the analysis area is calculated. The results are then made up as an averaged SWT per train-km, since the 3 main alternatives do not include the same number of train departures.



	Current situation	Extended line	New line
East Denmark	0.042	0.048	0.057
Copenhagen-Ringsted	0.033	0.046	0.033

Figure 2. Scheduled waiting time in minutes for the Copenhagen-Ringsted Project.

In both the current and the new line scenarios the SWT drops considerably, if it is only calculated locally as opposed to a larger part of the network. Therefore, an isolated local examination will underestimate the SWT compared with the rest of the railway network. The SWT analysis shown in Figure 2 indicates that the capacity conditions are underestimated when effects are only analyzed locally. This impact is highly strategic and currently not applied in any type of evaluation schemes in Denmark (Hansen 2004).

Evaluating the Copenhagen-Ringsted project is especially difficult due to the previously mentioned three components (SWT, timetabling and network effects). These impacts are not applied in the Danish manual (DMT 2003) hence they are defined as non-monetary impacts. To comprehend with the latter it is proposed to apply a composite approach (Salling et al. 2007) & (Barfod et al. 2008) combining the conventional CBA approach with a MCA approach. Finally, to appraise the underlying uncertainties a quantitative risk analysis (QRA) is performed by the use of Monte Carlo simulation (MCS) (Vose 2000).

3. The Appraisal Framework – COSIMA-DSS

The COSIMA model aims at examining a project where a mix of CBA and non-CBA effects – the so-called strategic MCA impacts – has been found relevant to include in the case study. In overview the structure and content of COSIMA is presented below. CBA impacts refer to effects, where pricing manuals and procedures exist, and MCA impacts refer to remaining effects which are also of importance for the appraisal task but are ”less known” or more difficult to assign a monetary value than the CBA impacts.

The COSIMA-DSS model consists of three different modules brought together in the main module developed in Microsoft Excel (Salling et al. 2007). The model is based upon an argument that the MCA impacts are additive to the CBA impacts if value functions for the MCA criteria are computed and assigned with a weighting procedure describing the importance of each criterion. The system shown in Figure 3 gives a brief overview of the module structure of the COSIMA-DSS model.

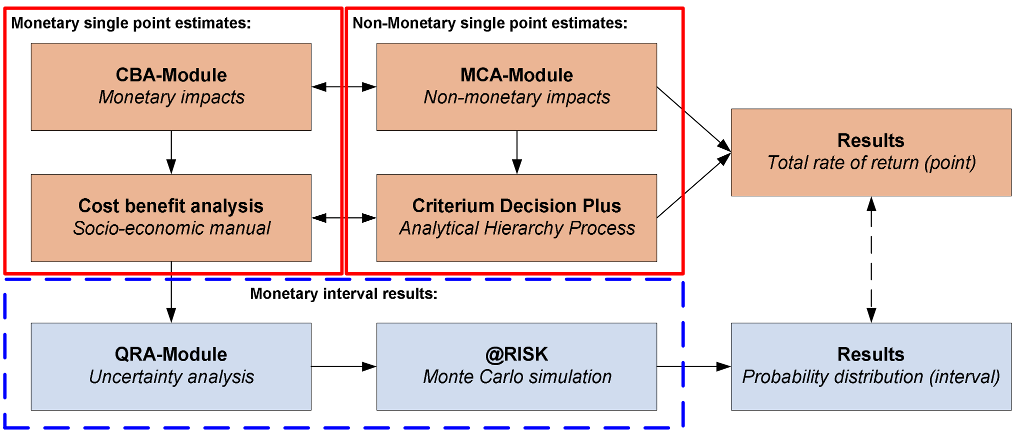


Figure 3. Main structure of the COSIMA-DSS model.

The two boxes in the top consist of a deterministic single point calculation combining CBA with MCA. As shown in Figure 3 the CBA module is of monetary character whilst the MCA module is of non-monetary character, in this case consisting of the previously mentioned SWT, timetabling and network effects. The embedded uncertainties are appraised by the use of quantitative risk analysis (QRA) that facilitates a complex analysis of the importance of uncertainty regarding some key input parameters by the use of Monte Carlo simulation (MCS).

3.1 Cost Benefit Analysis (CBA) Module

CBA is traditionally used in Danish appraisal studies when it comes to road transport infrastructure investments. However, the public transport sector is of higher complexity in the determination of different impact groups and "actors". (Gissel 1999) investigates some of the different aspects in railway operations with respect to a CBA but further work is needed to complement the latter. Traditionally, the main input in a socio-economic analysis is the travel time savings. In evaluation schemes towards a railway line, this is only partly the case as both operators and providers have to benefit from a new infrastructure investment. Furthermore, the strategic impacts such as the Scheduled Waiting Time are equally important to make the overall performance of a railway investment accountable and informative.

In the case of the Copenhagen-Ringsted railway line it is clear that building a new line or extending the existing line, the travel time will decrease meaning that the users will benefit from shorter travel time. Hopefully, the operators will gain from an increase in travellers resulting in higher revenue and the infrastructure providers will benefit from more travellers resulting in higher taxes and fees etc. In Figure 4 the different impact groups together with their corresponding "actors" are illustrated together with the benefit and cost groups.

The criteria and impacts depicted in Figure 4 are determined on basis of the socio-economic manual towards the transport area published in 2003 by the Danish Ministry of Transport (DMT 2003) and a Ph.D. study published in 1999 (Gissel 1999).

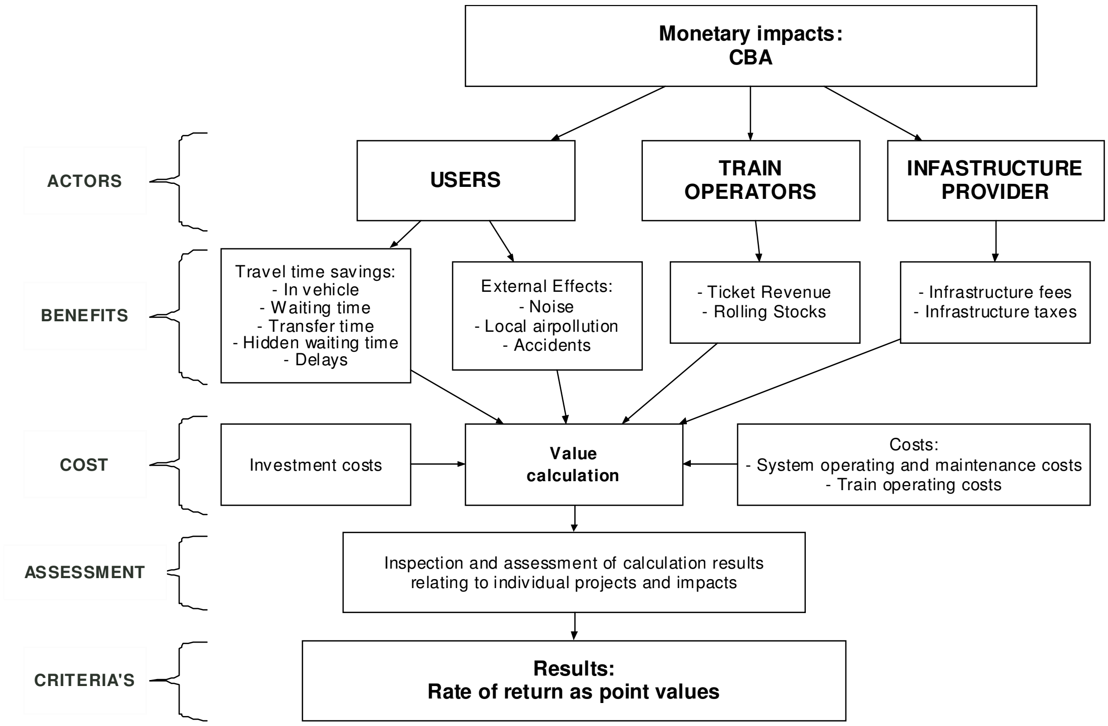


Figure 4. Flowchart on the different monetary impacts applied in the COSIMA-DSS model.

In the appraisal phase of the study, one general objective for the transport sector is to strengthen the competitiveness of the public transport as compared to the road sector. This should be done via different secondary objectives such as high service frequencies, low travel times, high service reliability, high comfort and good transfer possibilities to other transport modes (intermodality). These different groups are to some extent incorporated within the travel time savings. However, the CBA requires that all relevant impacts of the project are assigned a monetary value. In the case where different time impacts need to be taken into account these should as well be considered in the decision process.

3.2 Multi Criteria Analysis (MCA) Module

To make a comprehensive assessment including all elements with influence on the appraisal task the MCA module is introduced. The MCA makes use of the Analytical Hierarchy Process (AHP) technique by (Saaty 2001) for the assessment of the various strategic impacts. The technique introduces a nine point intensity scale that is applied for pair-wise comparisons of the attributes/criteria (Goodwin & Wright 1998) & (Belton & Stewart 2002). Hereby, it is possible calculate an AHP score describing the performance/importance of each attribute/criterion. Different applications of AHP have been widely used for various appraisal tasks –

e.g. transportation projects (Leleur et al. 2007) – and its results are well described and documented through several scientific articles, e.g. in (Vaidya & Kumar 2006). Applying the MCA module makes it possible through steps involving AHP scores and considerations regarding the trade-off between CBA and MCA in the composite module to assign a "fictitious" monetary unit to the MCA impacts even when quantitative ratings are unavailable.

In discussion with decision-makers and based upon earlier sections, it has been decided that three non-monetary effects should be taken into account, namely the SWT, the timetabling and the network effects, cf. Figure 5. The different alternatives are, as previously mentioned assigned a score for each impact using the AHP technique with pair-wise comparisons. Afterwards, the same is repeated for the three MCA criteria. There are several software solutions available for conducting these steps, however, for the current case study it has been chosen to use a software system named Criterium Decision Plus (CDP) (Infoharvest 1999). Figure 5 shows the decision tree with respect to the overall goal and the AHP scores for each of the criteria and the overall score for the alternatives. The two outer right boxes of the figure show the preliminary BCR; in this case the new line alternative is slightly better than the extension alternative.

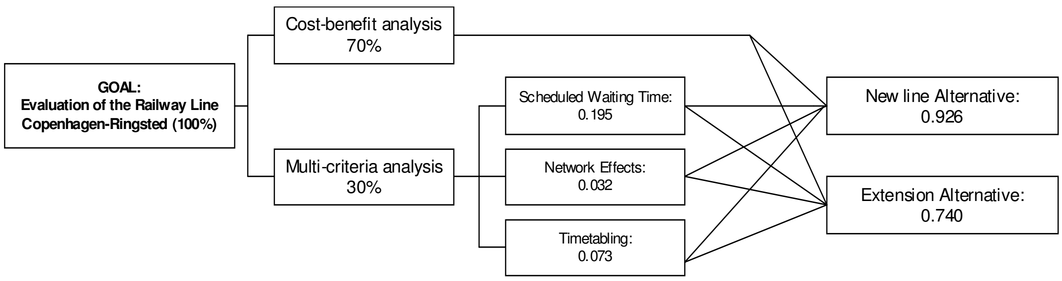


Figure 5. Decision tree for the composite analysis as shown in CDP.

The output from CDP is a set of normalized scores for all the impacts. These are transferred back to the CBA-module, and the MCA impacts are then indirectly assigned a monetary value based on these scores. To conduct this, a trade-off describing how much weight the MCA should account for in the composite model compared to the CBA has to be chosen. The CBA/MCA trade-off is expressed on a relative scale and is therefore not an absolute measure, e.g. a CBA/MCA trade-off on 50/50 only implies that the CBA and the MCA has the same importance on the appraisal. It is important to note that the result of the CBA is at no time altered in the composite appraisal: *MCA information is only added to the already existing CBA information* (Salling et al. 2007). In this preliminary appraisal scheme it is chosen to use a CBA/MCA trade-off on 70/30 for illustration. There are no specific guidelines for how to determine this CBA/MCA trade-off – only some reflections about the issue. It is considered reasonable within large infrastructure project assessments to consider CBA with a higher influence on the appraisal than the MCA, as the funds for construction is limited and “economic reason” has to be present. According to this the MCA should probably not account for more than 30 % of the total appraisal relatively measured, hence this trade-off is chosen (Leleur et al. 2007).

The strength of the pair-wise comparisons and the CBA/MCA trade-off is that these steps necessitate involvement from the decision-makers in the overall decision process. This could for instance be done through a decision conference (Phillips 1984) which guides the decision-makers through the process and makes it easier for them to accept the results. This also means that the decision-makers will work harder for the implementation of the result as they have influenced it.

3.3 The Deterministic Single Point Results

Figure 6 depicts a run in COSIMA-DSS where the bottom red part denotes the CBA part whilst the top blue part denotes the MCA part. Herein, it is shown that the ratio only applying conventional CBA for both alternatives is below 1.0 which means that none of the proposed alternatives are socio-economically feasible. However, by adding the MCA criteria to the evaluation scheme a new set of total rate of returns (TRR) are achieved. The TRR comprises information concerning return rates from both parts in which TRR is not to be confused with BCR.

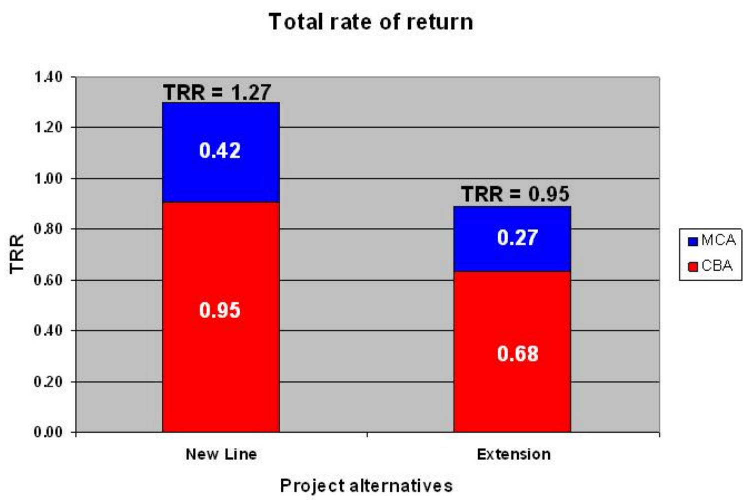


Figure 6. Graphic representation of a COSIMA-DSS deterministic calculation.

The COSIMA-DSS evaluation of the Copenhagen-Ringsted railway line shows that by assessing only two different alternatives the new line situation produces the best overall performance. Further development of the modelling scheme will be implemented as more alternatives are suggested. The conclusion to be drawn from the deterministic runs is therefore that when making a socio-economic analysis it is important not only to look upon the traditional, narrow effects from a CBA but also include wider strategic impacts made up by the SWT, network and timetabling effects modelled by the applied MCA in the COSIMA-DSS model.

The set of single point estimates determined by TRR's depicts in many ways a modal value of the evaluation scheme. Traditionally, these modal values are assessed by sensitivities performed on each individual impact to determine how much the output might vary before the project is either accepted or rejected. These combinations of possible values around the best guess are commonly known as "what if" scenarios. However, the assessment of transport projects increasingly requires a greater understanding of the complexity of alternatives. Hence, the number of "what if" scenario combinations increases rapidly. This paper proposes to apply quantitative risk analysis (QRA) with Monte Carlo simulation which is embedded in the process. The simulation procedure goes one step further than the "what if" procedure as it effectively accounts for every possible value each input variable could take and weighs each scenario by the probability of occurrence. Consequently, instead of receiving single point results, the decision-makers receive interval results in terms of an output probability distribution.

3.4 Quantitative Risk Analysis (QRA) Module

Although a key advantage of using CBA is the transparency, this may also be considered a weakness. The method relies on single result values, where all the considerations and calculations are reduced to just a single aggregated value. The deterministic results from COSIMA-DSS depict the most influential impacts towards the TRR namely the travel time savings and the construction costs. Studies conducted in the UK presents the Optimism Bias principle towards transport infrastructure projects (DfT 2004; Flyvbjerg 2007). This principle assesses the construction costs and travel demand forecasts as the most uncertain and influential parameters of an evaluation scheme. Consequently, construction costs tend to be underestimated and demand forecasts tend to be overestimated, thus, the appraisal outcome most often is overly optimistic (DfT 2004). Clearly, the three MCA impacts are assigned with a great deal of uncertainties, however, literature and studies are extremely sparse in determining suitable probability distributions on the latter impacts.

The construction costs are modelled by the use of an Erlang distribution taking into account the possible underestimation. Studies conducted shows, that the existing skewness from the distribution functions resembles the uncertainty involved in making ex-ante based construction cost estimations (Lichtenberg 2000; Salling & Leleur 2006). The demand forecasts uncertainties is transformed directly into the travel time savings effect accounting for the hours saved as a consequence to the new infrastructure proposal. By implementing a Beta-PERT distribution, the skewness interpreted as overestimation of demand is assessed. The PERT distribution is non-parametric in the sense that decision-makers are to appraise a minimum and maximum limit for the travel time savings (Vose 2000; Salling and Banister 2008).

3.5 The Interval Results

A software program developed by (Palisade 2002) named @RISK is applied as an add-on to COSIMA-DSS. The Monte Carlo simulation has been set-up to run 2000 iterations from a random uniform distributed sample. It has furthermore been assumed that none of the chosen uncertain variables are correlated. The results of this configuration and the previously mentioned parameters and distributions results in the graph illustrated in Figure 7 showing the variation of the B/C-ratio with interval results respectively regarding the New Line from 1.1 to 1.6 and the Extension Line from 0.7 to 1.2. Note that for the descending cumulative curves with the probability on the y-axis and the rate of return on the x-axis more reliable data will lead to steeper curves.

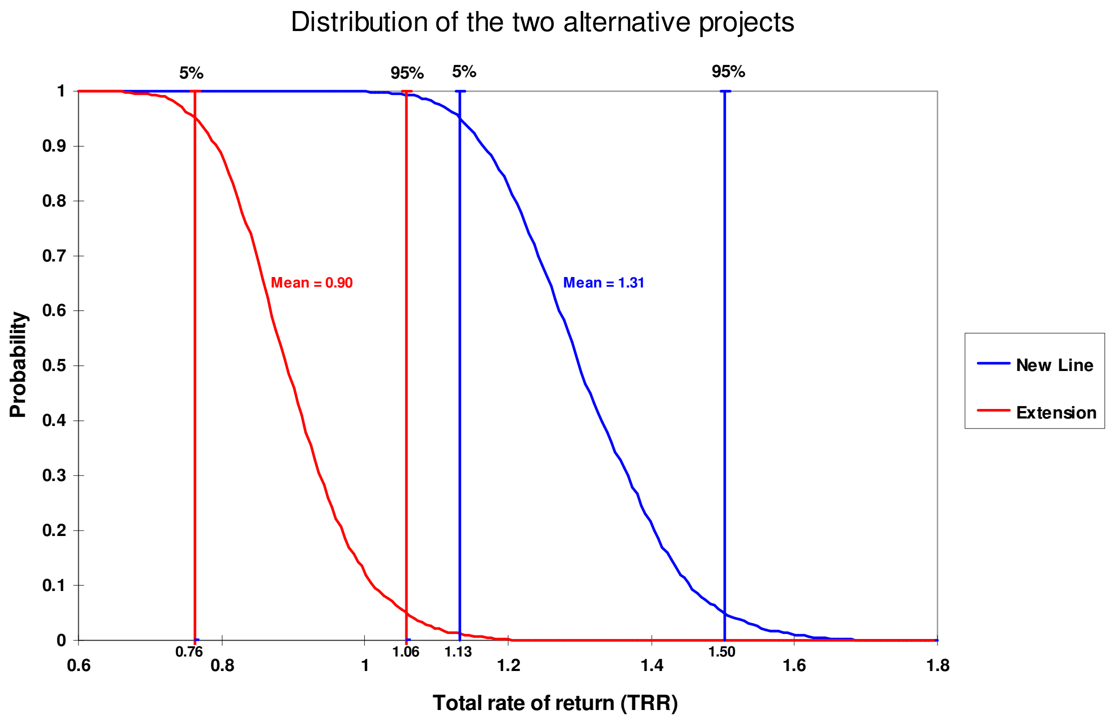


Figure 7. Result of the stochastic calculation respectively showing the New Line and Extension.

It is clear that the New Line alternative performs better than the Extension alternative at all times. With a mean of 1.31 for the New Line compared with 0.90 as concerns the Extension line, there are no doubt to which alternative is to be preferred seen from a societal point of view.

The main advantage of the COSIMA approach compared to the commonly single used CBA and MCA methods is that COSIMA-DSS combines the comprehensiveness of the MCA with the information given in the CBA about socio-economic viability. Secondly, the QRA converts CBA single point estimates into interval results, thus, the embedded can be shown for the decision-makers. The major strength of this way of communicating the results can be transferred into the risk aversion towards decision-makers allowing for budget overruns (Vose 2000).

This new adoption of the accumulated descending curve communicates the results of feasibility risk assessment allowing for decision-maker involvement. The feasibility risk assessment to be adopted in actual case studies is up to the decision-makers to debate but the features described in the latter may help support their considerations. Combining the validity in terms of moving from point to interval results with the communicable descending accumulated curve comprises the informed decision support to be assessed.

Results from the single point estimates (TRR's) and the interval results both showed that the new line alternative was the most optimal choice seen from a societal point of view. To supplement empirical aggregated rate of returns with stochastic interval results is proven very useful in decision making prospects. Future development of the COSIMA-DSS model is to introduce probability functions on the input criteria of the MCA in which the TRR's are used as output distributions instead of the BCR's.

4. Conclusions and Perspective

To deal with the some of the difficulties in calculating monetary and non-monetary impacts, the article has presented a decision support system – COSIMA-DSS – that aims at assisting decision-makers in the appraisal of transport infrastructure project investments. The assessment principles of COSIMA-DSS have been to link the conventional cost-benefit analysis with the multi-criteria analysis. The variety of different features embedded within a CBA and MCA approach makes it particularly useful for addressing complex transportation decision problems. COSIMA-DSS gives the decision-makers a set of tools relevant for planning and assessment of project proposals where a conventional CBA will be too narrow a methodological approach.

Three various multi-criteria impacts have been classified as relevant in evaluating railway infrastructure projects, namely scheduled waiting time, timetabling and network effects. One major outcome is that narrow CBA-based impacts – in many European countries described in a national manual – needs to be supplemented with wider impacts to appraise whether the project is feasible or not feasible from a socio-economic viewpoint. This prospect has been determined through the COSIMA-DSS model, in which a set of decision criteria is depicted.

By implementing a stochastic module taking care of the underlying model uncertainties interval results are derived based on prior point estimates. The examined case study emphasizes the need for stochastic modelling within decision support models, as the given point estimate produces a false sense of feasibility. On this background it is concluded that COSIMA-DSS can be seen as a useful tool in ongoing infrastructure planning.

Further model work and more comprehensive case studies will seek to demonstrate and validate the COSIMA-DSS approach. The principles of COSIMA necessitate when used in practice that a ready-made calculation system is available. Thus the COSIMA software has been developed to conduct decision conference sessions where the panel members, the facilitators and the analysts can work together within a search-learn-debate process.

Most socio-economical evaluations of railway infrastructure projects are focusing on the improvements for the punctuality of trains and thereby only implicitly of the passengers. However, it is complex to convert train delays to passenger delays as there are many uncertainties – e.g. the passengers can choose other trains. By changing the approach and calculate the SWT as passenger delays a more accurate input for the COSIMA-DSS can be provided.

References

Barfod, M.B., Salling, K.B. & Leleur, S. 2007. A Composite Modelling Approach to Decision Support based on Cost-benefit Analysis and Multi-criteria Analysis: The Hornsherred case. *Proceedings of the Mini-EURO XXII 2007*, Prague, Czech Republic

Belton, V. & Stewart, T.J. 2002. *Multi Criteria Decision Analysis: An integrated approach*. Kluwer Academic Publishers

Danish Ministry of Transport 1997, Upgrading the main railway lines. *Technical Report*, "Baneplansudvalget", April 1997 (in Danish)

Danish Ministry of Transport 2003. *Manual concerning socio-economic analysis – applied methodology in the transport sector*, December 2003 (in Danish).

Danish Ministry of Transport 2006. *Key Figure Catalogue – for socio-economic analyses on the transportation area*, December 2004 – revised February 2006 (in Danish)

Department for Transport 2004. Procedures for Dealing with Optimism Bias in Transport Planning. *Guidance Document*, prepared by Bent Flyvbjerg in association with COWI Consult, June 2004

Flyvbjerg, B. 2007. Megaproject Policy and Planning: Problems, Causes, Cures. *Doctoral Dissertation*, faculty of Engineering, Science and Medicine, Aalborg University

Gissel, S. 1999. Decision aid methods in rail infrastructure planning. *Ph.D. thesis* at Department of Planning, Technical University of Denmark

Goodwin, P. & Wright, G. 1998. *Decision Analysis for Management Judgment*. 2nd edition, pp. 387-399, John Wiley & Sons Ltd., Chichester, England

Hansen, S. 2004. Large Transport Infrastructure Investments and their Strategic Impacts with a Special Focus on Enterprises. *PhD. Thesis* at Centre for Traffic and Transport, Technical University of Denmark (in Danish)

Infoharvest, Inc. 1999. Criterium Decision Plus – *User´s guide*. Version 3, Seattle USA

Leleur, S., Petersen, N.B. & Barfod, M.B. 2007. The COSIMA Approach to Transport Decision Making: Combining Cost-benefit and Multi-criteria Analysis for Comprehensive Project Appraisal. Proceedings form the Korean Development Institute *World Bank Conference*, Seoul, May 2007

Leleur, S., Salling, K. B. & Jensen, A. V. 2007. Documentation of the TGB evaluation model in Greenland. *Technical Report*, Decision Modelling Group, Centre for Traffic and Transport at the Technical University of Denmark

Lichtenberg, S. 2000. *Proactive Management of uncertainty using the Successive Principle*. Lyngby: Polyteknisk Press, Denmark

Mackie, P., Jara-Diaz, S.R. & Fowkes, S.R. 2001. The value of travel time savings in evaluation. *Transportation Research Part E: Logistics and Transportation Review* 37 (2-3), pp. 91-106, Elsevier

Ortuzár, J. de D. & Willumsen, L. G. 2002. *Modelling Transport*, 3rd edition, John Wiley & Sons Ltd. England

Palisade Corporation 2002. @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel. Version 4.5, *User Manual*, Newfield USA

Phillips, L.D. 1984. A Theory of Requisite Decision Models. *Acta Psychologica 56*, pp. 29-48, Elsevier Science Publishers

Saaty, T.L. 2001. *Decision Making for Leaders: The Analytical Hierarchy Process for Decisions in a Complex World*. The Analytical Hierarchy Process Series

Salling, K. B., Leleur, S. & Jensen, A.V. 2007. Modelling Decision Support and Uncertainty for Large Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link. *Decision Support Systems 43* (2007), pp. 1539-1547, Elsevier

Salling, K. B. & Banister, D. 2008. Assessment of Large Infrastructure Projects: the CBA-DK model. *Accepted for the International Conference on Infrastructure Systems*, Rotterdam, The Netherlands, November 2008

Vaidya, O. S. & Kumar, S. 2006. Analytical Hierarchy Process: An overview of applications, *European Journal of Operational Research* 169, pp 1-29

Vose, D. 2000. *Risk Analysis - A Quantitative Guide*. 2nd Edition, John Wiley & Sons Ltd., England

Paper 4

Transport Appraisal and Monte Carlo Simulation by use of the CBA-DK Model

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Keywords: Quantitative Risk Analysis, Monte Carlo Simulation, Decision Support Systems, Separation of variability and uncertainty

Abstract

This article presents the Danish CBA-DK software model for assessment of transport infrastructure projects. The assessment model is based on both a deterministic calculation following the cost-benefit analysis (CBA) methodology in a Danish manual from the Ministry of Transport and on a stochastic calculation, where risk analysis is carried out using Monte Carlo simulation. A special emphasis has been put on the separation between inherent randomness in the modelling system and lack of knowledge. These two concepts have been defined in terms of variability (ontological uncertainty) and uncertainty (epistemic uncertainty). After a short introduction to deterministic calculation resulting in some evaluation criteria a more comprehensive evaluation of the stochastic calculation is made. Especially, the risk analysis part of CBA-DK with considerations about which probability distributions to make use of is explained. Furthermore, comprehensive assessments based on the set of distributions are made and implemented by use of a Danish case example. Finally, conclusions and a perspective are presented.

1. Introduction

Project appraisal is the process of comparing virtues and deficiencies of a project. The task is to find the consequences of a project and to handle this knowledge. It is obvious that a project is only feasible if the virtues compensate for the deficiencies and that the best project is the one where the so-called net gain is the greatest. The challenge is to find a method to describe the criteria in a way that makes them comparable and to find a rational and trustworthy method to compare the criteria. The method proposed within this article is to support decision-making regarding new transport infrastructure projects by the use of cost-benefit analysis (CBA) and risk analysis (RA). In Denmark the foundation of such analyses is made up by the manual for socio-economic analysis published by the Danish Ministry of Transport in 2003 (DMT 2003). This manual is an elaborate review of the Danish methodology and an attempt to bring a clarified and identical way of performing socio-economic analyses towards Danish transport infrastructure projects.

Based on the principles in this manual an Excel-based software model CBA-DK has been developed in collaboration between the Danish Road Directorate and the Technical University of Denmark (Appendix 1). CBA-DK contains as one of its features a risk analysis module investigating the underlying model uncertainties within the CBA-DK framework. Hereby, Danish infrastructure projects can be appraised based both on a deterministic calculation which follows the Danish manual's CBA methodology and a more elaborate stochastic calculation where the RA methodology is based on Monte Carlo simulation (MCS) making use of @RISK software (Palisade 2002).

The deterministic calculation consists of 8 worksheets set out as a top-down approach. The calculation is performed in accordance with the Danish manual on socio-economic analysis resulting in point estimates represented by the various evaluation criteria described in the main report.

The stochastic calculation is processed by the use of Monte Carlo simulation (MCS) where various probability distributions are made use of and tested within the modelling scheme. This calculation is organized in two worksheets consisting of respectively an entry and result sheet. The module structure of CBA-DK is shown in Figure 1.

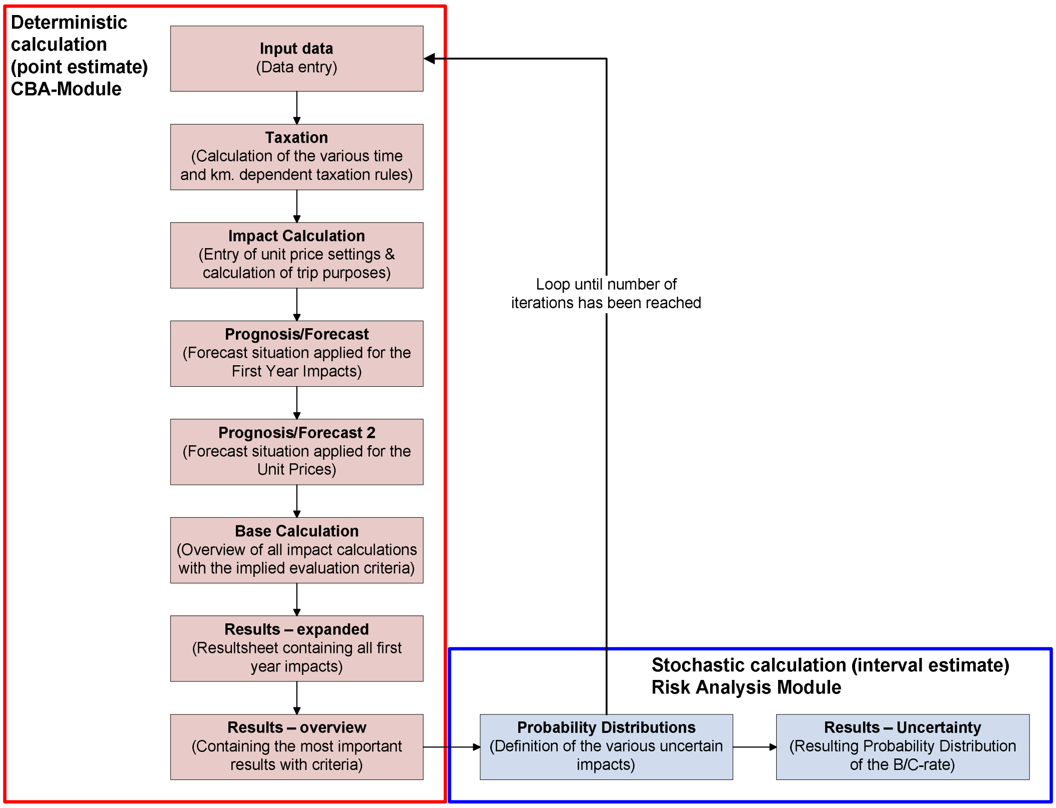

Figure 1. The module structure of CBA-DK shown by the various worksheets.

This article is disposed as follows: After this introduction, the two types of calculations are described respectively in Sections 2 and 3 by the deterministic (CBA approach) and the stochastic calculation (MCS approach). Some case based results are then presented in Section 4. The final Section 5 presents some conclusions and gives a perspective on the further work on the development of the model.

2. Deterministic Calculation

Most governments are confronted with the problem of prioritizing transport infrastructure projects. Generally cost-benefit analysis (CBA) seeks to determine whether or not a certain output shall be produced and, if so, how best to produce it. Furthermore, CBA calls for the examination of all costs related to the production and consumption of an output, whether the costs are borne by the producer, the consumer, or a third party. Similarly, the method requires an examination of all benefits resulting from the production and consumption of the output, regardless of who realizes the benefits. The use of this method basically "answers" the latter by comparing a set of objectives or scenarios for further investigation. By modelling the net changes in a number of effects, e.g. due to the implementation of a new transport infrastructure project, these effects represent benefits or costs towards society. After assessing the value of these changes, obtained benefits can be set against the costs of the project to calculate the various evaluation criteria.

The CBA module of CBA-DK consists of four categories: Passenger cars, lorries, heavy vehicles and external effects. The three vehicle categories are modelled in a traffic model in the before – and after project situation with regard to the following impacts: travel time savings, vehicle operating costs, congestion, and changing traffic. It can be noted that changing traffic is assessed by making use of the so-called rule-of-a-half principle (Leleur 2000, pp. 89-91). The external effects are of different types such as accidents, air-pollution, barrier and perceived risk, severance and noise. Additional entries in the input sheet are the main data concerning the case project: construction costs (investment costs), operating and maintenance costs, evaluation period and key parameters such as discount rate, growth in the economy, etc. Figure 2 shows the input data sheet. The Danish methodology is further described in (Leleur 2000, pp. 129-134) and (DMT 2003).

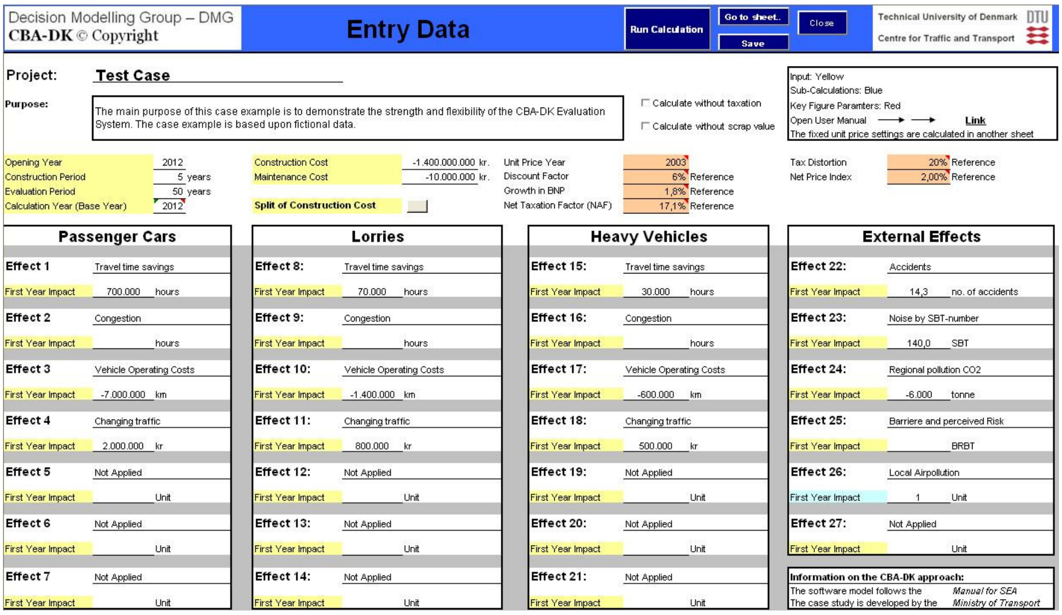

Figure 2. Overview of the Input data sheet from CBA-DK (Appendix 1).

A systematic examination concerning the sensitivity of the results from the model is made based on the impact categories: passenger cars, lorries, heavy vehicles and external effects shown in Figure 2. On this basis it is decided to split the model parameters into three categories, see Table 1, depending on the critical level of influence on the model results with the model parameters categorized as: not critical, critical or very critical.

Not Critical	Critical	Very Critical
Traffic prognosis/forecasts	Time unit prices as concerns passenger cars, lorries and heavy vehicles	Construction costs
Maintenance Costs – growth in real terms	Vehicle operating costs for passenger cars, lorries and heavy vehicles	Travel time savings (saved hours per year)
Regional air pollution CO_2 emission in tones	Number of hours saved as concerns the changing traffic – rule-of-a-half principle	Maintenance costs
Local air pollution e.g. NOx, SO_2 etc emission in tones	Number of accidents saved per year	Accident unit price
Barrier and perceived risk e.g. in more complicated road crossings	Length of evaluation period	
External effects growth in real terms	Social discount rate	

Table 1. Examination of the influence of model parameters on the model outcome (adapted from Leleur 2000, p. 163).

By applying the net changes relating to the user impacts and the external effects as input to a socio-economic analysis, it is possible to obtain values for decision criteria such as the benefit-cost ratio (BCR), net present value (NPV), internal rate of return (IRR) and first year rate of return (FYRR). A run of CBA-DK produces a result sheet like the one shown in Figure 3. The two bars to the right depict the costs and the benefits presented in the same absolute scale. The colouring scheme applied in the results-overview sheet only serves the purpose of illustration. By comparing the decision criteria from different runs on different projects or objectives a prioritisation can be made (e.g. Leleur 2000, pp. 99-105).

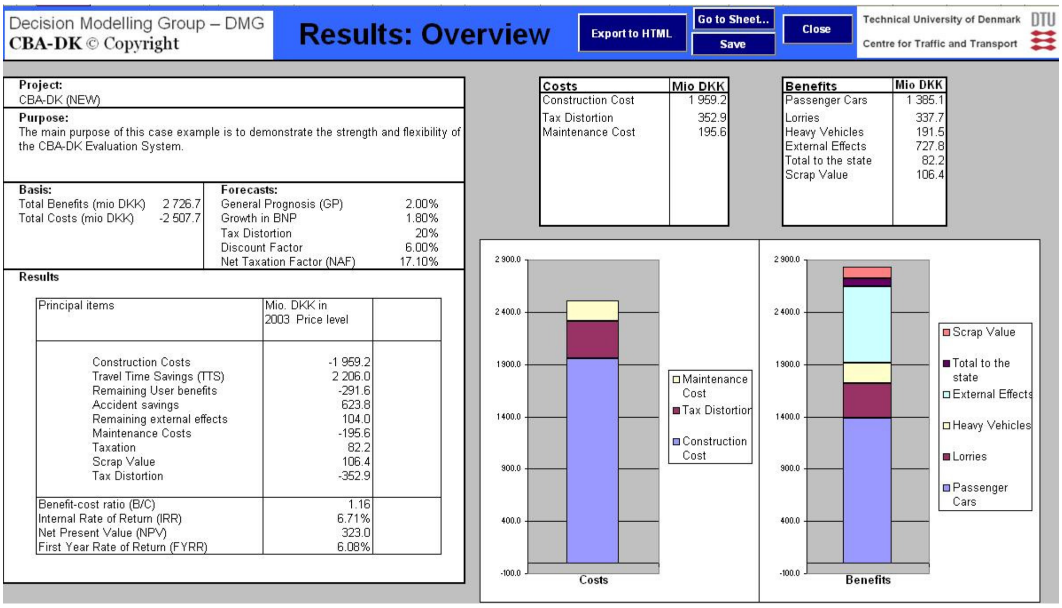

Figure 3. Overview of the results-overview sheet containing the most important case results.

The decision criteria point estimates depict the profitability of the case. However, it is increasingly a requirement within model based decision support to map and communicate the uncertainty underlying such estimates. By applying risk analysis (RA) it is possible to achieve BCR intervals as the output which provide broader basis for setting decision information about the individual projects. The following section serves to describe the application of RA for transport appraisal. The four model parameters determined very critical, see Table 1, are examined in more detail after the treatment of the underpinning principles of stochastic calculation.

3. Stochastic Calculation

To make a CBA, as performed in the modelling framework, it is necessary to obtain information from various traffic and impact models. Typically, traffic modellers are well aware of future uncertainty for which reason model forecasts are best taken as possible developments rather than firm predictions. Unfortunately, while the modeller recognizes these limitations, some decision-makers and other users of the forecasts (in CBA-DK implemented as prognosis sheets) may tend to treat them as perfect predictions. Risk and uncertainties are key features of most business and government problems and need therefore to be assessed before any decisions are implemented. The essence of the traditional risk analysis (RA) approach is to provide the decision-maker with a mean to treat the totality of any future outcome. The advantage of using the RA approach is the possibility of differentiating the feature of risk information in terms of outcome criteria such as the BCR by applying parameter related probability distributions (Hertz & Thomas 1984).

Prior investigations, i.e. Ashley (1980) have divided the sources of forecast error in a traffic model into two basic classes. Firstly, the accuracy of the forecasted exogenous input variables, describing the general data and economic parameters set out in the model. Secondly, the accuracy of each of the individual sub-models, which especially characterizes traffic models, i.e. car ownership, trip generation, distribution and assignment etc. (Ashley 1980). These two accuracy concepts have later been related to more general aspects of the RA terminology namely the division of variability and uncertainty (Vose 2000) & (Walker et al. 2003). Sir David Cox defines the two concepts as:

Variability is a phenomenon in the physical world to be measured, analyzed and where appropriate explained. By contrast, uncertainty is an aspect of knowledge.

The human striving of predicting a future outcome has been a wanted skill for many decades. Uncertainty and variability describe our inability to be able to precisely predict the future meaning: if we were able to determine these two components we would be able to predict the future outcome.

The various types of models combined with varying degrees of effort and resource input for impact modelling result in different degrees of uncertainties. In this respect, it is necessary to use different probability distributions, in accordance with the variability/uncertainty (Vose 2000) that characterize the parameters set focus upon in the risk analysis, such as the construction costs, maintenance costs, travel time savings, etc. The Danish manual determines unit prices which in the CBA-DK model remain fixed (time unit price, vehicle operating costs a.o.). In this context these parameters are assumed as certain (DMT 2006). The modelling system examines selected parameters that are considered the most important for RA such as: construction costs, number of hours saved per year for travelling time, maintenance unit costs and safety unit price i.e. Figure 3 depicts the most influential impacts towards the modelling framework. The first two are matters of variability and the latter two of uncertainty as discussed in Vose (2002) p. 18. Variability and uncertainty reflect the ontological and epistemic issues, see Figure 4 from (Walker et al. 2003, p. 13).

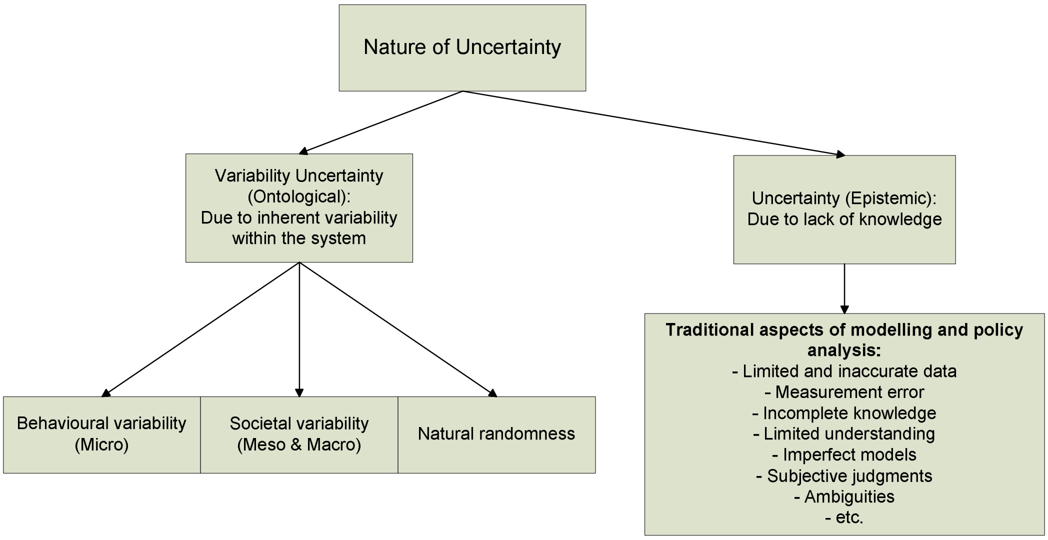

Figure 4. The nature of Uncertainty: Inherent variability or lack of knowledge (adapted from Walker et al. (2003)).

The epistemic uncertainty is defined as imperfection of our knowledge, which may be reduced by more research and empirical efforts. The ontological uncertainty is due to inherent variability, which is especially applicable in human and natural systems and concern social, economic, and technological developments. Assessing the nature of uncertainty may help to understand how specific uncertainties can be addressed. In the case of epistemic uncertainty, additional research may improve the quality of our knowledge and thereby improve the quality of the output. However, in the case of variability uncertainty, additional research may not yield an improvement in the quality of the output (Walker et al. 2003).

Intuitively, a separation of the two terms is not easy to establish in modelling terms as they both share exactly the same probability distributions thereby appearing and behaving identically. A reasonable approach is therefore to create the same Monte Carlo model by just separating the different uncertain and variable parameters by making use of different distributions. This is, however, likely to give misleading information from the simulation, as the model outcome is represented in a resultant single distribution. This resulting distribution represents the "best guess" distribution in terms of a composition between the uncertainty and the variability parameters. In this sense the interpretation of the modelling result is difficult to handle. In a later section concerning the results, Figure 7, both a resulting histogram as well as an accumulated graph is illustrated. This probability scale is a combination of both components resulting in ignorance in determination both of the inherent randomness of the system and what component is due to our ignorance of the same system.

One of the main advantages including both the epistemic and ontological uncertainty, however, is that the total uncertainty of a model system is produced. The information corresponding to the two sources implied in the total uncertainty is of great relevance towards the decision-makers in a given situation. If a result shows that the level of uncertainty in a problem is huge this means that it is possible to collect further information and thereby reduce the level of uncertainty, this enables us to improve our estimate. On the other hand, if the total uncertainty is nearly all due to variability it is proven to be a waste of time to collect further information and the only way to improve and hereby reduce the total uncertainty would be to change the whole modelling system.

Hereafter it is sought to define a set of suitable distributions for examination of feasibility risk relating to examination of transport infrastructure projects. Based on data available on a number of studies the following five distributions have been adopted and tested within the CBA-DK framework:

- Uniform distribution
- Normal distribution
- Triangular distribution
- PERT (Program and Evaluation Review Technique) (Beta) distribution
- Erlang (Gamma) distribution

In the analysis work so far this set has been adequate. In case some other distributions will be needed, e.g. on the basis of new data analysis, these can be added to the set. Below the four CBA-DK model parameters found to be very critical are treated where the first two are expressions of epistemic uncertainty and the last two of ontological uncertainty (variability).

3.1 The Construction Costs

One of the key effects and probably the one with the highest overall impact on an appraisal study is the construction cost, at least in the preliminary phase of any transport infrastructure project. To help the road authorities or government preparing reliable financial road programmes the necessity for accurate estimates of future funding are vital. Future funding is obviously never known as they are dependent on shifting governments etc. The difficulties in this respect is often underestimated and normally explained by, e.g., technical problems or delays. Some authors even think that construction costs in general are underestimated in the planning phase (Wilmot & Cheng 2003) & (Flyvbjerg et al. 2003). Other explanations of underestimation are the dynamical way an infrastructure project is developing over time. In the pre-construction phase you normally look upon traditional impacts of building e.g. a new road such as pavement constructions, rent of material etc. However, most often during the implementation period new and better options become available for instance with respect to noise protection, a new alignment of the road etc. Such costs are not possible to take into account in advance as they relate to ad-hoc decisions during the course of action – especially as concerns large-scale projects. Thus overall construction costs tend to rise over the implementation period.

Concerning the construction of road infrastructure projects in Denmark the forecasting of future construction costs has been achieved as a first estimate by applying a unit rate, e.g. Danish Kroner (DKK) per kilometer highway of a predefined road type (Lahrmann & Leleur 1997). This method is, however, sometimes too unreliable due to site conditions such as typography, in situ soil, land prices, environment etc. (Wilmot & Cheng 2003). The following shows a way to handle the uncertainty by use of probability distributions.

In the following four conditions for estimating construction costs with probability distributions have been proposed (Back et al. 2000):

- Upper and lower limits which the analyst is relatively certain the values do not exceed. Consequently, a **closed-ended** distribution is desirable.
- The distribution must be **continuous**
- The distribution will be **unimodal**; presenting a most likely value
- The distribution must be able to have a greater freedom to be higher than lower with respect to the estimation – **skewness** must be expected.

Examining these conditions three probability distributions become of interest. The most obvious choice is the triangular distribution and the so-called Beta-PERT distribution which both satisfy the latter conditions. However, the authors also point to the Gamma distribution as a likely and suitable distribution even though it is open ended (Back et al. 2000, p. 30 tab. 1).

A Danish researcher has developed a principle based upon successive calculation (Lichtenberg 2000). The strength of applying the so-called Lichtenberg principle is that the decision-maker only has to consider a minimum, most likely and a maximum value. Some key areas where the principle has been applied are strategic planning and budget analysis. It proceeds by use of a so-called triple estimation approach where the mean (μ) and standard deviation (s) is calculated by the two following formulas (Lichtenberg 2000, p. 125), with *ML* indicating the most likely value:

$$\mu = \frac{(\min. + 2.9 \cdot ML + \max.)}{4.9} \tag{1}$$

$$s = \frac{|\max. - \min.|}{4.65} \tag{2}$$

Lichtenberg further documents the applicability of an Erlang distribution for the estimation of the construction costs which corresponds to the article by (Back et al. 2000). The properties of the Erlang distribution requires a shape (k) and a scale (θ) parameter. From the above triple estimation the mean is calculated by (1). The scale parameter (θ) is found by: $\theta = \frac{\mu}{k}$. The applicability of the Erlang distribution is related to the variation of the scale parameter.

Based on experience it is found that a shape parameter in the range of k = 5-15 matches the distribution of the variability uncertainty for construction costs (Lichtenberg 1990, 2000). The family of Erlang functions is a generalization of the exponential function (describing the "function of a single life's duration") known from, e.g. the biological sciences and the reliability area within control theory. In fact the Erlang function with k = 1 is identical to the exponential function (hereby the illustration of lifespan methodology due to the extremely skewed distribution). Using k = 5 the function resembles a Lognormal distribution which also is highly appropriate when the parameter is a product of many factors. Finally, when $k \geq 10$ the distribution is brought closer to the Gaussian distribution (Normal Distribution) which again is relevant when a cost parameter is the sum of more than one element (Lichtenberg 2000). The family of Erlang functions, as shown in Figure 5, seems to represent the vast majority of real life uncertainties quite well.

Tests show that a k value ranging from 4-7 do not lead to a significant change in the result (Rosenstand 2007). Actually, Lichtenberg (2000) states that: .... *according to the choice of the value of k the resulting error is only a few per thousand for the local mean value, while the error for the related local standard deviation (s) is only a few per cent of s. Both of these methodological errors are insignificant compared with the normal practical uncertainties* (Lichtenberg 2000, p. 128). Therefore a k-value of 5 is applied in the CBA-DK runs described later, with the Erlang function as a representation of the variability inherent in the construction costs.

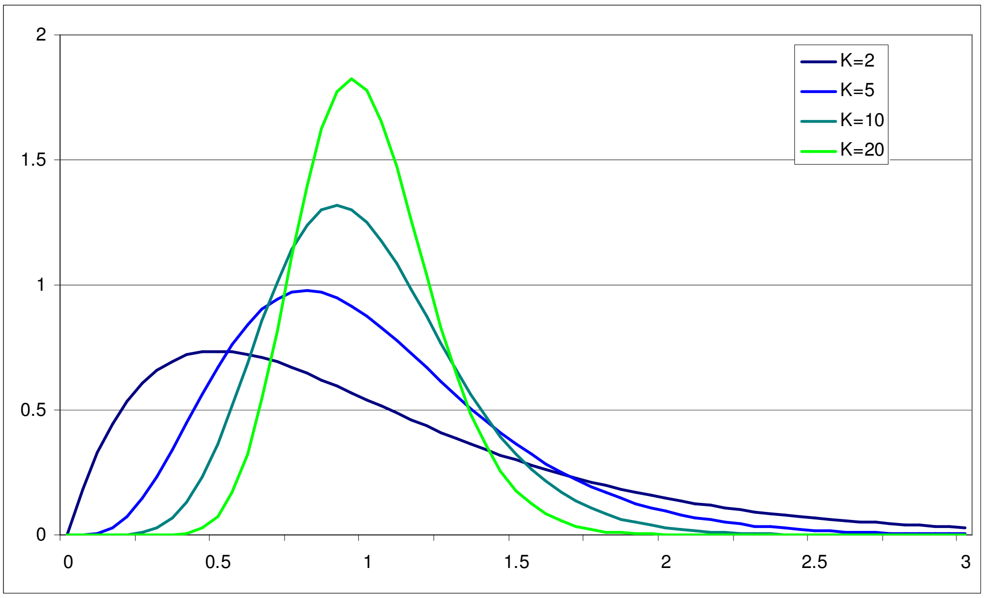

Figure 5. The family of Erlang distributions. *k* is the shape (skewness) parameter and *k*=5 is applied in the CBA-DK runs.

3.2 Travel Time Savings

One of the most obvious advantages of constructing new or improved infrastructure is travel time savings (TTS). This impact is the most important benefit, thus these benefit very often may add up to 70-90% of the overall benefits (Leleur 2000, p 108). Based on traffic model research it is found that TTS measured as hours per year, follow a normal distribution (Knudsen 2006). Standard deviations (*s*) relating to traffic models applied in Denmark have been found to be around 10-20% (Knudsen 2006, p. 105) & (Leleur et al. 2004). By testing a traffic model in several scenarios it turns out that a standard deviation equal to 10% for smaller projects and 20% for large projects are relevant to apply (Knudsen 2006). The literature show that empirical values for general standard deviations are difficult to determine, see (Walker et al. 2003), (Mackie et al. 2003), (Rodier & Johnston 2002) & (de Jong et al. 2005). The latter has on basis of international journals and proceedings been used to set up in Table 2. In this context it is concluded that general recommendations are very sparse.

Publication	Type of uncertainty	Variables for which uncertainty is studied	Order of magnitude of uncertainty
Armoogum (2003)	Model and input uncertainty	Number of trips and passenger kilometers (pkm)	Model uncertainty: For trips in 2030 variance 27% of the mean for pkm: 6%
Beser Hugosson (2004)	Parameter uncertainty	Total and OD demand by mode, link flows, train lines and Value of Time	95% confidence interval mostly between ± 5% and ± 10%
Brundell-Freij (2000)	Model uncertainty (Specification, sampling, estimation)	Value of time (VoT)	Standard error between 3 and 20% of in-vehicle Value of Time
De Jong (1989)	Model uncertainty (Sampling, Parameters)	Number of households with a car; number of car km/year	Estimation standard error between 3 and 6% of mean value
De Jong et al. (1998)	Model uncertainty (specification, parameters)	Value of time (VoT)	Standard Deviation between 6 and 24% of average VoT
Leurent (1996)	Input uncertainty	Travel time; daily number of cars on a link	Standard deviation is about 10% of predicted flow
Lowe et al. (1982)	Input uncertainty (focus) and model uncertainty	Link flows	Probability of 5% that flow will be less than 14,000 vehicles/day
Rodier and Johnston (2002)	Input uncertainty	Trips, vehicle hours delay, emissions	0-70% under or over prediction
Rodier (2003)	Model and input uncertainty	Trips, Vehicle hours and vehicle hours delay	0-39% under or over prediction

Table 2. Summary and integration of the literature on uncertainty of traffic forecasts (e.g. passenger kilometers (pkm), Vehicle kilometers (vkm) and value of travel time (VoT) (Adapted from de Jong et al. 2005, pp. 4-10).

Henceforth, it has been chosen to make use of the Danish results from (Knudsen 2006) and apply standard deviation values between 10 and 20% for small and large projects respectively. On this basis the CBA-DK runs seek to calculate the variability uncertainty relating to travel time savings.

3.3 The Maintenance Cost

The maintenance costs (MC) examined for the CBA-DK model are based on empirical accounting formulas considering different cost factors (Leleur 2000, p. 158). This approach has been adopted by analyzing previous expenditures together with the actual road type, the average daily traffic and the width of the lanes. Furthermore, it has been found suitable to apply a Triangular distribution to represent the uncertainty, which is of the epistemic type.

An alternative distribution of interest is the PERT distribution. PERT (Program Evaluation and Review Technique) stems from 1958 where it was assigned a so-called schedule procedure. PERT is derived from the Beta distribution which mathematically is fairly simple and furthermore covers a huge variety of types of skewness. These types of distribution, require the same three parameters, but interpret them with a smooth curve that places less emphasis to the max. value, see Figure 6.

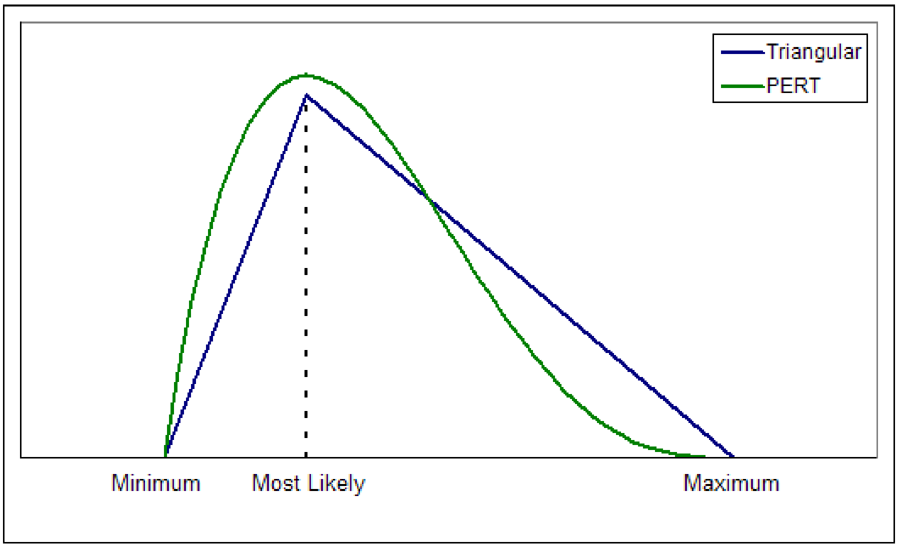

Figure 6. Illustration of the Triangular distribution vs. the PERT distribution (Vose 2006).

The difference between the two distributions can be seen from the determination of mean values: $Mean_{Triang} = \frac{Min + Mode + Max}{3}$ vs. $Mean_{PERT} = \frac{Min + 4 \cdot Mode + Max}{6}$. Thus the mean in the PERT distribution gets a four times higher weighting on the mode. In real-life problems we obtain more confident guesses of the mode than of the extreme values. Therefore the PERT distribution brings a much "smoother" description of the tales of the impacts to be considered.

For the CBA-DK runs it has been decided to apply the triangular distribution with 10% possibility of achieving a lower MC (min.), the most likely value as MC calculated by accounting formula and 50% possibility of achieving a higher (max.). It should be noted that this effect normally is a disbenefit for society due to the fact that new infrastructure projects tend to enlarge the maintenance area.

3.4 Safety Unit Price

The benefits or costs stemming from the change in accidents due to new infrastructure are determined by multiplying the expected number of accidents saved with a societal unit price. By estimating material costs such as car damage, policy costs etc. with personal and social costs, e.g. loss of production, hospital costs, a set of monetary units are derived. The Danish methodology is accounting for 9 various unit costs per traffic accident which contributes to the overall uncertainty of this impact, see Table 3. The uncertainty included is interpreted to be of epistemic type.

	Reported traffic accident	**Reported traffic accident with personal injury**	**Reported personal injury**
Cost related to personal injury	374	876	674
Cost related to material loss	476	1,115	858
Cost related to the society (loss in production)	264	620	477
Total costs	**1.115**	**2.611**	**2.009**

Table 3. Various unit costs for traffic accidents in 1,000 DKK per accident in price level 2003 (DMT 2006).

Dependent on the road types contained in the before – and after networks the net change in accidents with personal injuries can be determined. The unit price for accidents with personal injuries is based on statistical information (Leleur 2000, pp 111-113). Due to the recognized high uncertainty the uniform distribution is adopted. The CBA-DK case runs are estimated with ± 10% to the standard unit price given a rather conservative estimate. The restricted variation is due to a general agreement among Danish teams of decision-makers about the level of the unit price.

4. The Risk Analysis and its Results

Simulation models such as CBA-DK use random variables as input stated as randomized probability distributions for which reason the simulation output data themselves are random (Vose 2000). Care must be taken in drawing conclusions about the model's true characteristics both concerning the random variables and the involved correlations. The four chosen impacts used for the MCS are all assumed uncorrelated, hence no interdependencies are present.

The actual Monte Carlo simulation shown in Figure 7 is based upon the two sets of previously mentioned parameters and distributions, rooted in the epistemic and ontological uncertainties. The purpose of the CBA-DK RA result sheet is to provide the decision-makers with a mean for widen their assessment of the possible BCR (Hertz & Thomas 1984). Specifically, Figure 7 shows three reports based on @RISK: Histogram showing the most frequent BCR, a descending accumulated graph that shows the "certainty" of achieving a certain BCR or better and finally a correlation tornado graph that illustrates the impact (correlation) of each variable or parameter to the overall BCR. Obtaining a probabilistic view of the BCR is especially beneficial when several projects are to be evaluated. The possibility of applying, e.g. different scenarios, evidently by various input parameters creates varying degrees of uncertainty expressed by the steepness of the descending accumulated graph (Leleur et al. 2004).

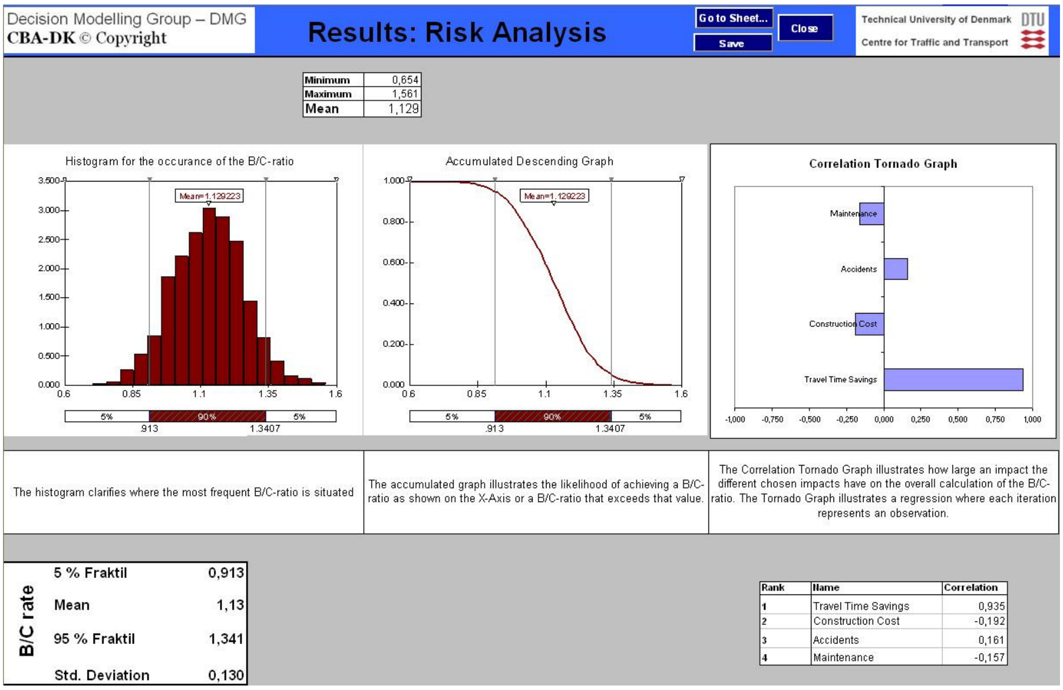

Figure 7. Screen-dump of the resulting sheet from a Monte Carlo Simulation in CBA-DK (Appendix 1).

The feasibility risk to be adopted in the actual case is, of course, up to the decision-makers to debate but the features to deal with uncertainty in the CBA-DK model may help support their considerations. Some of these will be to get acquainted with the various assumptions behind the scenarios, probability distributions, and the way the latter have been assessed/estimated and related to the different scenarios. The resulting graph illustrated in Figure 7 shows the variation of the BCR with interval results spanning from 0.65 to 1.56. Note that for the descending cumulative curves with the probability on the y-axis and the rate of return on the x-axis more reliable data will lead to steeper curves.

Finally, the correlation tornado graph provides information on how the inputs affect the outputs. A correlation coefficient value of 1 indicates a complete positive correlation between two variables, whereas a value of -1 indicates a complete negative correlation and 0 indicates no correlation between the variables. Any other values indicate a partial correlation; the output is affected by changes in the selected input. In the example above the travel time savings (TTS) have a strong positive correlation of 0.925 indicating that this effect has a very high impact on the overall BCR. This is problematic in the sense that the TTS impact is considered as a part of the variability uncertainty. Any reduction of the uncertainty assigned this impact is therefore difficult to assess. For this reason, it is not possible in the study context to further minimize the variability of this impact. New research on traffic models, however, could be seen as desirable based on a view of the variability uncertainty being "too high".

The accumulated graph that illustrates the likelihood of achieving a BCR as shown on the vertical axis or a BCR that exceeds that value has been enlarged. The cross section shown on Figure 8 indicates a BCR of 1.00 with 80% probability of having a BCR greater than or equal to 1.0, which is the theoretical cut-off value for a societal reasonable project. A higher degree of certainty corresponds to a lower BCR and vice versa.

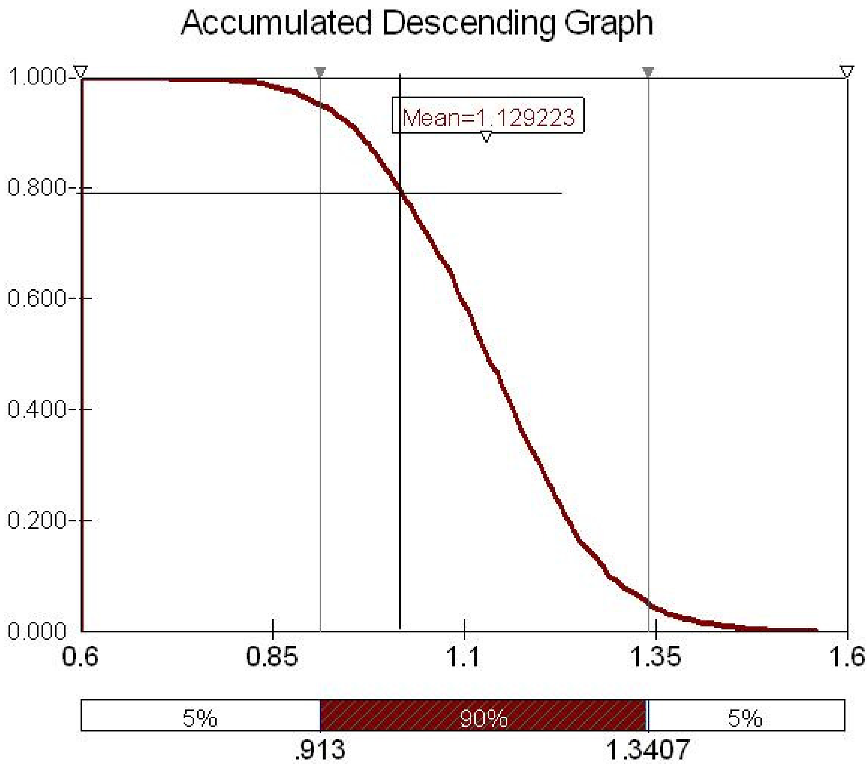

Figure 8. Resulting accumulated graph illustrating the variation of the BCR. The y-axis indicates the probability of the project having a BCR greater than or equal to the x-axis value.

A practical use of the model result could be as follows: There is a 60% probability of having a BCR greater than or equal to 1.1, which is not by decision-makers in this case considered to be sufficient for an implementation decision.

5. Conclusions and Perspective

The CBA-DK model software makes it possible to conduct a comprehensive assessment examination of transport infrastructure projects. In practical studies, it has been seen as an advantage that conventional cost-benefit analysis can be supplemented with a risk analysis examination. However, even though Monte Carlo simulation is a well-established technique in the field of risk analysis, it still lacks a generally approved way of implementation in the transport infrastructure area. A particular interest is the variety of various probability distributions and their strengths and weaknesses. Five types of probability distributions have been set out as a suitable set for risk analysis consisting of uniform, normal, triangular, PERT (Beta) and Erlang (Gamma) distributions.

By implementing a stochastic module taking care of the underlying model uncertainties interval results are derived based on prior point estimates. The examined case study emphasizes the need for stochastic modelling within decision support models, as the given point estimate produces a false sense of feasibility, whereas a practical use of the model points towards rejection. On this background it is concluded that in its current version CBA-DK can be seen as a useful tool in ongoing infrastructure planning.

The decision support model will be further developed in future studies. In this respect it can be mentioned that a new modelling scheme is applied in a large transport study for Greenland with focus upon appraisal of airfields. In this study the CBA-DK model and its risk analysis module are tested further. Additionally, a Master Thesis is currently undertaken at the Technical University of Denmark trying to illuminate the deficiencies in making traffic forecasts.

References

Ashley, D.J. (1980). Uncertainty in the Context of Highway Appraisal. *Transportation*, vol. 9: 249-267.

Back, W.E., Boles, W.W. & Fry, G.T. (2000). Defining Triangular Probability Distributions from Historical Cost Data. *Journal of Construction Engineering and Management*, Vol. 126, No. 1: 29-37

Danish Ministry of Transport (2003). *Manual concerning socio-economic analysis – Applied methodology in the transport sector*. Copenhagen, Denmark (In Danish).

Danish Ministry of Transport (2006). *Key Figure Catalog for use in socio-economic analysis on the transport area*. Revised June 2006, Copenhagen, Denmark (In Danish)

De Jong, G., Pieters, M., Miller, S., Daly, A., Plasmeijer R., Graafland, I., Lierens, A., Baak, J., Walker, W. & Kroes, E. (2005). Uncertainty in traffic forecasts: literature review and new results for the Netherlands. *Working Paper prepared for AVV Transport Research Center* - RAND Europe.

Flyvbjerg, B., Bruzelius, N and Rothengatter, W. (2003). *Megaprojects and Risk – An Anatomy of Ambition*. Cambridge University Press.

Hertz, D.B. and Thomas, H. (1984). *Risk Analysis and its Applications.* England: John Wiley and Sons Ltd.

Knudsen, M.A. (2006). Evaluation of uncertainty in traffic models – a theoretical and practical analysis of the Naestved model, *Master Thesis*, Technical University of Denmark, Lyngby (In Danisk).

Larhmann H & Leleur S. (1997). *Road Traffic: Traffic Enginnering & Traffic Planning*. 2nd issue, Lyngby: Polyteknisk Press, Denmark (In Danish).

Leleur, S. (2000). *Road Infrastructure Planning – A Decision-Oriented Approach*. 2nd Edition, Lyngby: Polyteknisk Press, Denmark.

Leleur, S., Holvad, T., Salling, K. B. & Jensen, A. V. (2004). Development of the CLG-DSS Evaluation Model. *Technical Report*, Centre for Logistics and Freight Transport, Denmark.

Lichtenberg, S. (1990). *Project Planning – in an ever Changeable World*. 3rd Edition, Lyngby: Polyteknisk Press, Denmark (In Danish).

Lichtenberg, S. (2000). *Proactive Management of uncertainty using the Successive Principle*. Lyngby: Polyteknisk Press, Denmark.

Mackie, P. J., Fowkes, A.S., Wardman, M., Whelan, G. & Nellthorp, J. (2003). Value of Travel Time Savings in the UK – Summary Report. *ITS Working Paper*, University of Leeds to the Department of Transport, London, January 2003.

Palisade Corporation (2002). @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel. Version 4.5, *User Manual*, Newfield USA.

Rodier, C.J. & Johnston, R.A. (2002). Uncertain socioeconomic projections used in travel demand and emissions models: could plausible errors result in air quality nonconformity? *Transportation Research Part A* vol. 36 pp 613-631.

Rosenstand, K.G. (2007). A multi-criteria analysis of road infrastructure projects in Greenland. *Master Thesis*, Technical University of Denmark, Lyngby (in Danish)

Sanchez, P. (2006). As simple as possible, but no simpler: A gentle introduction to simulation modelling. *Paper in Proceedings of the 2006 Winter Simulation Conference*, Monterey USA.

Vose, D. (2002). Risk Analysis – A Quantitative Guide. 2nd Edition, England: John Wiley and Sons Ltd.

Vose, D. (2006). Selecting the right distribution in @RISK, Presentation hosted by Palisade, *1st European Palisade User Conference*, London, 22-23 June 2006.

Walker, W.E. et al. (2003). Defining Uncertainty – A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Journal of Integrated Assessment* Vol. 4, No. 1: 5-17.

Wilmot, C.G. & Cheng, G. (2003). Estimating Future Highway Construction Costs. *Journal of Construction Engineering and Management*, Vol. 129, Issue 3, pp 272-279.

Paper 5

Appraisal of Airport Alternatives in Greenland by the use of Risk Analysis and Monte Carlo Simulation

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Keywords: Quantitative Risk Analysis, Monte Carlo Simulation, Cost-Benefit Analysis, Decision Support Systems, Airport Appraisal

Abstract

This paper presents an appraisal study of three different airport proposals in Greenland by the use of an adapted version of the Danish CBA-DK model. The assessment model is based on both a deterministic calculation by the use of conventional cost-benefit analysis and a stochastic calculation, where risk analysis is carried out using Monte Carlo simulation. The feasibility risk adopted in the model is based on assigning probability distributions to the uncertain model parameters. Two probability distributions are presented, the Erlang and normal distribution respectively assigned to the construction cost and the travel time savings. The obtained model results aim to provide an input to informed decision-making based on an account of the level of desired risk as concerns feasibility risks. This level is presented as the probability of obtaining at least a benefit-cost ratio of a specified value. Finally, some conclusions and a perspective are presented.

1. Introduction

This paper introduces a new and improved appraisal model for assessment of large-scale transport infrastructure projects, CBA-TGB (cost-benefit analysis-traffic plan Greenland: Decision Support Model). The paper is a follow-up to a prior paper presented at the Winter Simulation Conference '06: *Assessment of infrastructure projects by the use of Monte Carlo simulation: the CBA-DK model* (Salling & Leleur 2006). That paper was focusing on the investigation of assigning the most suitable probability distributions as a consequence of respectively the epistemic (uncertainty due to lack of knowledge) and ontological (variability uncertainty due to the inherent randomness of the system) uncertainty within the modelling framework (Walker et al. 2003).

The Technical University of Denmark (DTU) is currently involved in a project, appraising the overall transportation network in Greenland incorporating both, air-, sea- and land transport. One of the key issues has been to conduct a socio-economic analysis on three airport alternatives in the capital of Greenland, Nuuk (Leleur et al. 2007).

In 2003 the Danish Ministry of Transport released a manual for socio-economic analyses on transport issues (DMT 2003). Based on these guidelines a transformation from Danish conditions to Greenlandic conditions has been made (Leleur et al. 2007). By the use of CBA-TGB an examination of the various project alternatives are structured to provide decision-makers and stakeholders with support that enables them to make more robust and informed decisions.

CBA-TGB consists of a traditional cost-benefit analysis (CBA) approach where impacts such as travel time savings, ticket revenue, maintenance and operating costs etc. are incorporated. By modelling the net changes of the latter impacts e.g. due to the implementation of a new transport infrastructure project these effects utilize benefits or costs towards society. After assessing the value of these changes, obtained benefits can be set against the cost of the project resulting in various evaluation criteria such as the Net Present Value (NPV), Benefit-Cost Ratio (BCR) etc.

The second stage in the CBA-TGB model contains a risk analysis (RA) module where an elaborate stochastic calculation can be assessed. The RA methodology is based on Monte Carlo simulation (MCS) making use of @RISK software (Palisade 2002). The key advantage of implementing MCS is obviously the transformation from a single point estimate towards an interval result illustrated by probability distributions.

This paper is organized as follows: after this introduction Section 2 brings a small case introduction where the different airport/runway alternatives are presented. Section 3 describes the deterministic calculations by use of a CBA resulting in 3 evaluation criteria. The following Section 4 makes an elaborate risk analysis by the use of Monte Carlo simulation. Particular special emphasis is given to uncertainty within air transportation especially as a consequence of an extreme increase of induced traffic. The final Section 5 presents some conclusions and gives a perspective on the further work on the development of the model.

2. The Greenland Case

Throughout the past decades transport to and from Greenland has been considered somewhat expensive and particularly troublesome. However, new infrastructure plans proposed by the Home Rule authority and municipalities within Greenland are now trying to address these problems.

Naturally, the various stakeholders are all interested in maximizing their attainment, resulting in several project proposals for new infrastructure investments in Greenland. All the municipalities want to gain from tourism, which means that new and improved airports, road connections, harbour connections etc. are of substantial importance.

There are two principal areas of interest; first of all to attract the major international airport to the capital of Greenland, Nuuk and secondly whether or not the existing international airport in Kangerlussuaq should remain open. If the airport is moved to Nuuk, it would be obvious to close the existing airport.

However, closing the airport in Kangerlussuaq would result in closing down the whole city as they rely heavily on the transfer traffic within the city (a so-called hub). A schematic overview of Greenland and the two cities Nuuk and Kangerlussuaq are shown in Figure 1.

In the case of Greenland two extraordinary types of impacts are to be assessed (Lund 2007):

- One is more efficient provision (the so-called production) of air transport, due to increased density in the utilization of the transportation network, because of no use (or less use) of the airport in Kangerlussuaq. This can be explained by the removal of Kangerlussuaq as a hub.
- The other effect, linked to the first, is that resources are released by avoidance of double work receiving the same passengers (and goods) in Kangerlussuaq and especially in Nuuk.

Figure 1. Map of Greenland with the two important cities Nuuk and Kangerlussuaq (Leleur et al. 2007).

The Home Rule authority and the municipality of Nuuk have proposed three different alternative scenarios in Nuuk, all relying on the closure of the existing airport in Kangerlussuaq. The first alternative is a lengthening of the already existing runway in Nuuk to 1799m (the current runway is 1199m). The second alternative is to lengthen the runway further to 2200m and finally the third alternative is the building of a new airport south of Nuuk with a 3000m runway in combination with closure the current airport in Nuuk.

3. The Deterministic Calculation

The major impacts to consider when modelling air transportation are the travel time split into in-flight time, waiting time, changing/connection time, etc. Another major impact is the so-called production costs covering jet fuel, personnel wages etc. ultimately resulting in the airline carriers profit or loss. Following is the ticket revenue concerning the airline carriers and the user benefits towards the passengers considered due to changes in the airfares. The airline carriers endure more passengers ultimately resulting in a higher turnover because of e.g. a higher level of service attracting more travelers. The passengers, on the other hand, experience a lower ticket price as a consequence to both more competition and the implementation of a direct connection to Nuuk. Finally, there is the abandonment of the airport in Kangerlussuaq resulting in a substantial benefit e.g. in direct operating and maintenance cost, freeing of resources etc. (Lund 2007; Leleur et al. 2007).

Four principal impact categories within the CBA-TGB are determined respectively: 1) user benefit within air transport, 2) mail and goods, 3) road transport & penalties and 4) Air Greenland (AG) impacts & abandonment of Kangerlussuaq, see Figure 2. Additional entries are the main data concerning the case project: construction costs (investment costs), operating and maintenance costs, evaluation period and key parameters such as discount rate, growth in the economy, etc. The underlying methodology (TGB) is further described in (Leleur et al. 2007; DMT 2003).

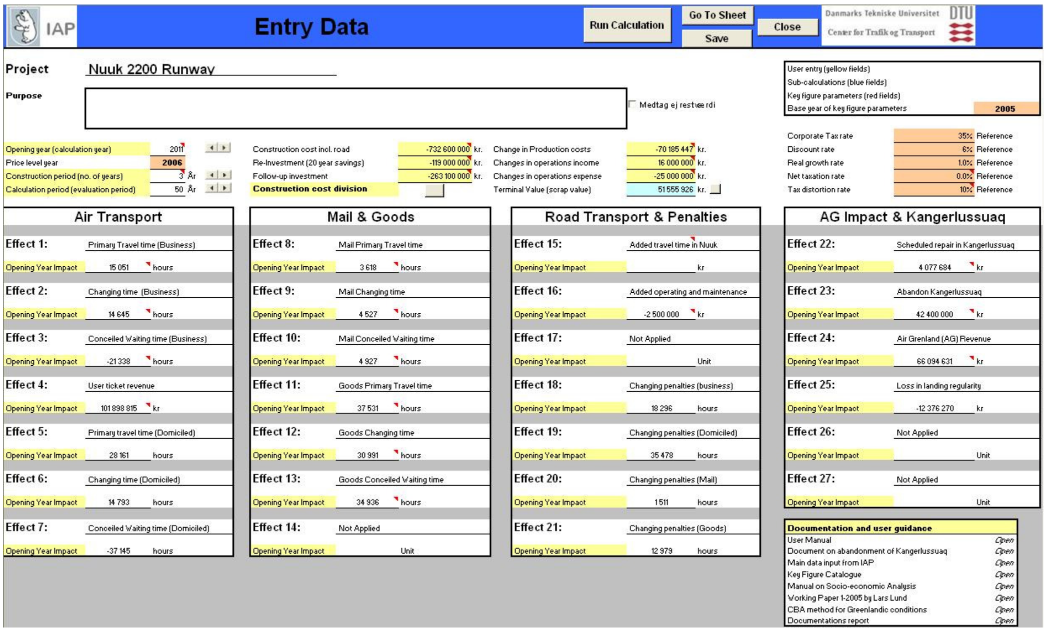

Figure 2: Overview of the Entry data sheet from CBA-TGB, the Nuuk 2200m Runway Alternative.

The implementation of an overall socio-economic analysis in Greenland is only considering trips concerning business and resident travelers leaving all tourism related trips out of the calculation. The argument is that the monetary cost and/or benefits stemming from tourists accrue to their respective countries and not Greenland. Hence, the travel time savings (TTS) and the user benefits are only appraised considering business and resident trips. Consequences on tourism, is of course not entirely excluded from the analysis, they are treated within the so-called multi-criteria analysis (MCA) where effects such as regional planning, mobility etc. are handled (Appendix 1) & (Leleur et al. 2007).

By calculating the net changes within the user impacts, operator impacts (Air Greenland) and Home Rule authority impacts it is possible to obtain decision criteria such as the net present value (NPV), the internal rate of return (IRR) and the benefit-cost ratio (BCR) with benefits and disbenefits measured against the investment costs together with any follow-up cost. A run of the CBA-TGB model provides outputs in a result sheet shown in Figure 3. The two bars on the right depict the costs and the benefits presented according to the same absolute scale. This result is illustrated for the 2200m alternative in Nuuk.

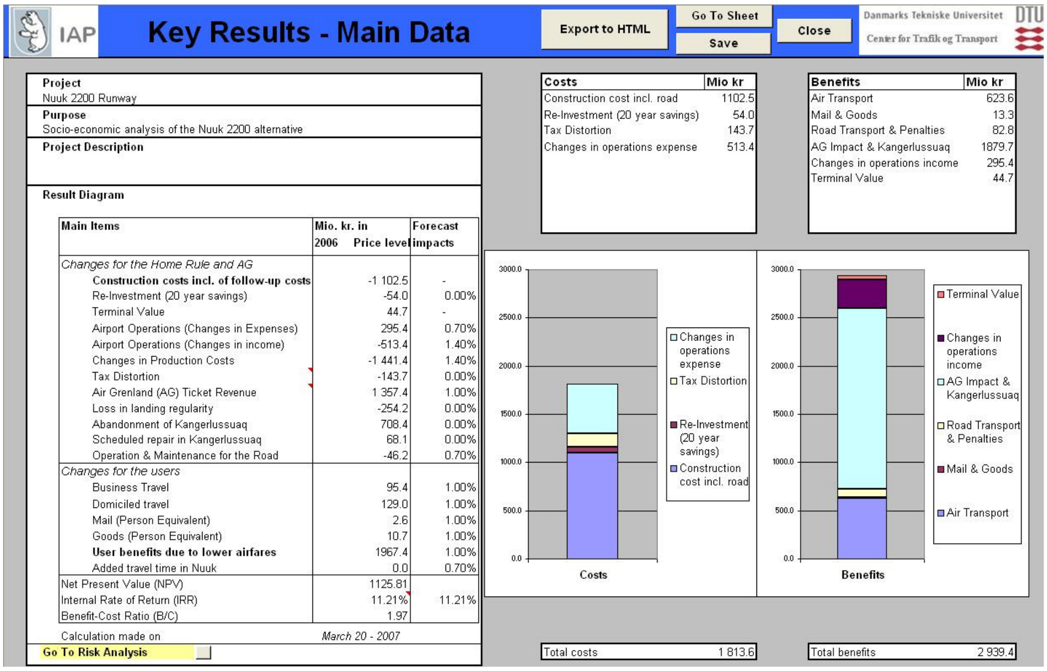

Figure 3: Overview of the Key Results sheet containing the most important results from the implied case.

The resulting evaluation criteria for all three alternatives are listed in Table 1 together with their investment costs in present values. The data set available for these calculations are from a draft version of February 2007. Currently, new traffic flows are considered, however, the prioritisation of alternatives is not altered (Leleur et al. 2007).

	Nuuk 1799	Nuuk 2200	Nuuk 3000
Investment	759.3 Mkr	995.7 Mkr.	2432.1 Mkr
NPV	701.2 Mkr	1125.8 Mkr	-814.2 Mkr
IRR	10.8%	11.2%	4.4%
BCR	1.80	1.97	0.72

Table 1: Overview of results for the three alternatives.

These point estimates indicates that the Nuuk 3000 alternatives performs worst with a negative NPV. The Nuuk 1799m & Nuuk 2200m are performing almost alike keeping in mind that the construction cost for Nuuk 2200m is nearly 50% higher. By comparing the decision criteria from different runs on different projects a prioritisation can be made e.g. (Leleur 2000, pp. 99-105).

Instead of point estimates for the BCR, intervals can be calculated using risk analysis. In this respect uncertain parameters can be assessed by implementing various probability distributions as appropriate. The details are included in the following section.

4. Stochastic Calculation

The methodology used within the stochastic calculation is Monte Carlo simulation (MCS) where appropriate probability distributions are applied on the uncertain parameters and variables. The results derived from Figure 3 give a clear identification of the main input variables that have the strongest effect on the overall framework model. It is clear that one of the key impacts is the investment costs (construction costs). Several studies have tried to determine the magnitude of uncertainty in the determination of the transport infrastructure project costs. In Paper 2 it is suggested to use the Lichtenberg's principle (Lichtenberg 2000) together with an Erlang distribution to illustrate the uncertainty of the construction costs. Furthermore, the travel time savings and especially the user benefits due to lower airfares are of significance. In the CBA-TGB framework this impact is treated with a normal distribution "describing" the uncertainties within the underlying traffic- and passenger flow model. The results are presented graphically using three different assumptions regarding the probability distribution: (1) only applying the Erlang distribution, (2) only applying the normal distribution and (3) a combination of the two.

4.1 Construction Costs

Traditionally, cost overrun in large-scale transport infrastructure projects is a relatively common issue. The difference between actual estimated investment costs and the actual costs can be as high as 100% in overruns (Flyvbjerg et al. 2003; Wilmot & Cheng 2003). Estimating investments costs ex-ante is of course assigned with a great deal of uncertainty. The purpose of assigning probability distributions on the investment costs is to incorporate these uncertainties in the appraisal study resulting in a more valid analysis.

Back et al. (2000) propose four conditions to be satisfied when assigning a probability distribution, a.o. that the distribution must be able to have a greater freedom in its tales as skewness must be expected. Further investigation show that the Gamma distribution converted to an Erlang distribution fulfills this condition (Paper 2). An adjusted method of the succesive principle is embedded within the CBA-TGB framework by the use of a triple estimation producing a mean (μ) on the basis of the ex-ante estimated investment costs (most likely *ML*), the minimum occurrence of investment cost (*min.*) and the maximum occurrence (*max.*) as illustrated by formula (1) (Lichtenberg 2000).

$$\mu = \frac{(\min. + 2.9 \cdot ML + \max.)}{4.9} \quad (1)$$

In the model the Erlang distribution is applied with a maximum cost overrun of 100% and an expected minimum underrun of 25% of the estimated investment cost (Flyvbjerg et al. 2003). Tests show that a skewness factor *k* (shape parameter) ranging between 4 and 7 do not lead to a significant change in the result (Salling & Leleur 2006; Rosenstand 2007). Therefore a *k*-value of 5 is applied in the CBA-TGB runs described later, with the Erlang function as a representation of the variability inherent in the construction costs (Walker et al. 2003), cf. Figure 4.

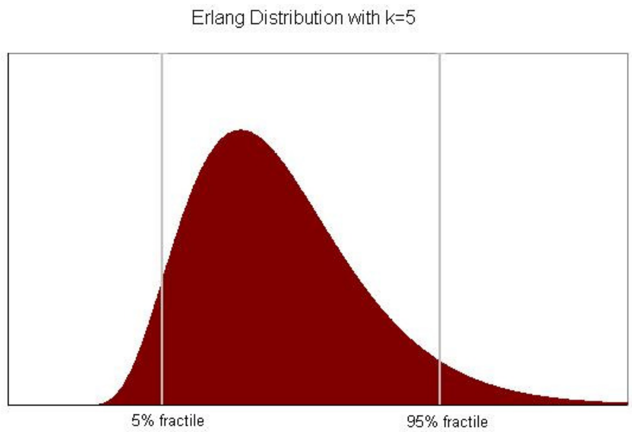

Figure 4: The Erlang distribution implemented for the construction costs with skewness parameter *k*=5.

The family of Erlang functions is a generalization of the exponential function (describing the "function of a single life's duration") known from e.g. the biological sciences and the reliability area within control theory (Lichtenberg 2000). Furthermore, the distribution function seems to represent the vast majority of real life uncertainties quite well thus the implementation within areas of strategic planning and budget analyses.

By implementing the Erlang distribution function a Monte Carlo simulation is set-up in CBA-TGB. It has been chosen to simulate around the BCR with 2000 iterations. The software used is @RISK from Palisade which acts as add-on to Microsoft Excel (Palisade 2002). The results are shown in Figure 5 where the accumulated probability distributions of the BCR for the three different Nuuk alternatives are presented.

The construction costs are seen as influenced by ontological uncertainty stemming from the inherent randomness in the modelling system (variability). This type of uncertainty depicts the flaws within any modelling system ultimately resulting in a type of randomness. Further simulations/calculation does not lead to a significant decrease of uncertainty thus a change in the existing framework would be recommended (Paper 2). In this light the following simulation only applying the construction cost denotes the variability of the CBA-TGB modelling system i.e. illustrated by the steepness of the curves.

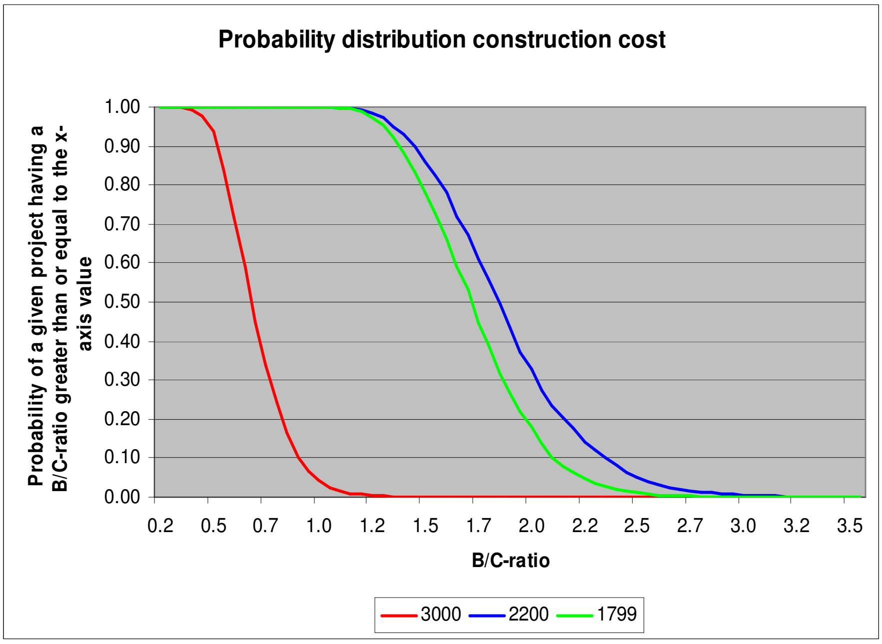

Figure 5: Resulting accumulated probability distributions of the three Nuuk alternatives for the construction costs.

The y-axis in Figure 5 indicates the probability of a given project having a BCR greater than or equal to the B/C-value shown on the x-axis. Nuuk 2200 clearly performs the best whereas the Nuuk 3000 alternative performs the worst with only a 2% probability of achieving a feasible BCR or better. The steepness of the curves indicates the risk aversion of a given alternative: flatter curves especially will require decision-makers to formulate their expectations about the degree of certainty they want to associate with the BCR and vice versa.

4.2 Travel Time Savings

Traditionally, when predicting future traffic flows various techniques can be used if historical performance data in addition to current traffic flows are accessible. This could be accomplished using methods such as exponential smoothing, regression analysis and curve fitting (Vose 2000). The historical data in the Greenlandic case, however, creates a major challenge because of low and fluctuating traffic at present and in the past. The net changes of passengers after the implementation of a new airport due to the induced traffic lead to such changes that historical data will be of less value. Uncertainty within the future passenger flows must therefore be expected determined in the following as epistemic uncertainty due to "lack of knowledge" (Walker et al. 2003).

The travel time savings (TTS) have been subjected to extensive literature investigations due to its huge importance in appraisal of transport projects. Salling & Leleur (2006) investigates this impact as concerns the uncertainty of traffic models where a normal distribution is applied. The latter seeks to assess a road infrastructure project where travel time savings in some cases accounts for 90% of the overall benefits.

The implementation of uncertainty within the TTS in the Greenlandic study is assessed by simulating over the user benefits due to lower ticket fares. The total amount of benefits for the TTS is shown in Figure 3 clearly illustrating that the time benefits stemming from new infrastructure is minor compared to the amount of user benefits from lower air fares. The latter impact actually accounts for nearly 70% of the overall benefits for this alternative. Previously, it has been concluded that a standard deviation of 15% around the most likely value provides a good estimate of the uncertainty of the travel time savings for road projects (Knudsen 2006). On this basis and with due consideration to the increased uncertainty from the large amount of induced traffic the standard deviation in this model is set to 25%. The resulting descending accumulated graphs are shown in Figure 6 where the Nuuk 2200 alternative is still the best performing option. Clearly, further investigations would clarify this impact better based on improved passenger flow models. Therefore, this impact is seen as epistemic.

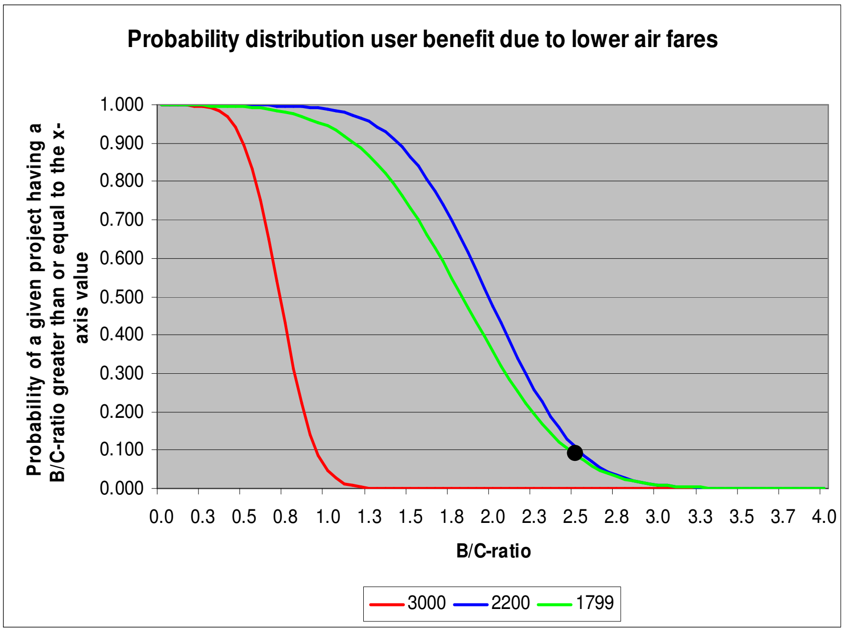

Figure 6: Resulting probability distributions of the three Nuuk alternatives for the user benefits due to lower airfares.

It is remarkable that the Nuuk 1799 and Nuuk 2200 alternatives almost achieve the same performance, e.g. illustrated by the intersection of the two curves with a probability of 2.5%. The Nuuk 1799 alternative is clearly the most uncertain project due to the flatness whereas the Nuuk 3000 alternative is the most robust. However, it only has a 4.6% probability of achieving a BCR above 1.00.

4.3 Overall Results

Previously, the two impacts subjected to Monte Carlo simulation were run independently - both indicating that the Nuuk 2200 scenario overall performs the best. The following tries to combine the two analyses within a single simulation implementing both the Erlang and the normal distribution. The two uncertain impacts are assumed uncorrelated.

In Figure 7 the overall results are illustrated.

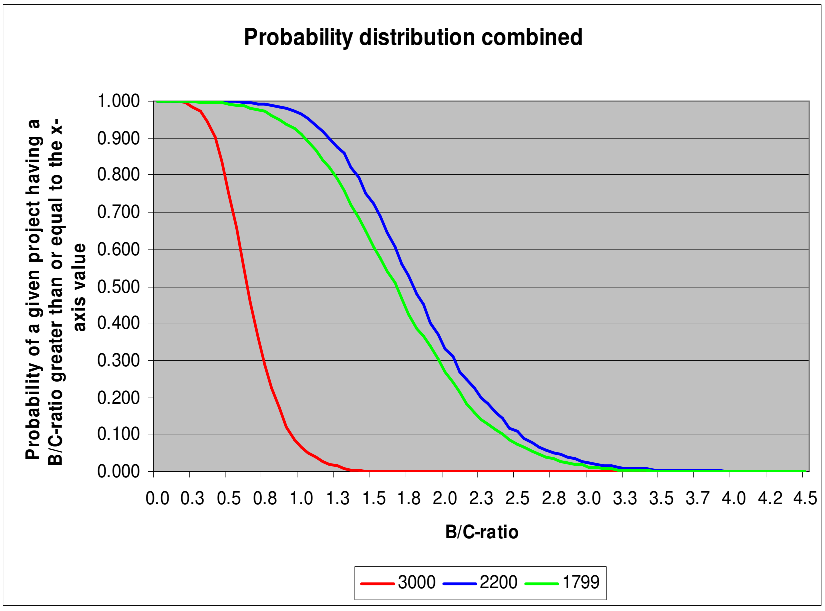

Figure 7: Resulting graphs of the BCR implementing both Erlang- and normal distributions.

The Nuuk 3000 scenario becomes slightly better with a feasibility of 7% of achieving a BCR above 1.00. The two curves representing the Nuuk 1799 and Nuuk 2200 scenarios seem to have the same steepness without crossing each other in this new run. It is shown that the Nuuk 2200 runway alternative overall performs the best for both the deterministic and the stochastic calculations.

Clearly, the two shorter runways are preferable from a societal point of view. However, distinguishing between these two alternatives are up to the decision-makers. Adapting Monte Carlo simulation within transport appraisal studies, however, need to be based on best available knowledge, where e.g. the user benefits as a consequence of lower air fares are clearly dependent on the quality applied of the passenger traffic flow models. The assumed normal distribution with a standard deviation of 25% may be judged on this basis.

5. Conclusions and Perspective

The CBA-TGB model software has demonstrated that a combination of conventional cost-benefit analysis and risk analysis examination can increase the decision-makers possibility of making informed decisions. The underlying modelling technique of Monte Carlo simulation provides comprehensive interval results of the given project alternatives replacing single value results.

Modelling feasibility risk by identifying uncertain parameters or variables has proven to be a tool that can assist decision-makers to address risk aversion in an explicit way, illustrated by descending accumulated probability graphs. Certainly, care must be taken in drawing rigorous conclusions especially when the project alternatives perform closely together. Therefore, the CBA-TGB model should be seen as an useful tool that allows consideration to uncertainty in the appraisal of infrastructure projects but with the precaution that the results are not better than the extent of the validity of the modelling assumptions.

The decision support model will be further developed in future studies. A general concern regarding the Greenlandic case has been the derivation of valid traffic model data. In this respect future implementation and validation need to be carried out before any final decision should be made.

References

Back, W.E., Boles, W.W. & Fry, G.T. (2000). Defining Triangular Probability Distributions from Historical Cost Data. *Journal of Construction Engineering and Management*, Vol. 126, No. 1: 29-37

Danish Ministry of Transport (2003). *Manual concerning socio-economic analysis – Applied methodology in the transport sector*. Copenhagen, Denmark (In Danish)

Flyvbjerg, B., Bruzelius, N. & Rothengatter, W (2003). *Megaprojects and Risk – An anatomy of Ambition*. Cambridge University Press, United Kingdom.

Knudsen, M.A. (2006). Evaluation of uncertainty in traffic models – a theoretical and practical analysis of the Naestved model, *Master Thesis*, Technical University of Denmark, Lyngby (In Danisk).

Leleur, S. (2000). *Road Infrastructure Planning – A Decision-Oriented Approach*. 2nd Edition, Lyngby: Polyteknisk Press, Denmark

Leleur, S., Salling, K.B. & Jensen, A.V. (2007). Documentation of the TGB evaluation model in Greenland. Report, *Decision Modelling Group*, Centre for Traffic and Transport at the Technical University of Denmark

Lichtenberg, S. (2000). *Proactive Management of uncertainty using the Successive Principle*. Lyngby: Polyteknisk Press, Denmark.

Lund, L. (2007). Abandonment of Kangerlussuaq. *Documentation Report*, Technical University of Denmark (in Danish)

Palisade Corporation (2002). @RISK – Risk Analysis and Simulation Add-In for Microsoft Excel. Version 4.5, *User Manual*, Newfield USA

Rosenstand, K. (2007). A socio-economic analysis of the road connection between Sisimiut and Kangerlussuaq with a special emphasis on construction cost and uncertainty. *Master Thesis*, Technical University of Denmark (in Danish)

Vose, D. (2000). *Risk Analysis – A Quantitative Guide*. 2nd Edition, England: John Wiley and Sons Ltd.

Walker, W. E. et al. (2003). Defining Uncertainty – A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Journal of Integrated Assessment* Vol. 4, No. 1: 5-17

Wilmot, C.G. & Cheng, G. (2003). Estimating Future Highway Construction Costs. *Journal of Construction Engineering and Management*, Vol. 129, Issue 3, pp 272-279.

Paper 6

Assessment of Large Transport Projects: the CBA-DK Model

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Abstract

The scope of this paper is to present a newly developed decision support model to assess transport infrastructure projects: CBA-DK. The model makes use of conventional cost-benefit analysis resulting in aggregated single point estimates and quantitative risk analysis using Monte Carlo simulation resulting in interval results. The embedded uncertainties within traditional CBA such as ex-ante based investment costs and travel time savings are of particular concern. The methodological approach has been to apply suitable probability distribution functions on the uncertain parameters, thus resulting in feasibility risk assessment moving from point to interval results. Decision support as illustrated in this paper aims to provide assistance in the development and ultimately the choice of action while accounting for the uncertainties surrounding transport appraisal schemes. The modelling framework is illustrated by the use of a case study appraising airport and runway alternatives in the capital of Greenland – Nuuk. This study has been conducted in coorporation with the Home Rule Authorities of Greenland.

1. Introduction

The main challenge when assessing large-scale transport infrastructure projects is to find a rational and trustworthy method to compare the advantages and disadvantages of the project, and to distinguish between the alternative characteristics of the project. Traditionally, Danish transport investment decisions are based on conventional cost-benefit analysis (CBA) converting the virtual impacts into monetary units such as pollutants, accidents, time savings etc. The virtues (pros) of a project are set against the deficiencies (cons) of the project leading to a set of investment criteria that can be exploited. However, these deterministic single point output criteria are based upon “best guess” estimates of each input variable to the model. Thus, the CBA depicts more of a modal value of the transport assessment scheme than the actual value.

Traditionally, these modal values are assessed by sensitivities performed on each individual impact to determine how much the output might vary before the project is either accepted or rejected. This is typically achieved by selecting various combinations for each input variable, for example running the model with a worst and best case scenario. These combinations of possible values around the best guess are commonly known as “what if” scenarios. However, the assessment of transport projects increasingly requires a greater understanding of the complexity of alternatives. Hence, the number of “what if” scenario combinations increases rapidly. Secondly, recent research exploits the concept of Optimism Bias to reflect the tendency for a project’s costs and demand forecasts to be respectively under-and overestimated. The Optimism Bias is defined as the percentage difference between ex-ante estimates of the appraisal and ex-post values from the final outturn of the projects (MacDonald 2002) and (Flyvbjerg & COWI 2004). These levels of uncertainty can be applied in ex-ante based project appraisal studies, but they are currently disregarded in transport appraisal schemes in Denmark.

This paper applies quantitative risk analysis (QRA) with Monte Carlo simulation which is embedded in the process. This is similar to the sensitivity analysis as it generates a number of possible scenarios. This procedure effectively accounts for the two input uncertainties of "what if" scenarios and Optimism Bias. The simulation procedure goes one step further than this as it effectively accounts for every possible value each input variable could take and weighs each scenario by the probability of occurrence. Consequently, instead of receiving single point results, the decision-makers receive interval results in terms of an output probability distribution. An advantage of this methodology is the possibility of incorporating expert opinions in terms of the probability distributions, which in turn can help depict the occurrence in the decision process of an uncertain variable due to the QRA.

The paper investigates whether the feasibility risk assessment (FRA) adopted for evaluation of transport infrastructure projects can provide useful decision support (namely by moving from single point estimates (CBA) to interval results (QRA)). By combining these two methodologies, a decision support model (DSM) has been developed – the CBA-DK model (Appendix 1) that conceptualizes the idea of feasibility risk assessment.

The remainder of this paper is structured as follows: After this introduction, the decision support model of CBA-DK is presented together with a case description. The model is made up by the three conceptualized modules of CBA, QRA and FRA, and each is described in their respective sub-sections. A fourth sub-section depicts the Optimism Bias approach embedded within the deterministic calculations. Finally, a conclusion and perspective are presented.

2. The CBA-DK Decision Support Model

The Danish Ministry of Transport issued in 2003 guidelines on how to perform socio-economic analysis (SEA) in the transportation sector (DMT 2003). This Manual supports a consistent and transparent approach to performing SEA in the situation where monetary quantifiable impacts can be allocated. This Manual has been the main reason for building a flexible and up-to-date decision support model (DSM) for assessing transport infrastructure projects.

SEA, as interpreted in Denmark, is based upon conventional cost-benefit analysis (CBA), in which deterministic single point evaluation criteria are calculated. Uncertainties can only be handled by sensitivity tests in terms of worst and best case scenarios. The proposed modelling scheme of CBA-DK combines a deterministic calculation (CBA-module) with a stochastic calculation (QRA-module). In this way, the model supports the SEA proposed in the Manual, but combines this with an additional stage covering the embedded uncertainties.

The model is developed on a Microsoft Excel platform forming the basis of the CBA, and the QRA is carried out with an add-in software from Palisade named @RISK implementing a Monte Carlo simulation (MCS) (Appendix 1) and (Palisade 2007).

2.1 The Greenlandic Case Study

Transport to and from Greenland has been considered to be expensive and particularly troublesome. However, new infrastructure plans proposed by the Home Rule authority and municipalities within Greenland are now trying to address these problems. This case study investigates the possibility of moving the major international airport from Kangerlussuaq to the Greenland's capital, Nuuk. Three case alternatives are presented, with two upgrade scenarios for the existing runway, namely from 1199 meter (m) to either 1799m or 2200m, and a closure of the existing airport in Nuuk and construction of a brand new airport in the south with a 3000m runway (Leleur et al. 2007).

The major impacts to consider when modelling air transportation are the travel time savings (TTS) split into in-flight time, waiting time, changing/connection time and hidden waiting time. Another major impact are the production costs covering jet fuel, personnel wages etc., as these factors ultimately determine the airline carriers' profit or loss. In addition, there is the ticket revenue for the airline carriers and the user benefits for the passengers resulting from the changes in airfares. The airline carriers carry more passengers, and this increase results in higher turnover, as the improved service attracts more travellers. The passengers, on the other hand, experience a lower ticket price as a consequence of both more competition and the implementation of a direct connection to Nuuk. Finally, there is the abandonment of the airport in Kangerlussuaq and this change results in a substantial benefit from reductions in direct operating and maintenance costs, and the freeing up of resources.

2.2 The CBA Module

The deterministic module produces a set of decision variables in which decision-makers can have a preliminary view of the project. Three sets of criteria are calculated, namely the net present value (NPV), the internal rate of return (IRR) and the benefit-cost ratio (BCR). The implementation of an overall socio-economic analysis in Greenland only considers trips made by business and resident travellers, with all tourist related trips being omitted. The argument here is that the monetary cost and/or benefits stemming from tourists accrue to their respective countries and not Greenland. Hence, the travel time savings and the user benefits are only appraised for business and resident trips. The consequences from tourism are not entirely excluded from the analysis, as they are treated within the multi-criteria analysis (MCA) where effects such as regional planning and accessibility are addressed (Salling et al. 2007) and (Banister and Berechman 2000).

A run of CBA-DK produces a result sheet like the one shown in Figure 1. The net changes are evaluated over a 50 year period and discounted into present values by a discount ratio of 6% (Mortensen and Andersen 2007). It is important to distinguish between the three groups implied in the evaluation namely, the users, the operators and the authorities. The following analysis focuses mainly on the users where most of the benefits accrue and the authorities[24] where the construction costs are present (Leleur et al. 2007). By comparing the decision criteria from different runs on different alternatives a prioritisation can be made.

Project:
Nuuk 2200 meter alternative

Purpose:
Socio-economic analysis on new runway/ariport alternatives in Greenland

Project Description:
Decommisioning of the Dash-7 airplanes leaves many of the runways obsolete in Greenland. The task is to find an overall transportation plan as concerns air, sea and road transport in Greenland.

Basis:		**Projections/Key figures:**	
Total Benefits:	2.824,6	Generel prognosis (NPI):	1,00%
Total Costs:	-1.118,8	Growth in GDP (excl. Inflation	0,50%
Benefit-Cost Ratio (BCR)	2,52	Tax Distortion Ratio:	10%
Net Present Value (NPV)	1.705,8	Discount ratio:	6%

Results, schematical overview:

Principal items	**Mio. DKK in 2006 Prices**
Construction Costs Incl. Follow-up costs	**-1.064,7**
Reinvestment costs (20 year savings)	-54,0
Operational costs (Home Rule & AG)	-211,3
User Benefits	**2.184,6**
Production Costs	-1.228,6
Mail & Packages	15,3
Air Greenland & Road Traffic	1.348,3
Abandonment of Kangerlussuaq	686,8
Terminal Value (Scrap Price)	43,1
Tax Distortion	-13,7
Benefit-Cost Ratio (BCR)	2,52
Internal Rate of Return (IRR)	13,84%
Net Present Value (NPV)	1.705,8
First Year Rate of Return (FYRR)	19,79%

Calculation performed on the: **01.05 - 2007**

Impacts not inclueded in the analysis:
- 4 strategic impacts are applied within the Multi-Criteria Analysis namely:
- Tourism, Trade/Business, Accessibility and Area Development
- These impacts are all presumed to have a positive influence on the analysis i.e. Benefit

Figure 1. Report from a fixed model run in CBA-DK (Mortensen and Andersen 2007).

[24] The authorities in this context are made up by the Home Rule and the Danish Government.

The report from Figure 1 depicts a calculation of the Nuuk 2200m scenario. Two other similar reports are calculated ultimately resulting in the following set of decision criteria, shown in Table 1.

	Nuuk 1799m	**Nuuk 2200m**	**Nuuk 3000m**
Investment	-831 Mkr	-1,059 Mkr.	-2,532 Mkr
NPV	1,249.8 Mkr	1,705.8 Mkr	-410.0 Mkr
IRR	14.1%	13.84%	5.23%
BCR	2.46	2.52	0.83

Table 1. Overview of the Results from the three alternatives (Leleur et al. 2007; Mortensen and Andersen 2007).

These point estimates indicate that the Nuuk 3000m alternative performs worst with a negative NPV. The Nuuk 1799m and Nuuk 2200m are performing almost identically with relatively high performances. The choice between the latter two alternatives can be debated by decision-makers. One major aspect, however, is that the Nuuk 2200m alternative is almost 30% more expensive than the 1799m alternative.

The following section develops the method to cope with the uncertainty involved in making calculations on ex-ante based construction costs.

2.3 Optimism Bias

Construction costs for large public procurements tend to be underestimated, which means that appraisals seem to be over optimistic with regard to estimates concerning the project's costs, benefits and duration. Mis-interpretation of ex-ante based costs, deliberate or otherwise, results in budget overruns called Optimism Bias (MacDonald 2002). The Department for Transport in UK (DfT) commissioned a study in 2004 that was aimed at providing empirical evidence with respect to Optimism Bias. By the use of Reference Class Forecasting a set of up-lift estimates as concerns a number of different transport type projects were determined (Flyvbjerg & COWI 2004) and (Flyvbjerg 2007).

A substantial amount of reference class projects have been determined, for example in (Flyvbjerg et al. 2003) examining budget overruns and demand forecasts for several road, rail and fixed link projects. The tendency showed that rail projects endured cost underestimations with an average of 45%, road projects with an average of 20% and fixed links with an average of 34% (Flyvbjerg et al. 2003, pp. 15-16). Making use of this type of references data, a table of uplifts was produced to cope with the Optimism Bias within transport infrastructure projects

(Flyvbjerg & COWI 2004). An adapted list of budget uplifts is given in Table 2 within the percentiles of 50% and 80% of risk aversion.

Uplifts	50%	80%
Road	15%	32%
Rail	40%	57%
Fixed Links	23%	55%

Table 2. Budget Expenditure Uplifts in constant prices (Flyvbjerg & COWI 2004).

Table 2 presents the general set of reference classes as concerns road, rail and fixed links. The two percentiles of 50 and 80% illustrate the associated risk aversion towards decision-makers or stakeholders. For instance, if decision-makers allow a 50% threshold of budget overruns for a road project, the estimated cost should be increased by 15%.

Recalculating the three case alternatives from Nuuk incorporating the Optimism Bias the following sets of criteria are determined (Table 3). It has been assumed that the empirical results from rail projects can be transferred directly to airport infrastructure projects.

	Nuuk 1799	Nuuk 2200	Nuuk 3000
Investment, 40%	-1,163.4 Mkr	-1,482.6 Mkr	-3,544.8 Mkr
Investment, 57%	-1,304.7 Mkr	-1,662.6 Mkr	-3,975.2 Mkr
BCR, 40%	1.74	1.79	0.60
BCR, 57%	1.54	1.59	0.53

Table 3. Resulting Criteria when applying Optimism Bias uplifts.

The set of "alternative" investment costs produces decision criteria in which the uncertainty of cost overruns is embedded. Decision-makers are now presented with an interval in which to base their decisions. Performing a set of sensitivity tests as shown in Table 3 copes with some of the uncertainties within transport infrastructure assessment. However, the problem of the number of "what if" scenarios remain, as there are situations where combinations of one or more uncertain impacts produce a large number of scenarios. Probability distributions with Monte Carlo simulation are one means by which the complexity of combinations of uncertain impacts can be included. This method uses combinatorial evaluations to perform uncertainty analysis on TTS and construction costs. The simulation approach differs to the Optimism Bias that is heavily dependent on detailed empirical analyses to determine the values to be used.

2.4 The QRA Module

Even though a key advantage of using CBA is the transparency, this may also be considered a weakness. The method relies on single result values, where all the considerations and calculations are reduced to just a single aggregated value. To the general public this methodology is a "black box" approach (Gissel 1999). Clearly, a practical measurement problem exists in the quantification of "non-market" impacts, such as accidents saved, air pollution and other externalities. Thus, the uncertainty embedded within the different pricing strategies is problematic. To set a price mark on an accident, the time saved in a vehicle or the emission of one tonne of CO_2 is highly uncertain (Leleur 2000).

Consequently, two sets of uncertainties are identified in the assessment of transport infrastructure projects: Firstly, the underlying model uncertainties embedded within any traffic- or impact model and secondly, the uncertainties in any CBA pricing strategy. By adding to the conventional CBA through the adoption of a quantitative risk analysis (QRA) incorporates the probabilities of occurrence where decision-makers and analysts can make use of their know-how expertise – denoted in the following as *level of knowledge*.

The technique used is Monte Carlo simulation (MCS) which involves a random sampling method concerning each different probability distribution selected for the actual model set-up (Rubinstein 1981). The selection of the most appropriate probability distribution has been a major task of the research where several distributions have been tested in terms of their suitability (Salling & Leleur 2006). A common mistake within QRA is to apply unsuitable or inadequate probability distributions. Thus, a separation of actual data fit and "expert opinion" is necessary (Vose 2000, p. 273). This distinction has lead to the conceptual interpretation in terms of *level of knowledge (LoK)* on the uncertain variables. If the uncertain variables are well defined in literature or by data, parametric distributions should be applied e.g. Normal, Gamma or Beta (high level of knowledge). On the other hand, if the variables rely on experts to judge the uncertainty, then non-parametric distributions should be assigned, such as Beta-PERT, triangular or uniform (low level of knowledge) (Vose 2000). The following short section only describes findings and applications of the two impact categories of travel time savings and construction costs.

2.5 Assigning Probability Distributions

The available data on transport infrastructure projects is extremely sparse, and often subject to copyright and other limitations. The following two sub-sections make use of graphical represented data from one reasonably sized database on large scale transport projects (Flyvbjerg et al. 2003). Even here, the level of detail is relatively low due to the fact that interpolations of column outputs have to be performed. The cases used are all taken from rail, road or fixed link projects, which mean that air transport demands and construction costs are not explicitly treated.

2.5.1 User Benefits due to lower airfares

As a consequence to the new airport investment that relocates the central hub to the capital Nuuk, passengers will experience lower airfares and travel time savings. Currently, passengers must transfer in Kangerlussuaq to alternate routes creating higher ticket prices and longer travel times. The TTS has been calculated by traffic and demand models where future demands are forecasted (Nielsen et al. 2007). The decision support model suggested applies probability distributions on the overall TTS effect. Thus, some may argue whether or not the same type of *uncertainty* is carried through from the inaccuracies within traffic demand, as illustrated in Figure 2, and the overall travel time savings effect. Attempts are made in separating so-called epistemic and ontological uncertainties commonly referred to as the “lack of knowledge” and the “inherent randomness of the system” (Vose 2000) and (Walker et al. 2003). However, due to modelling deficiencies this set of separation procedures are not applied in this case study.

Prior investigations of inaccuracies within traffic demand forecasts have shown huge variation between ex-ante and ex-post results. By comparing 27 rail projects the inaccuracy for traffic demand forecasts was on average 39% lower than predicted with a standard deviation of 52% (Flyvbjerg et al. 2003, p. 26). The approximated range of demand forecast bias is set between -92% and 144% (Figure 2). Figure 2 illustrates that overestimation of demand forecast occurs in 85% of the cases. Furthermore, nearly one third of the projects lie within -70% and -30% of overestimations. The data derived from this review of large infrastructure projects (Flyvbjerg et al. 2003) is made by rough calculations. However, it gives an idea on which probability distribution to fit to the data set. It should be noted, that CBA-DK automatically defines the number of bars in the histogram to describe the data fit. Currently, it is not possible to alter the range or number of bars in the modelling scheme.

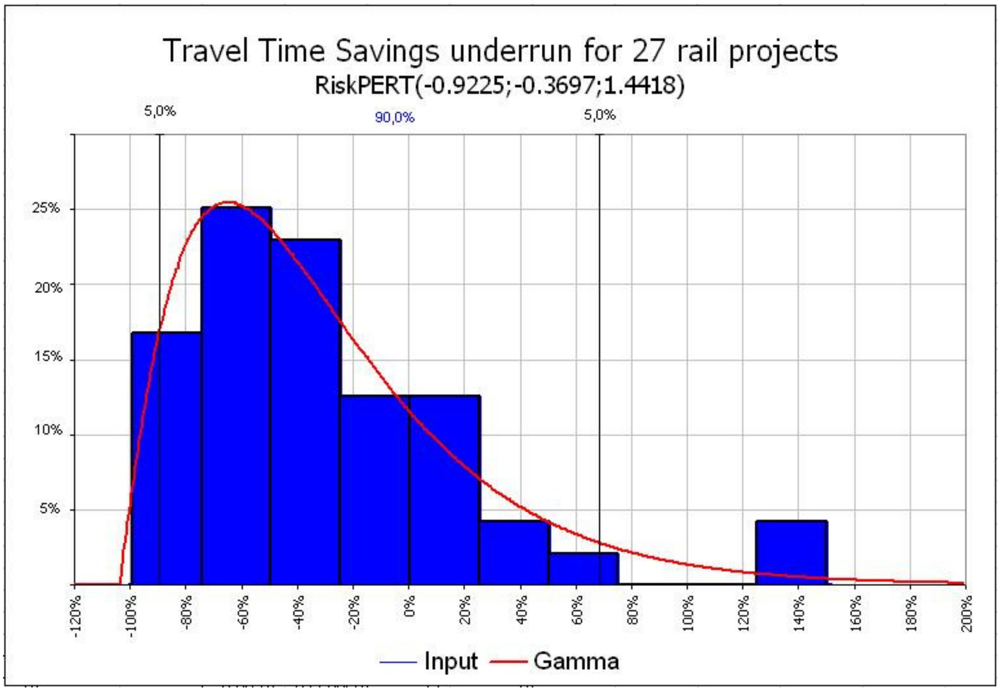

Figure 2. Inaccuracy of traffic forecasts from 27 different rail projects (adapted from Flyvbjerg et al. (2003)).

The CBA-DK is able to produce a fitted distribution as illustrated in Figure 2 (Palisade 2007, pp. 171-192). Even though the distribution is clearly skewed to the right, most emphasis must be placed on the central probability mass. A prior acknowledgement from David Vose[25] and David Kelton[26] proposes the use of a beta-PERT distribution for cases with a relatively high degree of skewness. The PERT[27] distribution is derived from the Beta distribution which mathematically is fairly simple and furthermore covers a huge variety of types of skewness (Lichtenberg 2000). From Figure 2 it is clear that the data fit from a PERT distribution is valid. This type of distribution requires a *min* and *max* limit in addition to the modal value, which acts as input from the CBA. This distribution, given the extra emphasis on the *mode*, makes it ideal for modelling expert opinions for a variable (Vose 2000).

2.5.2 Construction Costs

Transport infrastructure assessment needs to make a thorough investigation of the construction cost of the project, so that reliable estimates can be made of the total investment costs.

[25] Discussion at the 2nd European Palisade User Conference (2007) – London, UK
[26] Discussion at the 40th Winter Simulation Conference (2007) – Washington DC
[27] Program Evaluation and Review Technique

The determination of construction costs ex-ante tends to be underestimated, and these can be explained by technical problems, delays, and increases in labour and material costs. Other common explanations of general underestimations are the dynamic way an infrastructure project is developed over time. In the analysis one tends to normally consider only the traditional impacts of building a new road. However, most often during the project new and better choices are made for instance to address environmental concerns such as noise or the most suitable alignment for the road. These costs cannot be taken into consideration in advance, as they are added at a later stage. The decision-makers also tend to change their preferences during the construction of the project, and this is particularly apparent in large-scale projects.

The mega project database (Flyvbjerg et al. 2003) illustrates that extensive underestimation of future costs sometimes amounts up to 100% or more. Such budget overruns are clearly not to be encourages, and so "better" construction cost estimations are needed in order to make decision support analysis more robust. Figure 3 presents data collected before and after completion of all together 58 rail projects. Almost 88% of the probability mass lies above zero which means that only 12% of the rail projects have been below the preliminary budget.

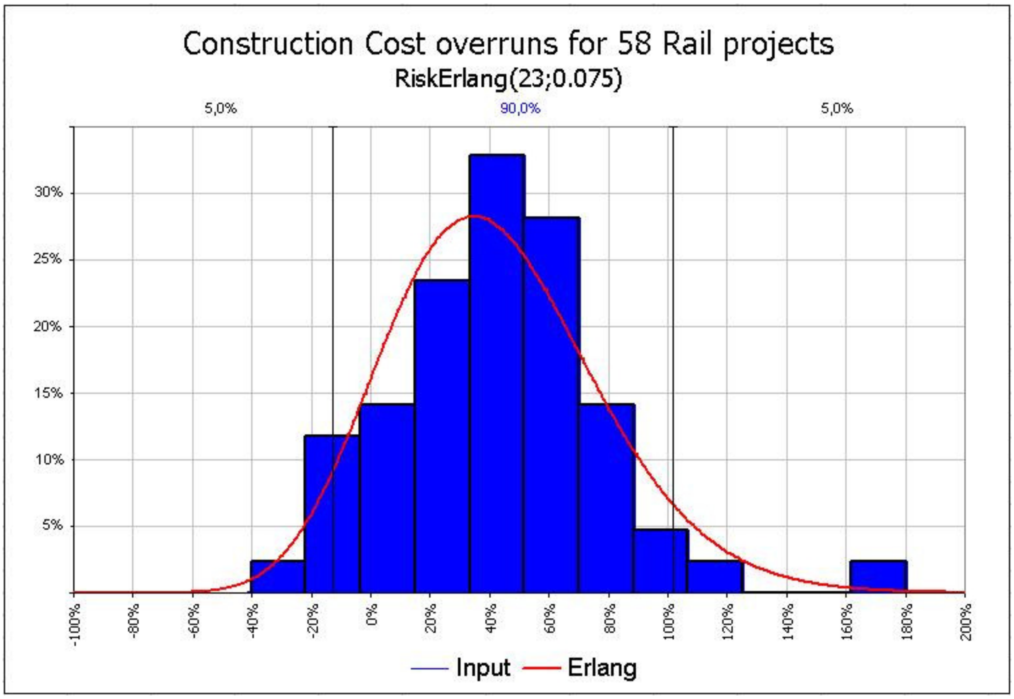

Figure 3. Inaccuracy of construction cost estimates from 58 various rail projects (adapted from Flyvbjerg et al. (2003)).

Another Danish study has elaborated on the various features of risks and uncertainties by applying the "successive principle" in ex-ante base construction costs. This principle is based on group decision-making allowing for extreme measures in finding respectively lower and upper thresholds. The "successive principle" is then transformed into a triple estimation approach in which a mean is derived (Lichtenberg 2000, p. 125). This approach, as in the PERT distribution (Figure 2), places more emphasis on the mode values as compared with traditional worst/best case scenarios, in which a smoother curve is determined.

In order to describe the uncertainty in terms of probabilities the approach depicted above makes use of an Erlang distribution. Combining the data from the mega studies report (Flyvbjerg et al. 2003) with the Erlang distribution found in (Lichtenberg 2000) CBA-DK performs a fit of the data. From Figure 3 the fitted Erlang distribution is determined with a relatively high shape parameter, $k = 23$. A k value of 1 relates to the exponential distribution whereas a k value of 5 relates to a lognormal distribution and higher values, e.g. $k > 20$ resembles the normal distribution. The k parameter is often referred to as the skewness parameter in which lower values corresponds to a higher degree of skewness and vice versa. The second parameter, $\beta = 0.075$, denotes the scale parameter commonly known as θ in which the shift of the distribution is defined (Lichtenberg 2000).

2.6 Feasibility Risk Assessment

The quantitative risk analysis (QRA)-module of CBA-DK enables the analyst to *enhance* the deterministic results from the cost-benefit analysis (CBA)-module into probabilistic outputs. The main scope of this module has been to incorporate risk and uncertainty within transport appraisal in a straightforward and comprehensive manner.

Currently, the BCR is treated as the uncertain output parameter subjected to Monte Carlo simulation. The default settings are 2000 iterations by the use of the Latin Hypercube sampling method (Vose 2000, p. 59). Currently, the travel time savings and construction costs are implemented in the analysis in which a PERT and Erlang distribution is applied. The limits and distribution functions are schematically illustrated in Table 4.

Impact	Distribution	Lower	Upper
Travel time savings	Beta-PERT	-92%	144%
Construction costs	Erlang	-40%	180%

Table 4. Budget Expenditure Uplifts in constant prices (Flyvbjerg et al. 2003).

The resulting outcomes of a fixed run in CBA-DK presents a set of descending accumulated graphs depicting the likelihood of achieving a BCR as shown on the vertical axis or a BCR that exceeds that value. Higher degrees of certainty correspond to a lower BCR and vice versa (Figure 4). The threshold of a BCR = 1.00 denotes the cut-off limit for "feasibility" in which lower values depicts infeasibility in terms of socio-economic viability.

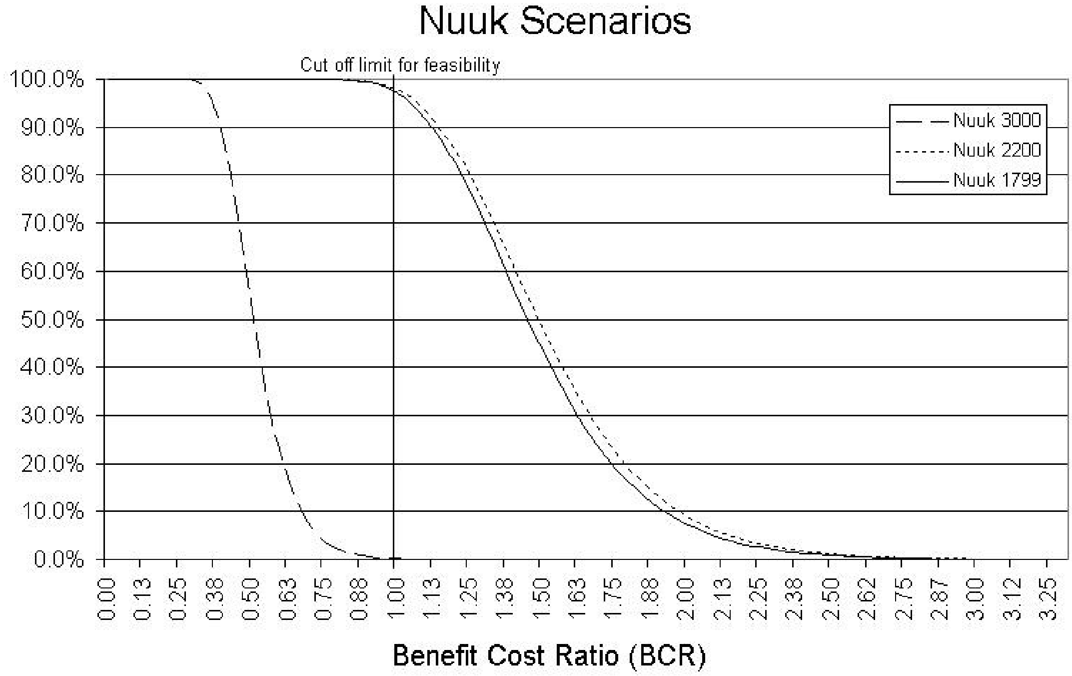

Figure 4. Resulting accumulated descending graph showing the probability on the y-axis and the BCR on the x-axis.

The resulting outcome of a run in CBA-DK results in the three probability curves as illustrated in Figure 4. Empirical results can be seen in Table 5 where the probability mass in the 90% confidence interval between 5 and 95% denotes the new decision support foundation.

Alternatives	Min	Max	Mean	5%	95%	Std. dev.
Nuuk 1799	0.73	3.49	1.49	1.04	2.08	0.33
Nuuk 2200	0.80	3.42	1.53	1.07	2.14	0.33
Nuuk 3000	0.24	1.14	0.49	0.36	0.73	0.11

Table 5. Resulting criteria when applying quantitative risk analysis.

From Figure 4 and Table 5 it is clear that the two shorter Nuuk runway scenarios are preferable. However, choosing between the two is for the decision-makers to debate. It is important to bear in mind that the quantitative risk analysis technique of CBA-DK is a "tool" to assist the decision-makers to arrive at the best possible decision. Ultimately, the risk associated with the analysis is to be interpreted by various decision-makers. The same results given to different individuals may be interpreted differently and lead to different courses of action. Risk averse decision-makers, for instance, would prefer a small spread in possible results with most of the probability associated with desirable results. On the other hand, if you are a "risk taker" then you will accept a greater spread or possible variation in your outcome distribution.

3. Conclusions and Perspective

The CBA-DK model has demonstrated that a combination of conventional cost-benefit analysis and quantitative risk analysis examination can increase the decision-makers opportunities to make informed decisions. The underlying modelling technique of quantitative risk analysis provides comprehensive interval results for the project alternatives, so that single value results can be replaced.

The two ways of handling uncertainties have been shown to complement each other. The Optimism Bias approach provides uplift estimates with a 50% and 80% threshold, and the quantitative risk analysis has been applied with a PERT and an Erlang distribution to create a mean in which the underlying uncertainty has been addressed.

Modelling feasibility risk by identifying uncertain parameters or variables has proved to be a tool that can assist decision-makers to address risk aversion in an explicit way, and this has been illustrated by descending accumulated probability graphs. Care must be taken in drawing rigorous conclusions, especially when the project alternatives perform closely together. Therefore, the CBA-DK model should be seen as a useful tool that allows consideration of uncertainty in the appraisal of infrastructure projects, but with the limitation that the results are not better than the extent of the validity of the modelling assumptions.

The decision support model will be further developed in future studies. Among others the model is being implemented in a new Asset Management scheme for the Rail Net Denmark optimizing the level of repairs in the overall railway network in Denmark.

References

Banister, D. & Berechman, J. (2000). *Transport investment and economic development*, UCL Press, London, UK

Danish Ministry of Transport (2003). *Manual for socio-economic analysis – applied methodology in the transport sector*. Copenhagen, Denmark (in Danish)

Flyvbjerg, B., Bruzelius, N. and Rothengatter, W. (2003), *Megaprojects and Risk – An anatomy of ambition*. Cambridge University Press, Cambridge, UK

Flyvbjerg, B. & COWI (2004). Procedures for Dealing with Optimism Bias in Transport Planning. *Guidance Document prepared for the British Department for Transport*, UK

Flyvbjerg, B. (2007). Megaproject Policy and Planning: Problems, Causes, Cures. *Doctoral Dissertation*, Faculty of Engineering, Science and Medicine, Aalborg University

Gissel, G. (1999). Decision aid methods in rail infrastructure planning. *Ph.D. dissertation*, Department of Planning, Technical University of Denmark, Copenhagen, Denmark

Leleur, S. (2000). *Road Infrastructure Planning – a decision-oriented approach*. 2nd ed., Polyteknisk Press, Lyngby, Denmark

Leleur, S., Salling, K.B. and Jensen, A.V. (2007). Documentation and Validation of the TGB Evaluation model in Greenland. *Technical Report prepared for the Home Rule Authorities in Greenland*, Centre for Traffic and Transport, Technical University of Denmark, Copenhagen (in Danish)

Lichtenberg, S. (2000). *Proactive Management of Uncertainty using the Successive principle – a practical way to manage opportunities and risks*. Polyteknisk Press, Copenhagen, Denmark

MacDonald, M. (2002). Review of Large Public Procurement in the UK. *Technical Report prepared for the HM Treasury*, London, UK

Mortensen, M. & Andersen, M.B. (2007). Joined Evaluation of airport alternatives in Nuuk – with special emphasis on Multi-Criteria Analysis. *Master Thesis*, Centre for Traffic and Transport, Technical University of Denmark (in Danish)

Nielsen, O.A., Rich, J. & Knudsen, M.A. (2007). Documentation and Validation of the TGB Traffic model in Greenland. *Technical Report prepared for the Home Rule Authorities in Greenland*, Centre for Traffic and Transport, Technical University of Denmark, Copenhagen (in Danish)

Palisade Corporation (2007). @RISK, Risk Analysis and Simulation Add-In for Microsoft Excel. Version 5.0, *User Guide*, NY, USA

Rubinstein, R.Y. (1981). *Simulation and the Monte Carlo Method*. John Wiley and Sons, Technion, Israel Institute of Technology

Salling, K.B., Leleur, S. and Jensen, A.V. (2007). Modelling Decision Support and Uncertainty in for Large Transport Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link. *Decision Support Systems*, vol. 43 issue 4, pp. 1539-1547, Elsevier

Salling, K.B. & Leleur, S. (2006). Transport Appraisal and Monte Carlo Simulation by use of the CBA-DK Model. Proceedings of the WSC '06, Monterey, CA-USA, submitted for publication in *Journal of Risk Research*

Vose, D. (2000). *Risk Analysis – a quantitative guide*. 2nd ed., John Wiley and Sons, London, UK

Walker, W.E, Harremoës, P., Rotmans, J., van der Sluijs, J.P., van Asselt, M.B.A., Janssen, P. & Krayer von Krauss, M.P. (2003). Defining Uncertainty – A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Journal of Integrated Assessment*, Vol. 4, Issue 1, pp. 5-17, Swets and Zeitlinger

Appendix 1

CBA-DK – Software for Project Appraisal & Risk Analysis in the Transportation Sector

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Documentation of the CBA-DK Decision Support Model, Version 1.0 (2008)

Keywords: Decision Support Model, Cost-Benefit Analysis, Quantitative Risk Analysis, Monte Carlo Simulation, Microsoft Excel, @RISK

Abstract

This documentation report describes the final version of the decision support model for assessment of transport projects: CBA-DK. The decision support model has been developed as part of my Ph.D. study and contains a cost-benefit analysis approach and quantitative risk analysis approach. The combination of these two methodologies makes up the feasibility risk assessment in which traditional point estimates are transferred into interval results. The following report is depicting a fixed model run within CBA-DK where altogether 9 different worksheets are in-calculated and discussed. The model is based upon a Microsoft Excel platform with add-in software of @RISK to perform the quantitative risk analysis using Monte Carlo simulation. The values contained in this appendix are all fictitious and is only serving the purpose of illustration. Finally, the software model of CBA-DK relies much on hands-on studies. For more information and background material please see the main report of my Ph.D. study entitled: *Assessment of Transport Projects: Risk Analysis and Decision Support*. This documentation report should be seen as a stand alone document, however, some references and assumption are made based upon the work of the current Ph.D. thesis report.

1. Introduction

CBA-DK is an Excel based software model to evaluate transport infrastructure projects comprising the involved uncertainties and risks. The program is developed at the Department of Transport (formerly known as Centre for Traffic and Transport) at the Technical University of Denmark. Consequently, CBA-DK is composed on prior research activities and the presented Ph.D. work. The calculation procedure follows the Manual for socio-economic analysis published in 2003 (DMT 2003).

It is assumed that users of CBA-DK are familiar with this documentation report together with the manual on socio-economic analysis as mentioned above. Furthermore, is the reader acquired to have some basic knowledge on risk analysis and probability theory. Finally, an updated version of the key figure catalogue containing unit prices and various index values is necessary to perform the evaluation of any transport infrastructure projects in Denmark (DMT 2006). In this context, a brand new version of the key figure catalogue has been developed by DTU-Transport in collaboration with COWI consult published in February

2008. This catalogue is an open source Excel sheet among others available through the so-called model centre at DTU-Transport (DTU-Transport 2008)[28].

2. Content of CBA-DK

CBA-DK is comprised by altogether 9 worksheets developed in Microsoft Excel. The 9 worksheets are all linked together in a top-down procedure, as shown in Figure 1. The third box depicting Prognosis/Forecasts is divided into two worksheets one for the first year impacts and one for the unit prices hence Figure 1 is only showing 8 boxes.

The *Input data* sheet forms the basis for any calculation in the CBA-DK model. Herein lies implicit entries such as construction costs, first year impacts, discount ratio etc. Secondly, the *impact and taxation* sheet performs sub-calculations of the tax distortion and net taxation rate as concerns publicly financed projects (DMT 2003, pp. 34-35). This sheet also contains sub-impact calculations such as the scrap or terminal value of the project and air pollution. The two sheets as concerns prognosis/forecasts are respectively applied the first year impacts and first year unit prices (*Prognosis/Forecasts* sheets). It is possible to make entries in all years of the evaluation period if wanted (note that: CBA-DK is only valid for a 60 year evaluation period).

These four preliminary sheets are all entry sheet where the user has to do something. The fifth sheet contains the base calculation where all impacts are discounted and the evaluation criteria compiled. A special feature of the model is that any first year impact can be further investigated at this specific point in time – for instance if an error message occur.

Finally, two result sheets are calculated. Firstly, the overall result sheet (*Results - expanded*) is produced containing all impacts discounted into the base year of calculation. Secondly, the *results overview* is produced containing the most "important" results, together with some illustrations. These two sheets conclude the deterministic calculations resulting in CBA based point estimates.

[28] The following, however, makes use of the key figure catalogue revised 2006 with base year of 2003

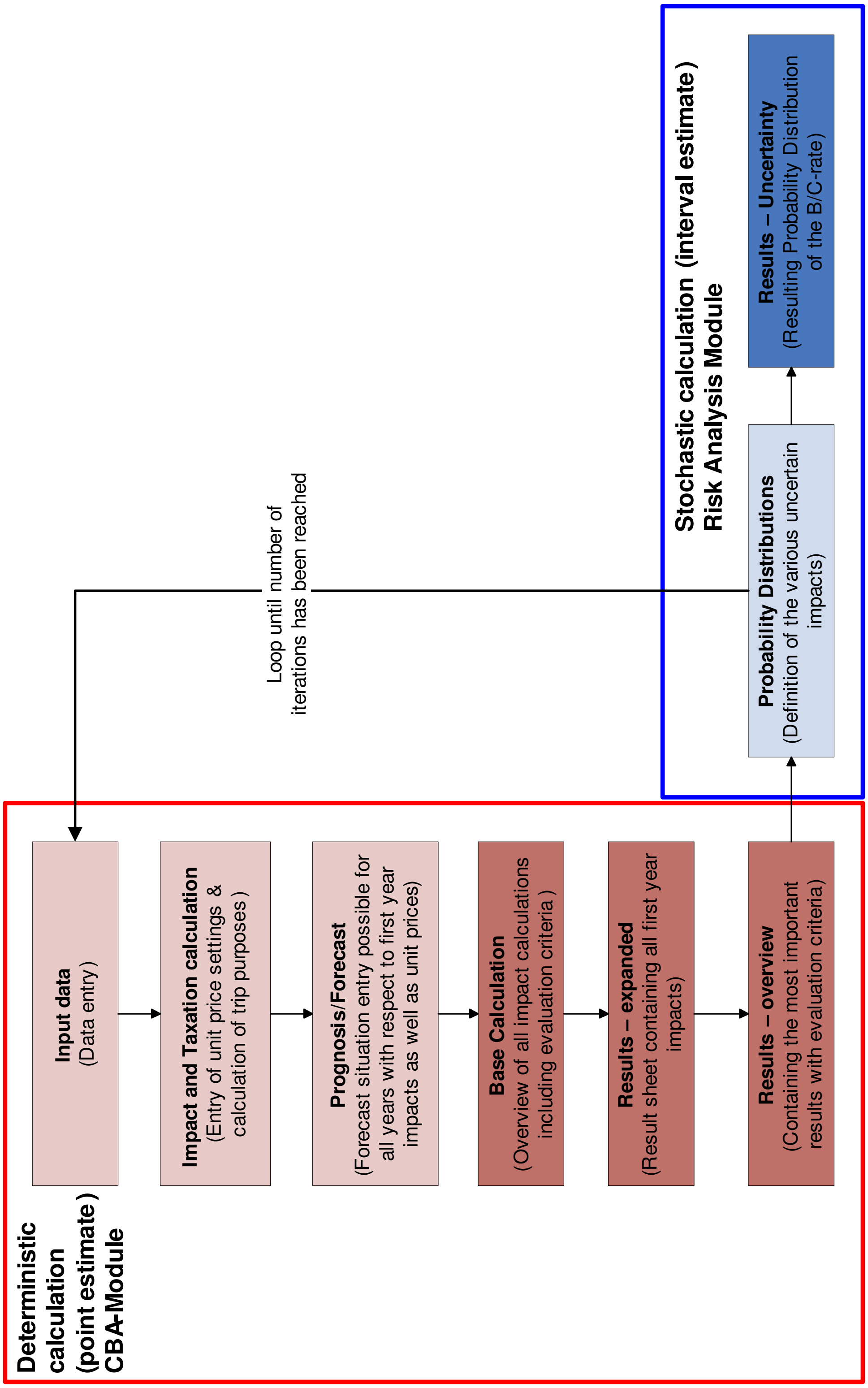


Figure 1. Illustration of the 9 various worksheets embedded within the CBA-DK software model respectively divided in a CBA and RA module.

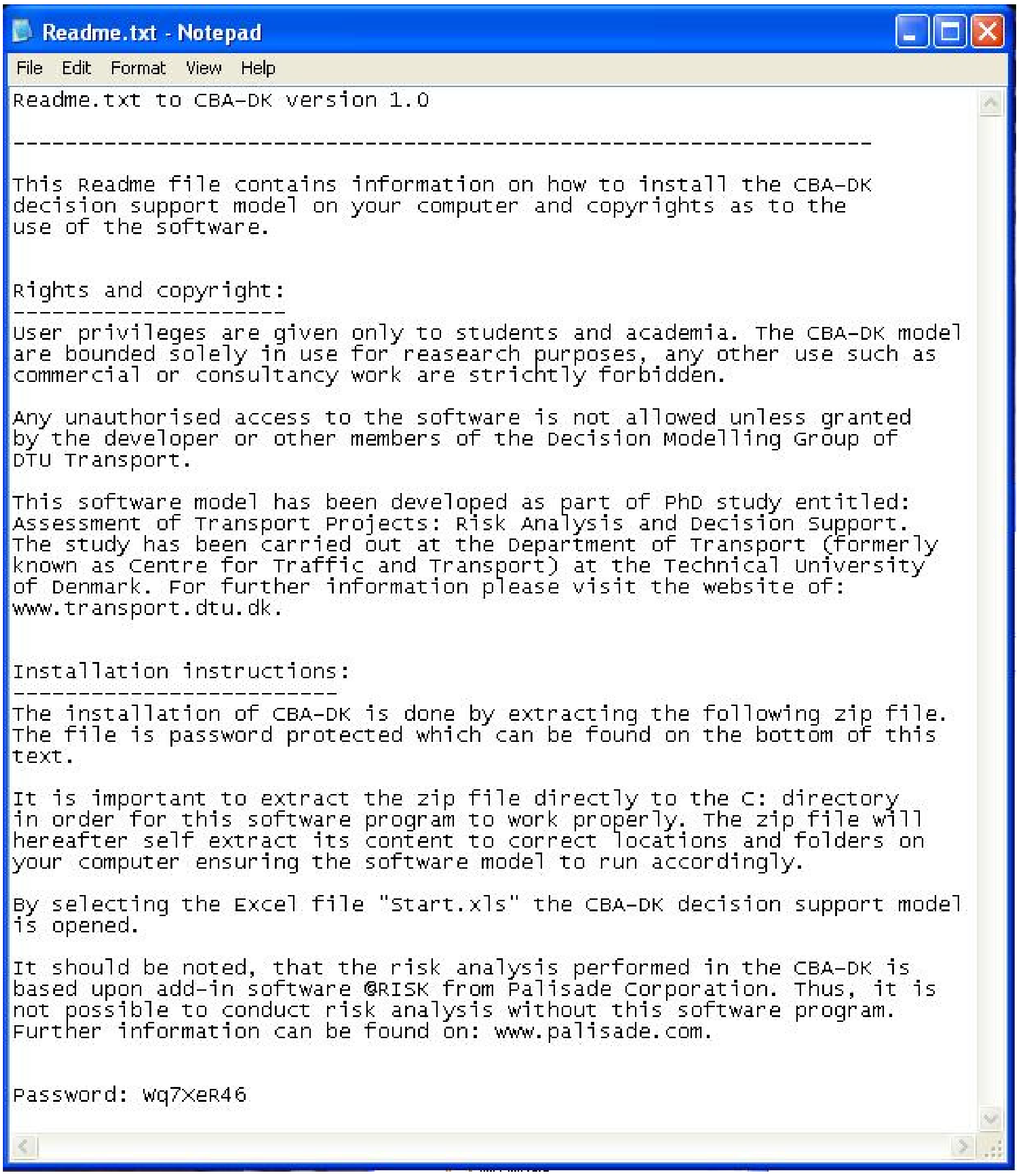
The stochastic calculation is founded on quantitative risk analysis (QRA) making use of Monte Carlo simulation (MCS). The *Probability Distribution* sheet contains entries to all first year impacts together with the construction costs and operating/maintenance costs of the project. For each impact it is now possible to enter a fixed probability distribution function (PDF) describing the underlying model uncertainties of this specific impact. Currently, the CBA-DK makes use of 5 various continuous PDFs – however, as explained later, the add-in software of @RISK allows several other distribution types. The final results of the stochastic calculation are then produced by an iterative process and presented in the *Results-Uncertainty* sheet.

The following sections of this documentation report are to be seen as a tutorial on how to use (conduct a calculation in) CBA-DK. The different worksheets will be explained in consecutive order as a calculation was to take place. In the end of this report, a small note is given on how to use Lichtenberg's principle and some general remarks on Monte Carlo simulation. The current Ph.D. thesis has, however, dealt with many of these subjects, why a more theoretical investigation can be found in the chapters 1 and 2.

2.1 Installation and set-up

The CBA-DK model comes in a zip file containing the model and a readme file. The readme file is essential to read before installing the software model on your computer, see Figure 2.

The CBA-DK model has to be extracted to the correct folder in order to work properly. Since the model makes use of @RISK the software must be obtained in order to perform any quantitative risk analysis (QRA). The CBA part, however, functions even though the software is not purchased.



Readme.txt - Notepad

File Edit Format View Help

Readme.txt to CBA-DK version 1.0

This Readme file contains information on how to install the CBA-DK decision support model on your computer and copyrights as to the use of the software.

Rights and copyright:

User privileges are given only to students and academia. The CBA-DK model are bounded solely in use for reasearch purposes, any other use such as commercial or consultancy work are strichtly forbidden.

Any unauthorised access to the software is not allowed unless granted by the developer or other members of the Decision Modelling Group of DTU Transport.

This software model has been developed as part of PhD study entitled: Assessment of Transport Projects: Risk Analysis and Decision Support. The study has been carried out at the Department of Transport (formerly known as Centre for Traffic and Transport) at the Technical University of Denmark. For further information please visit the website of: www.transport.dtu.dk.

Installation instructions:

The installation of CBA-DK is done by extracting the following zip file. The file is password protected which can be found on the bottom of this text.

It is important to extract the zip file directly to the C: directory in order for this software program to work properly. The zip file will hereafter self extract its content to correct locations and folders on your computer ensuring the software model to run accordingly.

By selecting the Excel file "Start.xls" the CBA-DK decision support model is opened.

It should be noted, that the risk analysis performed in the CBA-DK is based upon add-in software @RISK from Palisade Corporation. Thus, it is not possible to conduct risk analysis without this software program. Further information can be found on: www.palisade.com.

Password: Wq7XeR46

Figure 2. Readme file containing installation instructions.

2.2 Start-up procedure

To create a new project or open an existing project in the CBA-DK library a start-up procedure must take place. The model is opened by entering the start.xls, where the following Figure 3 is opened.

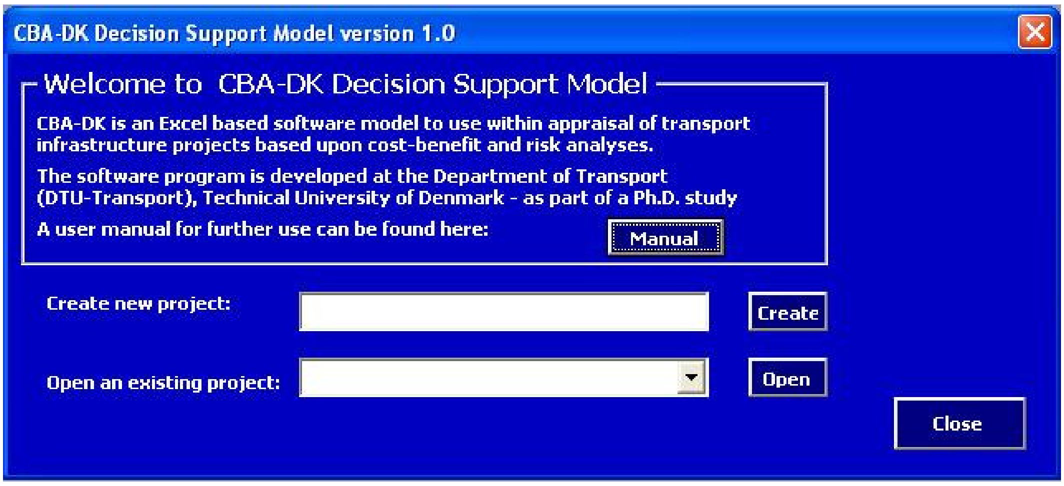


Figure 3. Start-up procedure from CBA-DK.

The user is left with the possibility of starting a brand new project where no data is entered. Hereby a new project name has to be entered in the *create new project* dialog. Likewise it is possible to *open an existing project* from the library of past projects. Finally, this user manual can be accessed or the user can choose to leave the spreadsheet model by *close*.

2.3 Entry Sheet

When CBA-DK is opened the entry sheet will appear as shown in Figure 4.

In the top bar, following each sheet within CBA-DK four options are available, as shown in Figure 5.

Figure 5. Illustration of the top-bar.

Firstly, you can choose to run a calculation at any time. The featured top bar is only applied in the cost-benefit approach where single point estimates are calculated. Secondly, the *Go to sheet…* is a scroll down feature where all 9 worksheet can be accessed. Thirdly, the *save* button can either save the project in its current project name and folder or you can choose to create a new project name and folder. Finally, you can *close* the model by choosing to save or not save the project.

Returning to Figure 4, three various colour codes exists namely yellow, blue and red. The yellow background indicates input areas where first year impacts should be applied. The blue background denotes a sub-calculation field where some calculations are performed elsewhere in the model. Finally, the red code depicts key figure values stemming from the key figure catalogue (DMT 2006; DTU-Transport 2008). It is important only to apply input data in fields with yellow colour coding.

Entry of key figures

The first user input to be applied with regard to the project is the construction costs, evaluation period, opening year etc., see Figure 6.

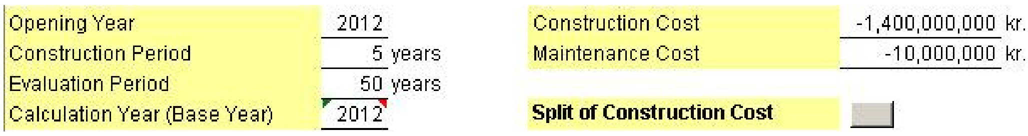


Figure 6. First user entry in CBA-DK.

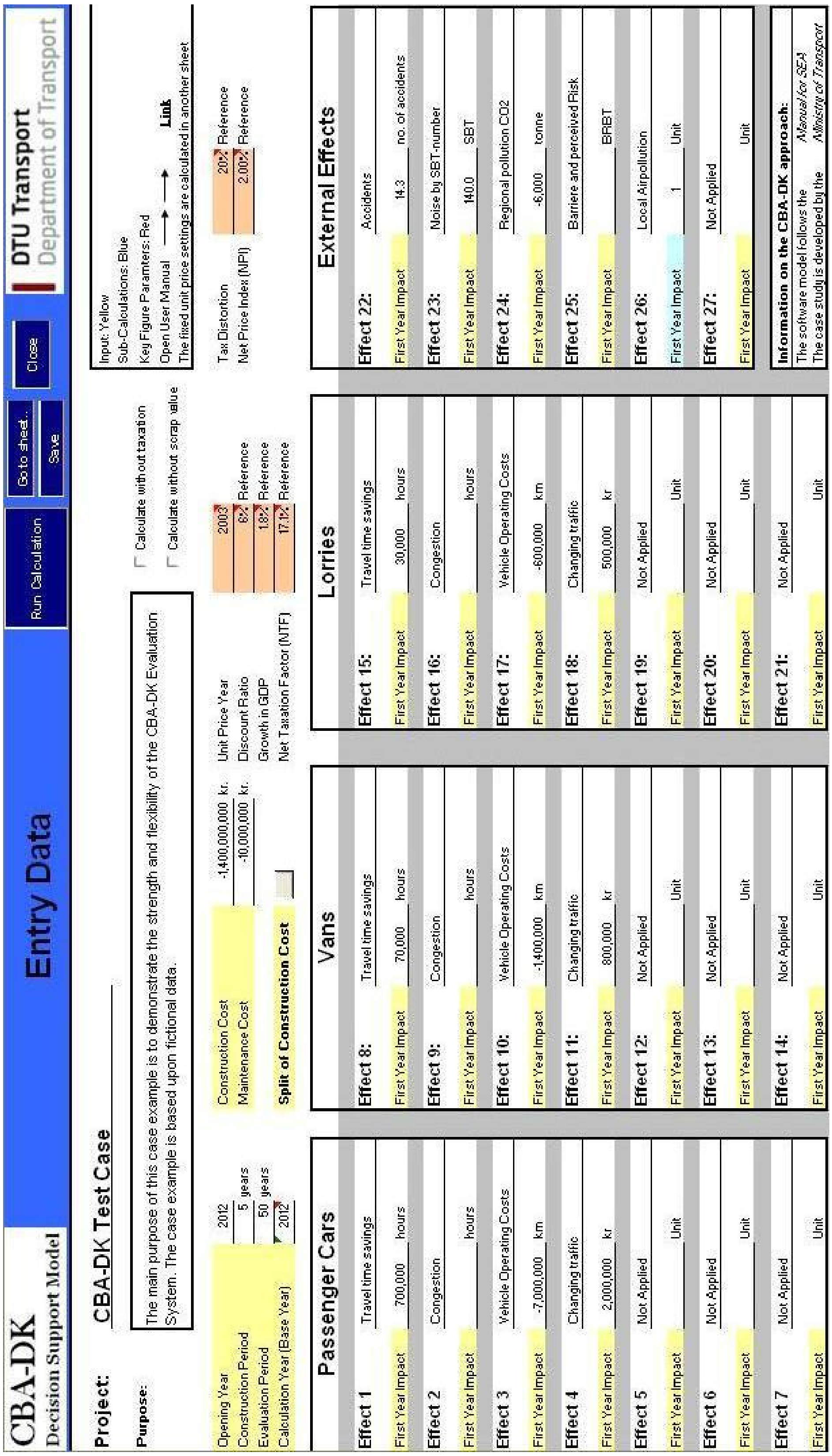


Figure 4. Illustration of the entry sheet divided on categories.

The construction period can currently be entered for integer values between 1 and 13 whereas the evaluation period has the possibility of a value between 10 and 60 years. The two impacts normally accounting for the highest negative input towards any transport infrastructure projects are the maintenance and construction costs. Furthermore, the construction cost depends on the construction period, in which a sub-division of costs can be entered pushing *split of construction cost*, see Figure 7.

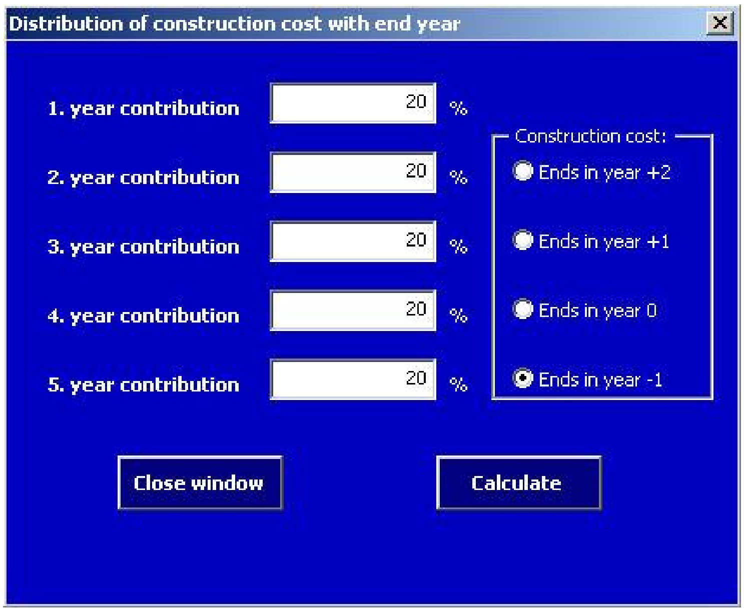


Figure 7. Split of construction costs over time.

Figure 7 enables the user to divide the overall construction cost into contributions in the building stages of the project. Traditionally, the last payment is made in year -1 which means that all investment costs have been paid before the opening year which also is the default settings. However, CBA-DK gives the possibility of continuing the payment in year 0, +1 and +2 years (which means that the payment continues after the project is opened or in use). The example shown above contains equally distributed contributions of 20% each year. The default values are automatically set to equally distributed payments over the construction period, this is, however, not always the case in which the user are allowed to change these values if needed (except the last year of entry which automatically is set to calculate an overall payment of 100%)[29].

The split of construction cost payments are made by pushing the *calculate* button. Hereafter, CBA-DK automatically makes the sub-calculation redirecting the user to the *Base Calculation* sheet. A new total construction cost is calculated on basis of discounting and taxation rules applied for Danish conditions, see Figure 8.

[29] An error box occurs if the user mistakenly tries to enter more than 100%.

Calculation of the Construction Cost including Net Taxation Factor (NTF), Tax Distortion and Discounting

Construction Period		5
Construction Cost		-1,400,000,000
Construction Cost	Split up pr year	-280,000,000
Net Taxation Factor (NTF)		0.171
Discounting		0.06

Year		-5	-4	-3	-2	-1	**Total**
In terms of percentage per year		0.20	0.20	0.20	0.20	0.20	1.00
Construction Cost	Excl. NTF	-280,000,000	-280,000,000	-280,000,000	-280,000,000	-280,000,000	-1,400,000,000
Construction Cost	Incl. NTF & revised factors	-327,880,000	-327,880,000	-327,880,000	-327,880,000	-327,880,000	-1,639,400,000
Construction Cost	Incl. NTF & discounting	-438,777,402	-413,940,946	-390,510,326	-368,405,968	-347,552,800	-1,959,187,442

Figure 8. Sub-calculation of the construction cost.

The illustrated example has an original construction cost of 1.4 mio Danish Kroner (DKr) which after the discounting and net taxation measures applied ends up with a result of 1.96 mio DKr. (DMT 2004; Salling 2006).

Returning to the entry sheet, the key figure parameters are shown as illustrated in Figure 9.

Unit Price Year	2003		Tax Distortion	20%	Reference
Discount Ratio	6%	Reference	Net Price Index (NPI)	2.00%	Reference
Growth in GDP	1.8%	Reference			
Net Taxation Factor (NTF)	17.1%	Reference			

Figure 9. Key figure parameters (default values).

The unit price year depends on the level of fixed prices and when they have been revised as mentioned before. The newly revised unit prices are given in an Excel sheet which makes the changes towards CBA-DK even more applicable. The discount ratio, an average of growth in Gross Domestic Product (GDP) and Net Price Index over the last 10 years together with the tax parameters is also given. It is possible to change these values, however, care must be taken since they are applied broadly within the CBA-DK model. However, as mentioned before, the previous version is currently applied due to the time constraint issue. A new version of CBA-DK implementing the new unit prices is to be commenced during the fall of 2008.

A special feature within this model is the possibility of choosing not to involve the taxation scheme and the scrap (terminal) value of the project as shown below by ticking the box next to.

☐ Calculate without taxation

☐ Calculate without scrap value

Figure 10. Special features as concern Danish conditions.

Figure 10 allows the user to compute the assessment scheme without the taxation and scrap value (or both). The calculation of the scrap value as concerns transport infrastructure projects in Denmark are treated with 100% of the construction costs discounted to the present year incl. the net taxation factor (NTF), see Figure 11.

Calculation of the Scrap Value	
Construction Period	50
Discounting	0.06
Scrap Value in market prices after the calculation period	1,959,187,442
Scrap Value incl. NTF & Discounting	106,361,077

Figure 11. Calculation of the scrap- or terminal value.

The scrap value as shown in Figure 11 becomes a relatively substantial benefit towards society. It can be argued whether for example a road project, with an evaluation period of 50 years actually still has the same worth as when it was built. Thus, many instances in Denmark disregard this benefit and presumes that the project is "worthless" when the evaluation period is terminated.

Finally, the four categories of first year impacts are to be entered in the modelling framework, see Figure 12 and 13.

Passenger Cars			**Vans**		
Effect 1	Travel time savings		**Effect 8:**	Travel time savings	
First Year Impact	700,000	hours	First Year Impact	70,000	hours
Effect 2	Congestion		**Effect 9:**	Congestion	
First Year Impact		hours	First Year Impact		hours
Effect 3	Vehicle Operating Costs		**Effect 10:**	Vehicle Operating Costs	
First Year Impact	-7,000,000	km	First Year Impact	-1,400,000	km
Effect 4	Changing traffic		**Effect 11:**	Changing traffic	
First Year Impact	2,000,000	kr	First Year Impact	800,000	kr
Effect 5	Not Applied		**Effect 12:**	Not Applied	
First Year Impact		Unit	First Year Impact		Unit
Effect 6	Not Applied		**Effect 13:**	Not Applied	
First Year Impact		Unit	First Year Impact		Unit
Effect 7	Not Applied		**Effect 14:**	Not Applied	
First Year Impact		Unit	First Year Impact		Unit

Figure 12. First year impacts as concerns category 1-2.

Lorries		
Effect 15:	Travel time savings	
First Year Impact	30,000	hours
Effect 16:	Congestion	
First Year Impact		hours
Effect 17:	Vehicle Operating Costs	
First Year Impact	-600,000	km
Effect 18:	Changing traffic	
First Year Impact	500,000	kr
Effect 19:	Not Applied	
First Year Impact		Unit
Effect 20:	Not Applied	
First Year Impact		Unit
Effect 21:	Not Applied	
First Year Impact		Unit

External Effects		
Effect 22:	Accidents	
First Year Impact	14.3	no. of accidents
Effect 23:	Noise by SBT-number	
First Year Impact	140.0	SBT
Effect 24:	Regional pollution CO2	
First Year Impact	-6,000	tonne
Effect 25:	Barriere and perceived Risk	
First Year Impact		BRBT
Effect 26:	Local Airpollution	
First Year Impact	1	Unit
Effect 27:	Not Applied	
First Year Impact		Unit
Information on the CBA-DK approach:		
The software model follows the	*Manual for SEA*	
The case study is developed by the	*Ministry of Transport*	

Figure 13. First year impacts as concerns category 3-4.

The CBA-DK model currently allows for 27 specific entries divided on four various categories. It is possible to customize the categories and impacts as one would like. In the bottom of Figure 13 it is possible to access the manual on socio-economic analysis (DMT 2003) together with the key figure catalogue available (DMT 2006). It will be possible in a later version to directly access the brand new Excel sheet covering all new unit price settings (DTU-Transport 2008).

2.4 Impact and Taxation Sheet

A sub-feature of the modelling framework is to introduce the net taxation and tax distortion impacts, see Figure 14.

These rules applied generate a net yield towards the public purse in terms of duties and taxes of e.g. petrol and other energy expenditures. If the general public for instance receives a travel length reduction the consumption of petrol will decrease resulting in fewer petrol dependent taxes. If the transport investment is funded through tax money (which currently is the case for the majority of transport investments in Denmark), the Government has to collect the "missing" taxes somewhere else. The consumer receives a surplus in tax revenue that assumable is used on other commodities. The problem is now, that the consumers buy products applied taxes and duties already. The net taxation factor eliminates the difference in loss expected for the government due to tax income in other sectors (DMT 2004).

The tax distortion factor is more transparent in its origin since a distortion loss can be determined as the financing of a project by using tax money. In order to fund projects through taxes the Government needs to collect taxes which obviously cost money to do. The tax distortion is only applied expenditures relevant for the government e.g. the construction cost and maintenance cost (DMT 2004). The two taxation impacts are very complicated in real practical situations since there is no common agreement on the implementation. Especially, since the impacts are relatively new, it is not possible to make any comparisons with old projects where these are not implied. Henceforward it has been assumed not to use the two impacts until a more common understanding of the latter has been agreed upon.

The sheet has a direct link to a small note (Salling 2006) in which a small example is calculated. Currently, these taxation rules are undergoing review in the Ministry of Transport. My opinion is that these rules will undergo substantial corrections, specifically when it comes to the implementation part.

Finally, the impact of air pollution is derived by a sub-calculation. As shown in Figure 15, various unit prices are corresponding to the different pollutants and whether it is local or regional areas the project is applied.

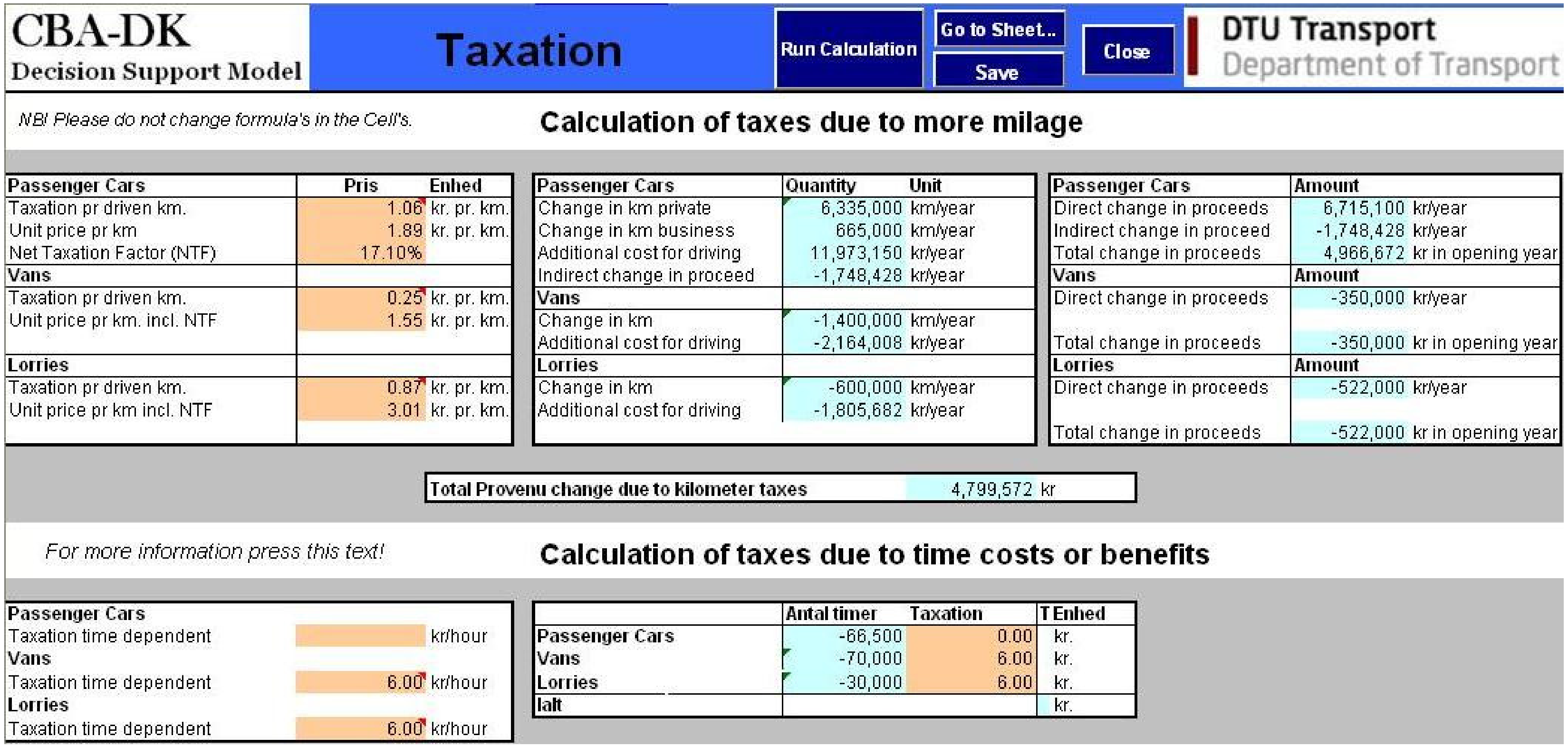


Figure 14. Taxation calculations depending on the mileage and time.

Calculation of local Airpollution

Marginal changes in local airpollution in quantity.

Urban

	Effect tonne pr. year	Unit Price kr. pr. Tonne	Total kr pr year
NOx	20.00	15,000	300,000
HC	0.10	4,000	400
CO	200.00	14	2,800
Particles	0.20	1,509,000	301,800
SO2	1.00	60,000	60,000
TOTAL			665,000

Inter-Urban

	Effect tonne pr year	Unit price pr kr tonne	Total kr pr year
NOx	-100.00	16,000	-1,600,000
HC	-0.20	4,000	-800
CO	-1200.00	2	-2,400
Particles	-1.00	321,000	-321,000
SO2	-5.00	32,000	-160,000
TOTAL			**-2,084,200**

Total Urban + Inter-Urban -1,419,200

Marginal changes in local air pollution in driven kilometers

Road Transport		**Low**	**Median**	**High**	
Passenger Cars	Petrol	0.01	0.02	0.11	kr/km
	Diesel	0.02	0.03	0.30	kr/km
Vans	Diesel	0.04	0.07	0.70	kr/km
	Petrol	0.02	0.03	0.15	kr/km
Lorries	Diesel	0.12	0.24	1.05	kr/km

If you choose to use amrginal changes in driven kilometeres, they are respectively present in E7, E14 & E21 for passenger cars, lorries and heavy

The used value per km. is at the moment for the lorries just taken as an average value between petrol and diesel. This is off course not the case, as more lorries drive on diesel and more passenger cars drive on petrol.

Figure 15. Calculation of the "local" airpollution.

Traditionally in Danish socio-economic analysis towards the road sector, CO_2 have been applied as a regional impact. However, recent studies have shown, that putting a price tag on this pollutant is extremely difficult, i.e. the price shifts between 10 DKr pr emitted CO_2 to 1000 DKr pr emitted CO_2 (Salling 2003). Thus, this impact has been placed within the so-called multi-criteria analysis (Salling et al. 2007). Key figures, however, exists in Denmark with regard to this impact, so if the tonne emitted are of relevance, it is possible to make an entry.

During recent years, this impact has deemed more and more political status, e.g. by the Kyoto agreement and lately the environmental summit in Copenhagen 2009. The need for evaluating environmental impacts is substantial, in which more effort must be placed upon finding valid unit prices. Currently, two methods are available in the Danish set-up. 1. relies on the emitted level of pollutants in tonnes and 2. relies on the number of kilometre driven. It should be noted, that 1. must be classified as the most reliant method whereas 2. is only applied for rough measures of the pollution.

2.5 Forecast/Prognosis

The purpose of the two forecast sheets are to apply future traffic increases/decreases as well as handling future economic tendencies as concerns the unit prices. Figure 16 shows the forecast of the first year impacts.

Each individual first year impact is listed on the left hand side. In top a *general prognosis (GP)* can be entered for which each check box can apply the GP. Otherwise, it is possible to make individual forecast entries as concern specific years e.g. incorporating trend scenarios (Leleur et al. 2004). As default settings the net price index as shown on the entry sheet is set in the *General Prognosis* accounting for 20 years. Hereafter the forecast is set to 0 which means that the prognosis settings are classified as constant.

The *Forecast* sheet as concerns unit prices is shown in Figure 17. The two sheets shown in Figure 16 and 17 are very similar where each first year impact is shown on the left. However, the forecast of unit prices relies on the growth in the economy denoted by the GDP. Furthermore, the *general price prognosis (GPP)* is currently only applied for the travel time savings. This default setting has been discussed among others with Jens Foller that previously acted as project manager in the Danish Road Directorate.

CBA-DK
Decision Support Model

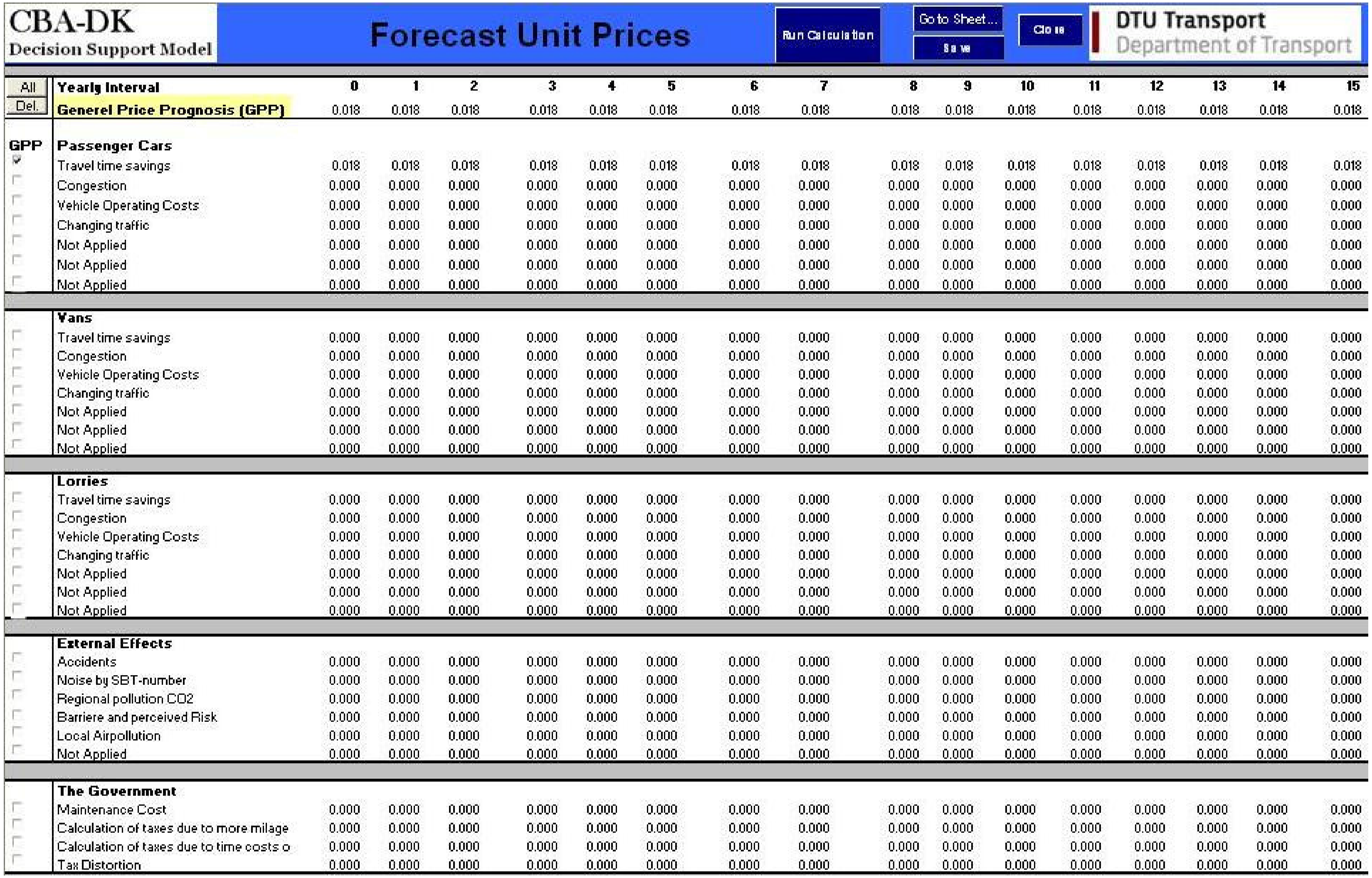
Forecast First Year Impacts

Run Calculation | Go to Sheet... | Save | Close

DTU Transport
Department of Transport

All / Del.	Yearly Interval	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	General Prognosis (GP)	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
GP	**Passenger Cars**																		
☑	Travel time savings	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☑	Vehicle Operating Costs	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☑	Changing traffic	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Vans																		
☑	Travel time savings	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☑	Vehicle Operating Costs	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☑	Changing traffic	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Lorries																		
☑	Travel time savings	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☑	Vehicle Operating Costs	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☑	Changing traffic	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	External Effects																		
☐	Accidents	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Noise by SBT-number	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Regional pollution CO2	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010
☐	Barriere and perceived Risk	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Local Airpollution	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010	-0.010
☐	Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	The Government																		
☐	Maintenance Cost	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Calculation of taxes due to more	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Calculation of taxes due to time c	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
☐	Tax Distortion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 16. Forecast of the first year impacts divided into categories.



Yearly Interval	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Generel Price Prognosis (GPP)	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Passenger Cars																
Travel time savings	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018	0.018
Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vehicle Operating Costs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Changing traffic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vans																
Travel time savings	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vehicle Operating Costs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Changing traffic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Lorries																
Travel time savings	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Congestion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Vehicle Operating Costs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Changing traffic	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
External Effects																
Accidents	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Noise by SBT-number	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Regional pollution CO2	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Barriere and perceived Risk	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Local Airpollution	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Not Applied	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
The Government																
Maintenance Cost	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calculation of taxes due to more milage	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Calculation of taxes due to time costs o	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Tax Distortion	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Figure 17. Forecast sheet for the Unit Prices divided into categories.

Key Figure Parameters and Value-of-Time calculations

In this current version of CBA-DK the key figure parameters together with the sub-calculation of the value of travel time are presented in the bottom of the *Forecast* sheet for the unit prices, see Figure 18.

It is assumed, that passenger vehicles are not used for any commercial transports hence the net taxation factor (NTF) is only applied vans and lorries (if road infrastructure project is assessed). The two outer columns revises the unit prices into current prices. The price level and calculation level is rarely the same, whilst a forecast is made. The forecast factor applied is based upon the GDP and only valid for passenger cars, as shown in Figure 17. These values are applied the modelling framework as unit prices in year 0.

The value-of-time (VoT) as concerns the travel time savings are divided into three categories, business, work related and leisure in which various time unit costs are applied. A default setting within Danish road infrastructure projects is also applied with regard to trip purposes (Figure 19). These figures are subjected to change for different modes and/or project types i.e. public transportation schemes or air transportation.

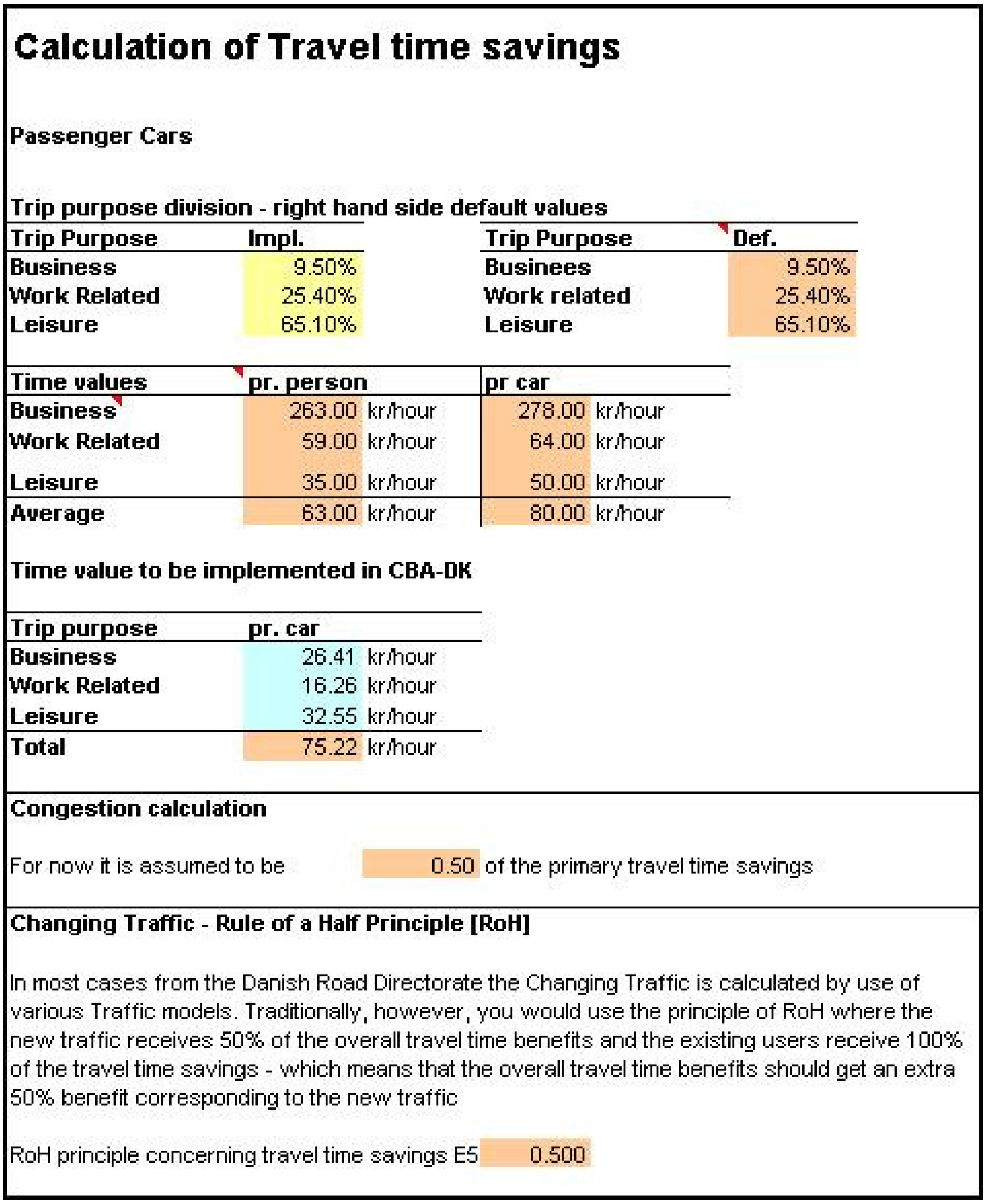
Key Figure Parameters — *To view the newest catalog press this text!*

	Unit Prices	2003	Units	Incl. HTF	Revised yearly growth	Revised Unit Prices
	Passenger Cars					
E1	Travel time savings	75.22	kr pr hour		1.80%	88.32
E2	Congestion	37.61	kr pr hour		1.80%	44.16
E3	Vehicle Operating Costs	1.89	kr pr km		0.00%	1.89
E4	Changing traffic	37.61	Unit		0.00%	37.61
E5	Not Applied	1.00	kr pr hour		0.00%	1.00
E6	Not Applied	1.00	Unit		0.00%	1.00
E7	Not Applied	0.03	kr pr km		0.00%	0.03
	Vans					
E8	Travel time savings	213.00	kr pr hour	249.42	0.00%	249.42
E9	Congestion	106.50	kr pr km	124.71	0.00%	124.71
E10	Vehicle Operating Costs	1.32	kr pr km	1.55	0.00%	1.55
E11	Changing traffic	106.50	Unit	124.71	0.00%	124.71
E12	Not Applied	1.00	Unit	1.17	0.00%	1.17
E13	Not Applied	1.00	Unit	1.17	0.00%	1.17
E14	Not Applied	0.05	kr pr km	0.06	0.00%	0.06
	Lorries					
E15	Travel time savings	297.00	kr pr hour	347.79	0.00%	347.79
E16	Congestion	148.50	kr pr hour	173.89	0.00%	173.89
E17	Vehicle Operating Costs	2.57	Unit	3.01	0.00%	3.01
E18	Changing traffic	148.50	Unit	173.89	0.00%	173.89
E19	Not Applied	1.00	Unit	1.17	0.00%	1.17
E20	Not Applied	1.00	Unit	1.17	0.00%	1.17
E21	Not Applied	0.24	kr pr km	0.28	0.00%	0.28
	External Effects					
E22	Accidents	2,611,000	kr pr accident		0.00%	2,611,000
E23	Noise by SBT-number	58,571	kr. pr SBT		0.00%	58,571
E24	Regional pollution CO2	130.0	kr pr tonne		0.00%	130
E25	Barriere and perceived Risk	11,943	kr. pr BRBT		0.00%	11,943
E26	Local Airpollution	-1,419,200	Kr pr year		0.00%	-1,419,200
E27	Not Applied	1.00	Unit		0.00%	1
	Construction costs, factor				0.00%	1.00
	Operating costs, factor				0.00%	1.00

Figure 18. Key figure parameters based upon 2003 price levels from DMT (2006).

With respect to the value-of-time a small sub-calculation is presented as concerns the induced (changing) traffic. The so-called rule of a half (RoH) principle is applied with respect to the induced traffic, in which the unit prices are multiplied with 50%, in this case impacts E4, E11 and E18. The impacts E2, E9 and E16 are denoted congestion which particularly concerns road infrastructure projects.

Avoided congestion receives a 50% extra time value which means that the hours saved previously as congested time actually accounts for 150% of the travel time savings (Figure 19).



Calculation of Travel time savings

Passenger Cars

Trip purpose division - right hand side default values

Trip Purpose	Impl.	Trip Purpose	Def.
Business	9.50%	Businees	9.50%
Work Related	25.40%	Work related	25.40%
Leisure	65.10%	Leisure	65.10%

Time values	pr. person		pr car	
Business	263.00	kr/hour	278.00	kr/hour
Work Related	59.00	kr/hour	64.00	kr/hour
Leisure	35.00	kr/hour	50.00	kr/hour
Average	63.00	kr/hour	80.00	kr/hour

Time value to be implemented in CBA-DK

Trip purpose	pr. car	
Business	26.41	kr/hour
Work Related	16.26	kr/hour
Leisure	32.55	kr/hour
Total	75.22	kr/hour

Congestion calculation

For now it is assumed to be 0.50 of the primary travel time savings

Changing Traffic - Rule of a Half Principle [RoH]

In most cases from the Danish Road Directorate the Changing Traffic is calculated by use of various Traffic models. Traditionally, however, you would use the principle of RoH where the new traffic receives 50% of the overall travel time benefits and the existing users receive 100% of the travel time savings - which means that the overall travel time benefits should get an extra 50% benefit corresponding to the new traffic

RoH principle concerning travel time savings E5 0.500

Figure 19. Sub-Calculation to the TTS by the use of rule of a half.

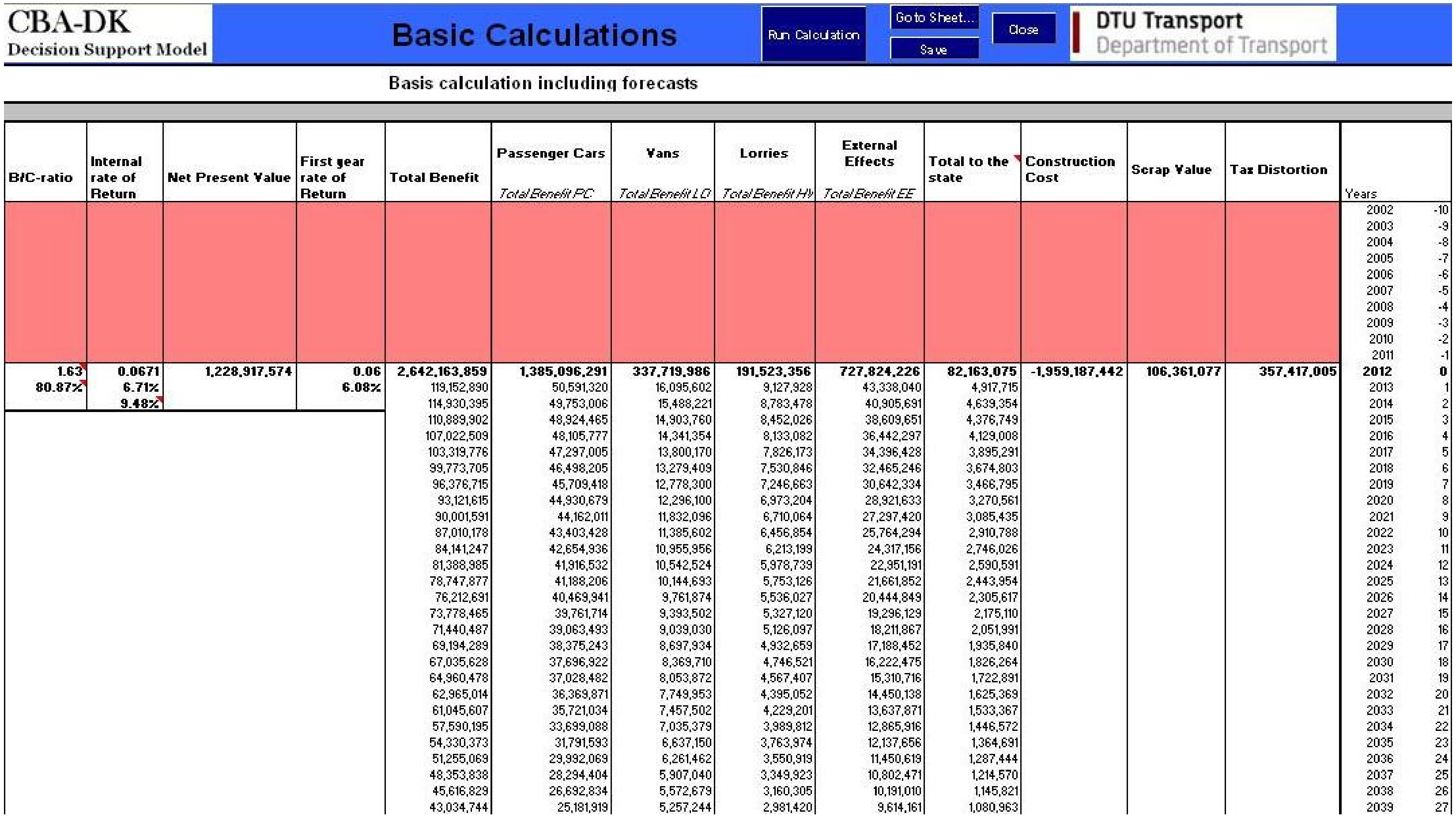
After checking all these various input parameters, it is now possible to make the first run of CBA-DK. You can either return to the entry sheet for a final check-up or you can run the model from where you are. CBA-DK automatically sends you to the *Result-Overview* sheet neglecting to show the two sheets of *Base Calculations* and *Results-All*.

2.6 Base calculation

All calculations in the model are gathered and processed in the Base Calculation sheet. The main purpose is for the user to be able, if relevant, to extract information with respect to a specific impact or parameter. By multiplying the first year impact with the unit price parameter and then discount the values over the evaluation period extensive amounts of data are presented in this sheet.

Figure 20 shows the summation of the most important results from a fixed run in CBA-DK.

On the far left the four evaluation criteria are listed. The internal rate of return is further subjected to two calculations in order to check the value: 1. implicit formula calculations done by conventional cost-benefit approach and 2. by the embedded formula expressions within Microsoft Excel. The benefit cost ratio is respectively found by two methods: 1. the traditional method where only the total construction cost is placed in the denominator and 2. the method used by the Danish Road directorate in which taxes are included together with other governmental subsidies (DMT 2003). The other columns depict the overall benefits from the different categories together with investment costs, a scrap value and the tax distortions. If the user scrolls to the right, all impacts are shown together with each individual calculation year of performance.



B/C-ratio	Internal rate of Return	Net Present Value	First year rate of Return	Total Benefit	Passenger Cars Total Benefit PC	Vans Total Benefit LO	Lorries Total Benefit HV	External Effects Total Benefit EE	Total to the state	Construction Cost	Scrap Value	Tax Distortion	Years	
													2002	-10
													2003	-9
													2004	-8
													2005	-7
													2006	-6
													2007	-5
													2008	-4
													2009	-3
													2010	-2
													2011	-1
1.63	**0.0671**	**1,228,917,574**	**0.06**	**2,642,163,859**	**1,385,096,291**	**337,719,986**	**191,523,356**	**727,824,226**	**82,163,075**	**-1,959,187,442**	**106,361,077**	**357,417,005**	**2012**	**0**
80.87%	**6.71%**		**6.08%**	119,152,890	50,591,320	16,095,602	9,127,928	43,338,040	4,917,715				2013	1
	9.48%			114,930,395	49,753,006	15,488,221	8,783,478	40,905,691	4,639,354				2014	2
				110,889,902	48,924,465	14,903,760	8,452,026	38,609,651	4,376,749				2015	3
				107,022,509	48,105,777	14,341,354	8,133,082	36,442,297	4,129,008				2016	4
				103,319,776	47,297,005	13,800,170	7,826,173	34,396,428	3,895,291				2017	5
				99,773,705	46,498,205	13,279,409	7,530,846	32,465,246	3,674,803				2018	6
				96,376,715	45,709,418	12,778,300	7,246,663	30,642,334	3,466,795				2019	7
				93,121,615	44,930,679	12,296,100	6,973,204	28,921,633	3,270,561				2020	8
				90,001,591	44,162,011	11,832,096	6,710,064	27,297,420	3,085,435				2021	9
				87,010,178	43,403,428	11,385,602	6,456,854	25,764,294	2,910,788				2022	10
				84,141,247	42,654,936	10,955,956	6,213,199	24,317,156	2,746,026				2023	11
				81,388,985	41,916,532	10,542,524	5,978,739	22,951,191	2,590,591				2024	12
				78,747,877	41,188,206	10,144,693	5,753,126	21,661,852	2,443,954				2025	13
				76,212,691	40,469,941	9,761,874	5,536,027	20,444,849	2,305,617				2026	14
				73,778,465	39,761,714	9,393,502	5,327,120	19,296,129	2,175,110				2027	15
				71,440,487	39,063,493	9,039,030	5,126,097	18,211,867	2,051,991				2028	16
				69,194,289	38,375,243	8,697,934	4,932,659	17,188,452	1,935,840				2029	17
				67,035,628	37,696,922	8,369,710	4,746,521	16,222,475	1,826,264				2030	18
				64,960,478	37,028,482	8,053,872	4,567,407	15,310,716	1,722,891				2031	19
				62,965,014	36,369,871	7,749,953	4,395,052	14,450,138	1,625,369				2032	20
				61,045,607	35,721,034	7,457,502	4,229,201	13,637,871	1,533,367				2033	21
				57,590,195	33,699,088	7,035,379	3,989,812	12,865,916	1,446,572				2034	22
				54,330,373	31,791,593	6,637,150	3,763,974	12,137,656	1,364,691				2035	23
				51,255,069	29,992,069	6,261,462	3,550,919	11,450,619	1,287,444				2036	24
				48,353,838	28,294,404	5,907,040	3,349,923	10,802,471	1,214,570				2037	25
				45,616,829	26,692,834	5,572,679	3,160,305	10,191,010	1,145,821				2038	26
				43,034,744	25,181,919	5,257,244	2,981,420	9,614,161	1,080,963				2039	27

Figure 20. Partial screen dump of the Base calculation sheet.

2.7 Results All

The *Results-All* sheet copies all data from the *Input data* sheet with respect to the 27 impacts and lists the results, see Figure 21.

The benefits and costs listed above are all discounted values through the whole evaluation period. The *Result-All* sheet merely serves as notice for the user if he wants to go in depth with an individual impact. Below, listed in Figure 22 and 23 are the first year impacts and unit prices shown outlining the inputs to the assessment scheme.

First Year Impacts in Opening Year

	First Year Impact 2012
Passenger Cars	
Travel time savings	700,000
Congestion	0.00
Vehicle Operating Costs	-7,000,000
Changing traffic	2,000,000
Not Applied	0
Not Applied	0
Not Applied	0
Vans	
Travel time savings	70,000
Congestion	0
Vehicle Operating Costs	-1,400,000
Changing traffic	800,000
Not Applied	0
Not Applied	0
Not Applied	0

	First Year Impact 2012
Lorries	
Travel time savings	30,000
Congestion	0
Vehicle Operating Costs	-600,000
Changing traffic	500,000
Not Applied	0
Not Applied	0
Not Applied	0
External Effects	
Accidents	14.30
Noise by SBT-number	140.00
Regional pollution CO2	-6,000
Barriere and perceived Risk	0.00
Local Airpollution	1.00
Not Applied	0

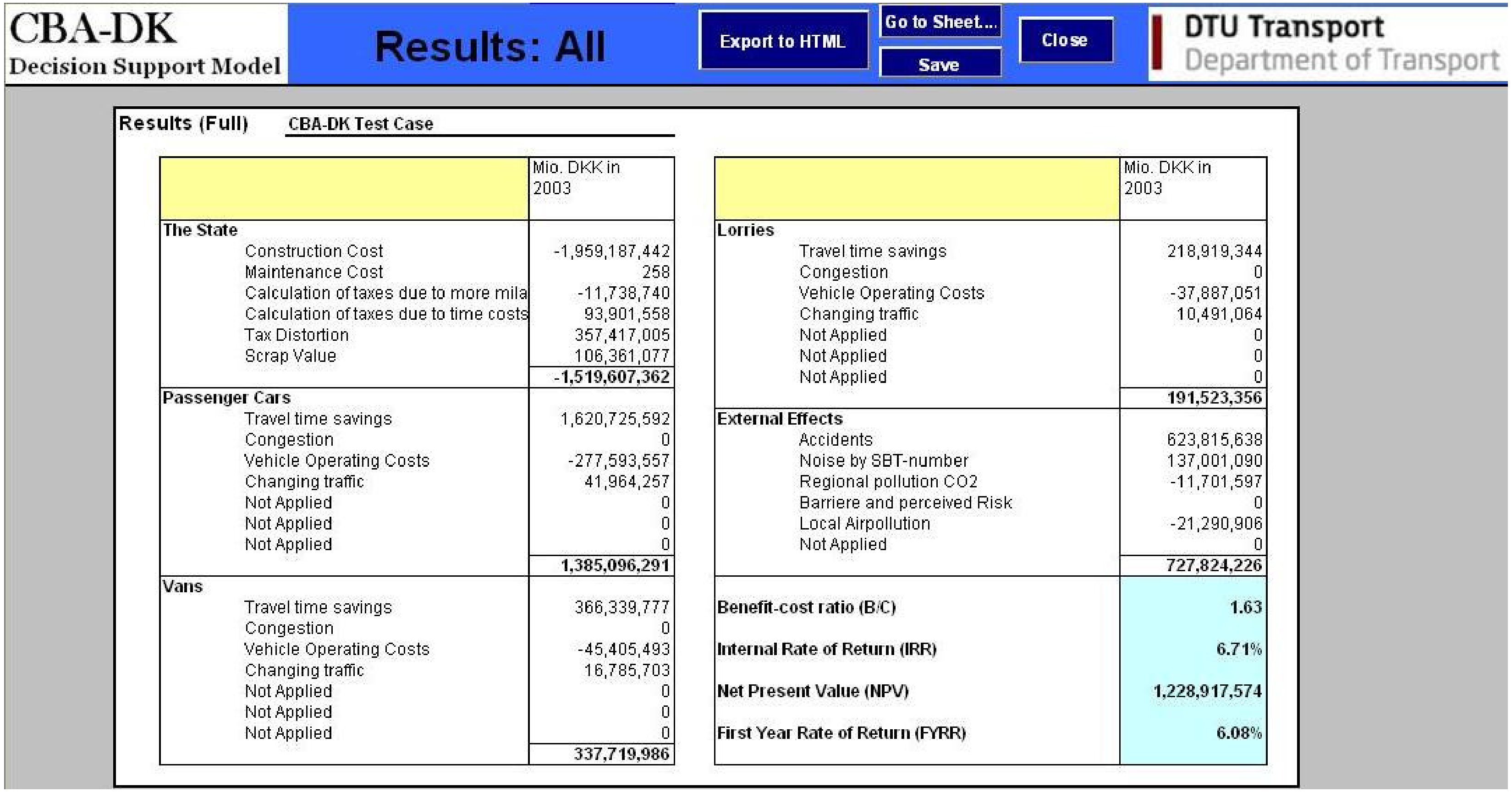
Figure 22. Result all sheet, the first year impacts.

Unit Prices

	Revised Unit Prices
Passenger Cars	
Travel time savings	88.32
Congestion	44.16
Vehicle Operating Costs	1.89
Changing traffic	37.61
Not Applied	1.00
Not Applied	1.00
Not Applied	0.03
Vans	
Travel time savings	249.42
Congestion	124.71
Vehicle Operating Costs	1.55
Changing traffic	124.71
Not Applied	1.17
Not Applied	1.17
Not Applied	0.06

	Revised Unit Prices
Lorries	
Travel time savings	347.79
Congestion	173.89
Vehicle Operating Costs	3.01
Changing traffic	173.89
Not Applied	1.17
Not Applied	1.17
Not Applied	0.28
External Effects	
Accidents	2,611,000
Noise by SBT-number	58,571
Regional pollution CO2	130
Barriere and perceived Risk	11,943
Local Airpollution	-1,419,200
Not Applied	1

Figure 23. Result all sheet, the unit prices.



Results (Full) CBA-DK Test Case

	Mio. DKK in 2003
The State	
Construction Cost	-1,959,187,442
Maintenance Cost	258
Calculation of taxes due to more mila	-11,738,740
Calculation of taxes due to time costs	93,901,558
Tax Distortion	357,417,005
Scrap Value	106,361,077
	-1,519,607,362
Passenger Cars	
Travel time savings	1,620,725,592
Congestion	0
Vehicle Operating Costs	-277,593,557
Changing traffic	41,964,257
Not Applied	0
Not Applied	0
Not Applied	0
	1,385,096,291
Vans	
Travel time savings	366,339,777
Congestion	0
Vehicle Operating Costs	-45,405,493
Changing traffic	16,785,703
Not Applied	0
Not Applied	0
Not Applied	0
	337,719,986

	Mio. DKK in 2003
Lorries	
Travel time savings	218,919,344
Congestion	0
Vehicle Operating Costs	-37,887,051
Changing traffic	10,491,064
Not Applied	0
Not Applied	0
Not Applied	0
	191,523,356
External Effects	
Accidents	623,815,638
Noise by SBT-number	137,001,090
Regional pollution CO2	-11,701,597
Barriere and perceived Risk	0
Local Airpollution	-21,290,906
Not Applied	0
	727,824,226
Benefit-cost ratio (B/C)	**1.63**
Internal Rate of Return (IRR)	**6.71%**
Net Present Value (NPV)	**1,228,917,574**
First Year Rate of Return (FYRR)	**6.08%**

Figure 21. Results all sheet containing an overview of all impacts divived on categories as introduced in the entry sheet.

2.8 Results Overview

The final outcome of a fixed run in the CBA-DK model run is shown in the *Results overview* sheet (Figure 24).

The overview sheet is divided into two parts, a report illustrating the most important impacts of the project and two columns picturing respectively the costs and benefits of the project in absolute terms. The report is based upon prior assessment reports presented for the Danish road directorate. The columns basically shows costs compared to benefits i.e. this fixed example shows that the benefits exceeds the costs in which the project is feasible seen from a societal point of view.

Contrary to other sheets, the top bar has embedded a new feature as shown in Figure 25.

Figure 25. Top-bar in the Results overview sheet.

The *Export to HTML* converts the *Results overview* sheet into a printable sized HTML page. Hereby the project is sizable to be presented to decision-makers in terms of the deterministic results.

Hereafter, the following treats the embedded uncertainties by stochastic calculations in terms of quantitative risk analysis (QRA). The scope is to transform the single point estimates found in the CBA-module into interval results. By interpreting the uncertain input parameters with probability distributions a Monte Carlo simulation is set-up. Currently, the benefit-cost ratio (BCR) is used as simulation output. The theoretical background of the following is given in the main report of this thesis report (Chapter 1).

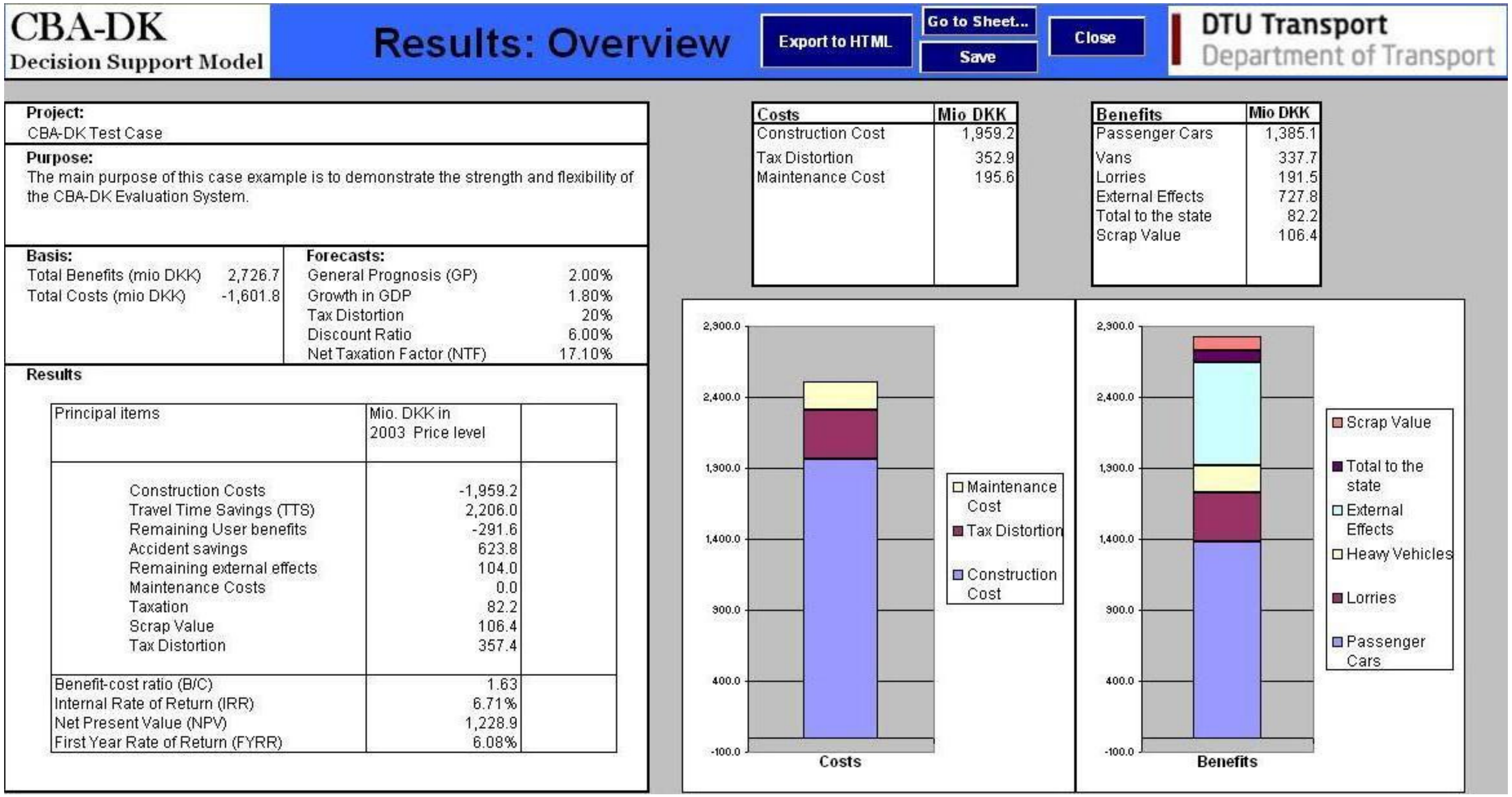


Figure 24. Results overview sheet containing the most important impacts gathered in predefined groups.

2.9 Probability Distributions (Quantitative Risk Analysis)

Banister & Berechman (2000) has defined *uncertainty* to indicate the degree of inaccuracy associated with the determination of the specific project's benefits and costs. Thus, uncertainty is considered as reflections of deterministic values which more or less are impossible to determine (Salling & Banister 2008). Another distinction is the term *risk* which Banister & Berechman (2000) indicates as the likelihood of selecting the wrong project or a project which is economically non-viable. This conceptual distinction between risk and uncertainty is important to remember, since we are trying to avoid risk by modelling the uncertainty. Thus, the probability distributions are associated with the risk of selecting the wrong project.

The input sheet of the quantitative risk analysis (QRA) is shown in Figure 26.

The four impact categories are shown in the left with various colour codes. All 27 first year impacts are shown together with their input values (from the entry sheet). Currently, the CBA-DK model uses these input values as the most likely (mode) values, however, it is possible to by-pass this feature by model the uncertainty directly in the @RISK tool-bar (Section 2.11 in the main report). The following treats the five types of PDFs together with proposed application areas.

The Erlang Distribution

The Erlang distribution is a probability distribution with wide applicability primarily due to its relation to the exponential and gamma distributions. The Erlang distribution has a positive value for all the numbers greater than zero, and is parameterized by two parameters: the shape k, which is an integer, and the rate λ, which is real. The distribution is sometimes defined using the inverse of the rate parameter, the scale θ, applicable within the software program @RISK. The Erlang distribution has been found useful in combination with the so-called Lichtenberg principle in obtaining a mean and a std. deviation from successive calculation (Lichtenberg 2000).

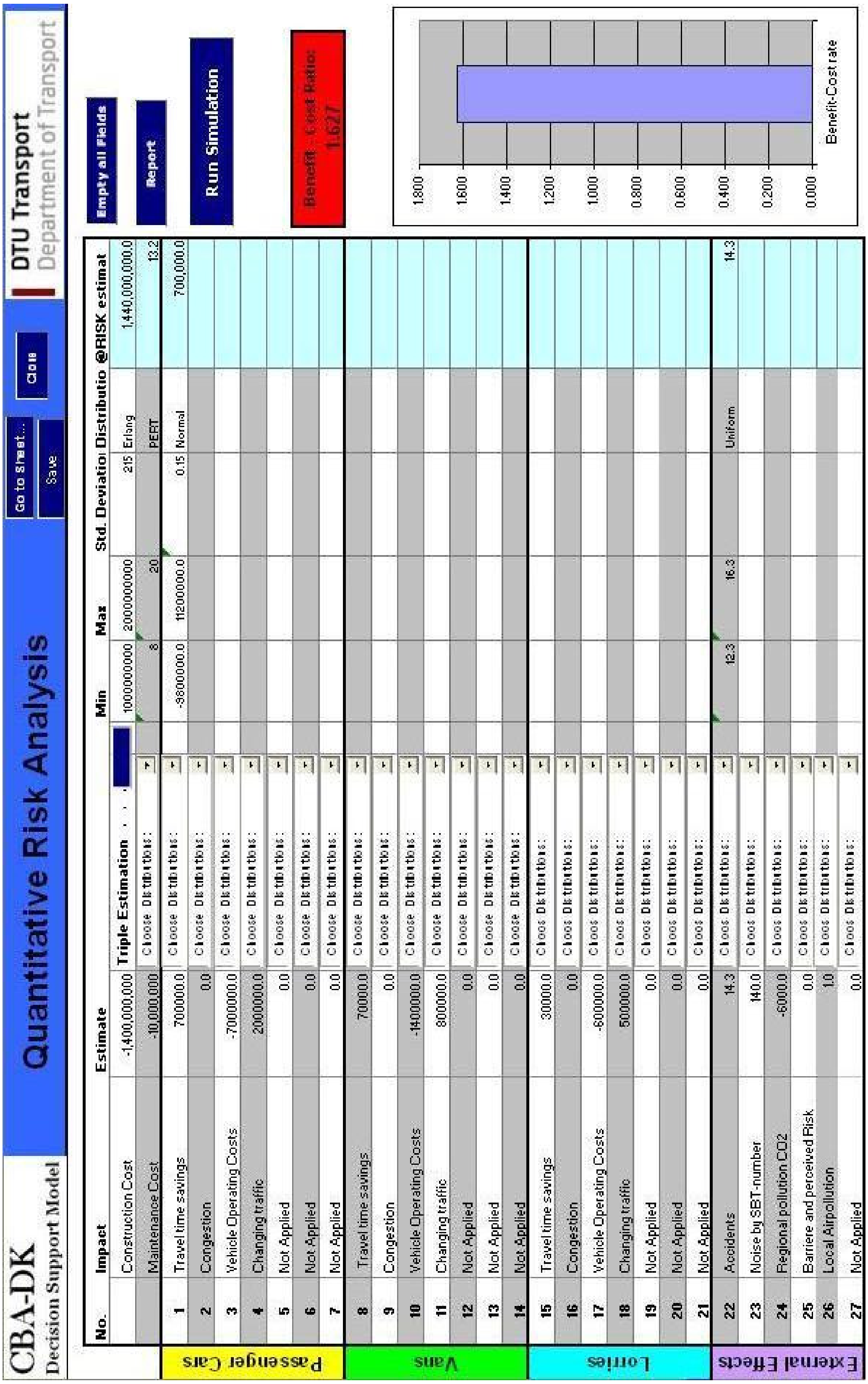


Figure 26. The Quantitative Risk Analysis input sheet.

The strength of applying the so-called Lichtenberg principle is that the decision-maker only has to consider a minimum, most likely (ML) and maximum value. It is among others used for several issues including support, optimize and estimating budget allowances especially within the construction area. Some other key areas where the principle has been applied are strategic planning and risk analysis. Then by use of a so-called triple estimation approach the mean (1) and standard deviation (2) are calculated by the two following formulas (Lichtenberg 2000, p. 125):

$$\mu = \frac{(\min + 2.9 \cdot Mode + \max)}{4.9} \tag{1}$$

$$s = \frac{|\max - \min|}{4.65} \tag{2}$$

The shape (k) and the scale (θ) parameter has the following relationship as illustrated in (3):

$$\theta = \frac{\mu}{k} \tag{3}$$

The calculations of the mean and standard deviation are automatically performed in CBA-DK shown in Figure 27, where the current mode value (not discounted or applied tax distortion) is used as the most likely value. If the user somehow wants to apply a normal distribution instead of the Erlang distribution, the box in Figure 27 allows for that as well (including the use of Lichtenberg's principle).

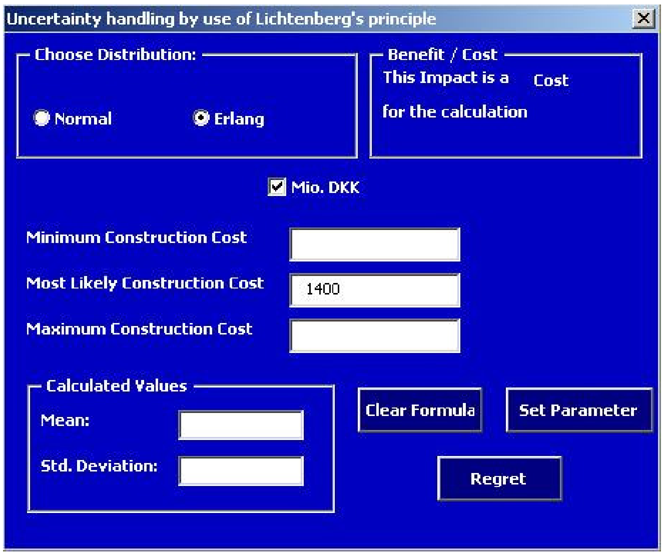


Figure 27. Calculating the construction cost by the triple estimation technique.

It should be noted, that the minimum and maximum values are respectively 1 and 99 percentiles (Lichtenberg 2000, p. 124). The applicability of the Erlang distribution is related to the variation of the scale and shape parameter as illustrated in Figure 28.

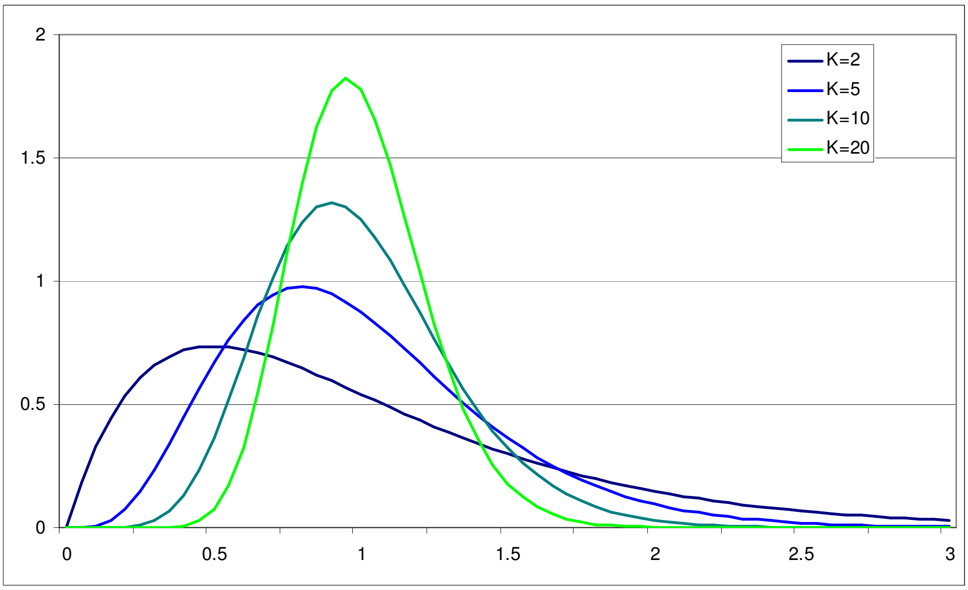


Figure 28. Various *k* parameters of the Erlang distribution (Salling & Leleur 2006).

Application of the Erlang distribution

The cost of investing or determining which projects to invest in ex-ante is often underestimated normally explained by e.g. technical problems, delays, etc. Some authors even think that construction costs in the field collectively are underestimated in the planning stage (Wilmot & Cheng 2003; Flyvbjerg et al. 2003). Other explanations of the general underestimation are the dynamical way an infrastructure project is developing over time. In the pre-face you normally look upon traditional impacts of building e.g. a new road. However, most often during the project new and better choices are made for instance in noise precautions, a new alignment of the road etc. These costs are off course not possible to take into account in advance. The decision-makers also tend to change their preferences during the course of action – especially in large-scale projects. These non-quantifiable preferences are often not taken into account in the preliminary phase which makes the overall construction cost more expensive than originally estimated.

During literature it is therefore clear that estimating construction costs during infrastructure appraisal has assigned a relatively high degree of uncertainty. Four bullet points for estimating construction costs with probability distributions have been proposed in (Back et al. 2000).

- Upper and lower limits which ensures that the analyst is relatively certain values does not exceed. Consequently, a **closed-ended** distribution is desirable.
- The distribution must be **continuous**
- The distribution will be **unimodal**; presenting a most likely value
- The distribution must be able to have a greater freedom to be higher than lower with respect to the estimation – **skewness** must be expected.

It has been found that a shape parameter in the range of k = 4-9 matches the distribution of the uncertainty involved in determining the construction cost (Rosenstand 2007; Lichtenberg 1990). The Erlang function with k = 1 is identical to the exponential function (hereby the illustration of lifespan methodology due to the extremely skewed distribution). Using k = 5 the function resembles a Lognormal distribution which also is highly appropriate when the parameter is a product of many factors. Finally, when $k \geq 10$ the distribution is brought closer to the Gaussian distribution (normal distribution) which again is relevant when a cost parameter is the sum of more than one element (Lichtenberg 2000).

By test it has, however, been shown that a k value ranging from 4-7 does not reveal any significant change in the result. In the following it has been chosen to select a k-value of 5 – further investigations of this value together with other families of the gamma distribution is to be implemented in the future work. The resulting standard error of k for relatively small fluctuations is, however, found to be insignificant compared with normal practical uncertainties (Lichtenberg 2000 p. 128).

The Beta-PERT distribution

The Beta-PERT distribution (from here on just referred to as the PERT distribution) is a useful “tool” for modelling expert data. The PERT stands for Program Evaluation and Review Technique and stems from 1958 where it was assigned a so-called schedule procedure (Lichtenberg 2000). The PERT is derived from the Beta distribution which mathematically is fairly simple and furthermore covers a huge variety of types of skewness. When used in a Monte Carlo simulation, the PERT distribution can be used to identify risks in project and cost models especially based on the resemblance to the triangular distribution. As with any probability distribution, the usefulness of the PERT distribution is limited by the quality of the inputs: the better your expert estimates, the better results you can derive from a simulation.

Like the triple estimation technique the analyst is only to enter an absolute minimum (min.) and maximum (max.) value. This distribution function resembles the triangular distribution in terms of input and output. However, as shown in Figure 29, the tales receives lesser emphasis and is smoother than the triangular distribution.

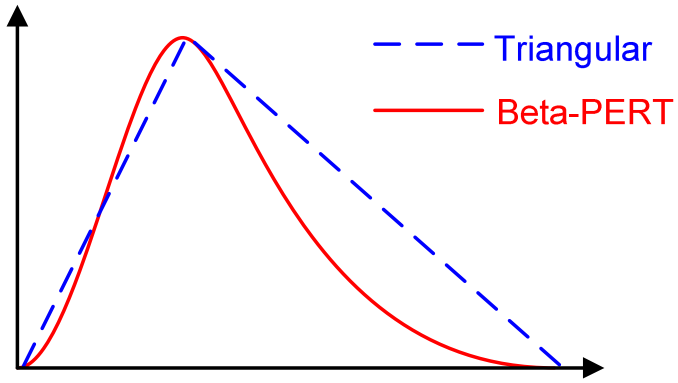


Figure 29. Illustration of the PERT vs. Triangular distribution (Salling & Leleur 2006).

The advantage as illustrated of using a PERT distribution compared with the triangular is the difference in the mean value i.e. (4) and (5):

$$Mean_{Triang} = \frac{Min + Mode + Max}{3} \quad (4)$$

$$Mean_{PERT} = \frac{Min + 4 \cdot Mode + Max}{6} \quad (5)$$

The average of all three parameters in the PERT distribution has got four time the weighting on the mode. In real-life problems we are usually capable of giving a more confident guess on the mode rather than the extreme values hence the PERT distribution brings a much smoother description of the tales of the impacts to be considered (Vose 2000).

Application of the PERT distribution

Demand forecasts or in transport related projects traffic prognosis, lays the basis for calculating travel time savings stemming from transport infrastructure projects. The embedded uncertainty in deriving these forecasts are depending on the time and effort put into data collection and traffic modelling. It is important to distinguish between the uncertainty involved in predicting future traffic flows and the embedded modelling uncertainty corresponding to traffic models. It has been argued that embedded modelling uncertainty corresponds to the inherent randomness of the system whereas the demand forecast typically corresponds to lack of knowledge, as discussed in (Vose 2000; Walker et al. 2003).

Flyvbjerg et al. (2003) made a large-scale data study with regard to the uncertainty of determining future traffic flows. Herein, hundreds of infrastructure projects with regard to traffic demand forecasts were gathered. This study concluded that generally traffic forecasts for road type projects lays within a threshold of ±40% accuracy. They also concluded that generally traffic forecasts with respect to road type projects are underestimated with an average of 9%, however with a relatively high standard deviation on 44%. Secondly, a comparison of 27 rail projects with respect to the inaccuracy for traffic demand forecasts was investigated with an average of 39% lower traffic than predicted (Flyvbjerg et al. 2003, p. 26). The approximated range of demand forecast bias is set between -92% and 144% which correspondingly results in a relatively high standard deviation of 52%.

The Remaining set of distributions

The remaining set of distributions applied in the context of CBA-DK accounts the normal-, triangular- and uniform distributions. These three distribution functions are briefly described in the following with examples of their applicability towards transportation schemes.

The normal distribution

The normal distribution is an extremely important probability distribution in many fields. Some of the most notable qualities of a normal distribution are that it is symmetric around the mean and the mean is also both the mode and median value. It is among others observed that variations of a naturally occurring variable are approximately normally distributed.

The input towards assigning an impact with a normal distribution is shown in Figure 30. In each of the following input boxes with respect to the probability distributions an info and benefit or cost box are shown. The info box gives a brief statement about the input towards the distribution whereas the benefit or cost depicts the impact on the analysis to be carried out. In Figure 30 the user is only to apply a standard (std.) deviation (unless a new mode value is needed). The benefit or cost shows that this impact is working as benefit for the society.

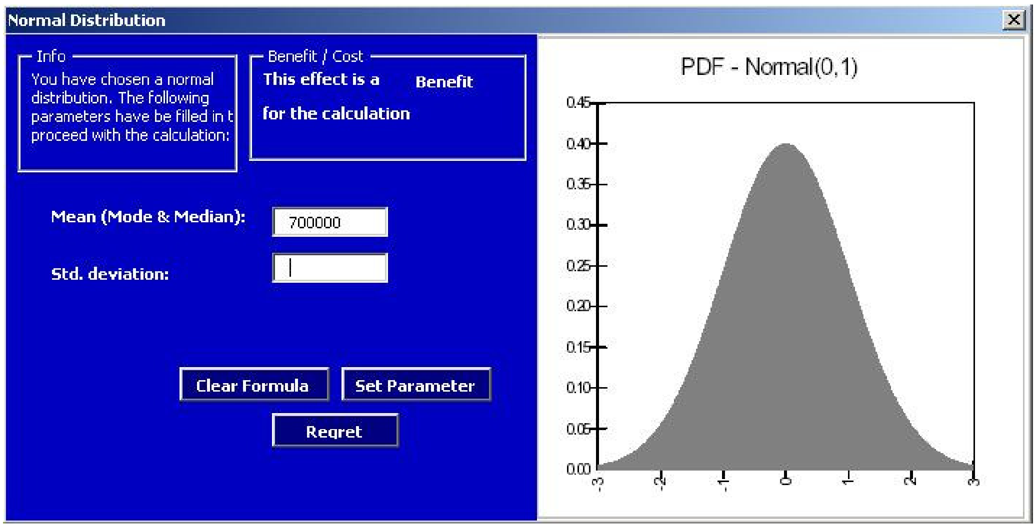


Figure 30. Input to normal distribution.

Generally, the normal distribution is applied within the travel time savings (TTS) effect where studies have been conducted i.e. de Jong et al. (2005) and (Knudsen 2006). The TTS is derived from traffic models and assignment models where several pitfalls arises ensuring uncertainty within the amount of hours saved. A theoretical and practical experiment has been conducted at the department trying to elaborate upon uncertainties within traffic models (Knudsen 2006). The study investigates the travel time savings calculated on basis of traffic models where it is found that the TTS follow a normal distribution where the mean is based upon the net change in hours spent on travelling in the influence area of the road project. However, the study carried out only looks upon a very small sample of resulting TTS and their implied uncertainties. In this relation, the standard deviations with respect to errors or uncertainties within traffic models are very sparse. In addition, the literature shows that empirical values for general standard deviations are very difficult to determine (de Jong et al. 2005).

However, as mentioned before, new research has proven that the PERT-distribution fits the data from demand forecasts under/overruns in which the normal distribution is only applied if knowledge exists with respect to uncertainty in the actual traffic model.

The triangular/trigen distribution

The triangular distribution is typically used as a subjective description of a population for which there is only limited sample data. It is based on knowledge of the minimum and maximum and an inspired guess (referred to as the Most Likely value ML – *mode*). Despite being a simplistic description of a population, it is a very useful distribution for modelling processes where the relationship between variables is known, but data is scarce. The triangular distribution or in an enhanced version; the *Trigen*-distribution, allows the upper and lower boundaries to be skewed (Palisade 2002). The *Trigen*-distribution further offers the analyst the possibility of choosing a confidence interval, where the upper and lower boundaries can be exceeded within a predefined percentage.

The input within CBA-DK follows the PERT and triple estimation technique where a min. and max. value is needed, see Figure 31.

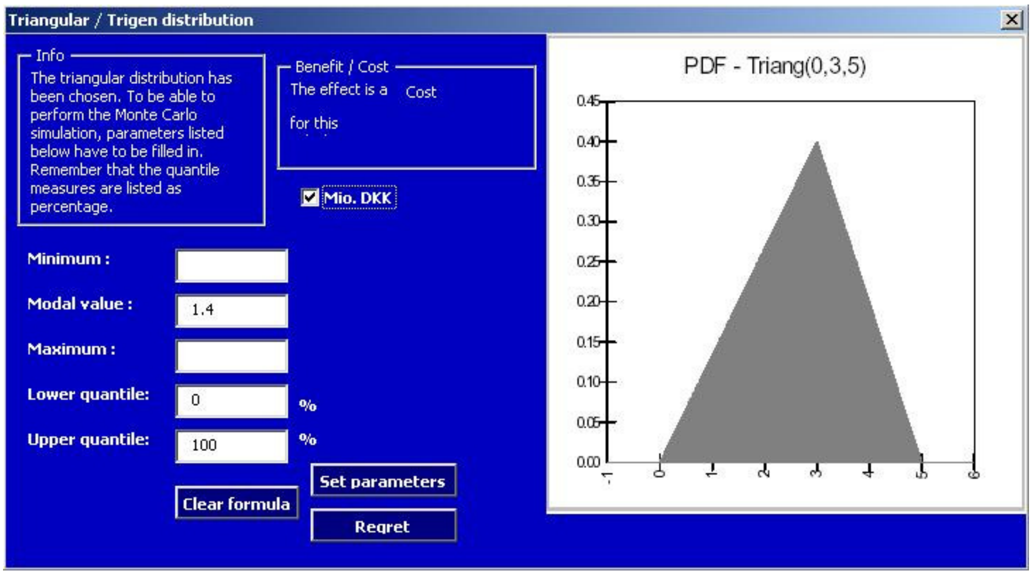


Figure 31. Input to triangular/trigen distribution.

The uniform (rectangular) distribution

The final distribution type is also of the non-parametric form, namely the uniform distribution. This distribution also known as the rectangular distribution is the simplest continuous distribution type. A uniform distribution is one for which the probability of occurrence is the same for all values of *X*. For example, if a fair die is thrown, the probability of obtaining any one of the six possible outcomes is 1/6. Since all outcomes are equally probable, the distribution is uniform.

The input within CBA-DK only needs a min. and max. value, thus it differs from the previous distributions due to the fact that the mode value is not needed, see Figure 32.

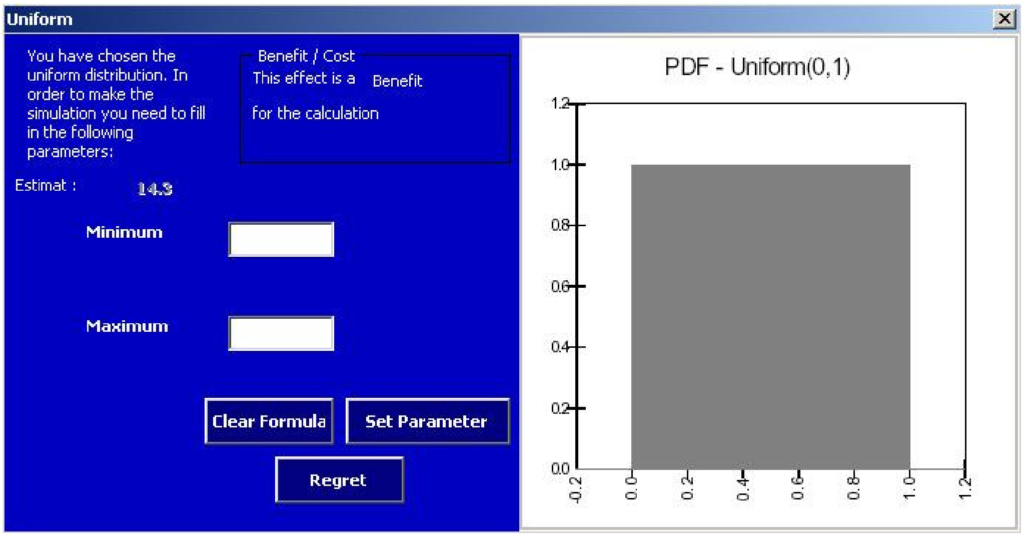


Figure 32. Input to uniform distribution.

The most likely value is depicted in a box below the info, in this case by 14.3. The user can now enter min. and max. statements as needed, however, an error will occur if the mode is not within the boundaries of the min. and max. values.

The two latter distributions are non-parametric which means that they rely heavily on user preferences and input measures. Herein, the final impacts as shown in the entry sheet (Figure 4) is recommended to be modelled by either of the two last distributions.

A fixed run of the CBA-DK model

The Monte Carlo simulation is run by the large button below, *Run Simulation*, see Figure 33.

Figure 33. Possible actions when making a fixed run in the CBA-DK Model.

Beside the run simulation button, the user has got the possibility of emptying all fields or change in the report settings from @RISK. Currently, the default settings applied calculates a histogram and descending accumulated graph (ADG) with respect to the BCR. The report button gives the user possibilities of other outputs such as correlation options, ascending graphs or tornado diagrams (Palisade 2002). Finally, the mode value of the BCR calculated in the cost-benefit analysis is shown below. As soon as the simulation starts, this value changes for each iteration (run) performed.

When the *Run Simulation* is pushed, an automatic pop-up window occurs, as shown in Figure 34.

Figure 34. Pop up window when run simulation is activated.

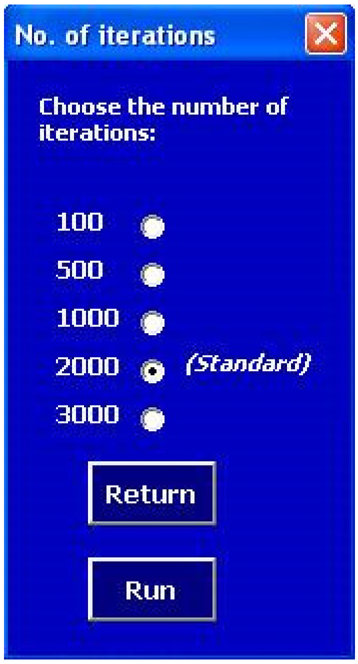


Figure 35. Number of iterations.

It is essential to have installed the @RISK software package before running the simulation. When you once have accepted this notification, the pop-up window will only appear when a new model is assessed.

Secondly, the number of iterations (or runs) has to be chosen. As default the CBA-DK model has 2000 iterations, see Figure 35. The simulation is now started by pushing the *Run* button.

2.10 Results of the Monte Carlo simulation

The results from the uncertainty analysis appear through two graphical representations and one table with empirical values. Currently, the BCR is used for assessing the feasibility risk within a given transportation infrastructure project. The result sheet is shown in Figure 36.

The purpose of the CBA-DK QRA result sheet is to provide the decision-makers with a mean to broaden the information level with respect to achieving a feasible project. Specifically, Figure 36 shows two reports based on @RISK: Histogram showing the most frequent BCR and an accumulated descending graph (ADG) that shows the “certainty” of achieving a certain B/C-ratio or better. Obtaining a probabilistic view of the BCR is especially beneficial when several projects are to be evaluated. The possibility of applying, e.g. different scenarios, evidently by various input parameters creates varying degrees of uncertainty expressed by the steepness of the descending accumulated graph (Leleur et al. 2004).

The feasibility risk to be adopted in the actual case is, of course, up to the decision-makers to debate but the features to deal with uncertainty in the CBA-DK model may help support their considerations. Some of these will be to get acquainted with the various assumptions behind the scenarios, probability distributions, and the way the latter have been assessed/estimated and related to the different scenarios. The resulting ADG illustrated in Figure 36 shows the variation of the BCR with interval results spanning from 0.68 to 1.69. The accumulated graph illustrates the likelihood of achieving a BCR as shown on the vertical axis or a BCR that exceeds that value. A higher degree of certainty corresponds to a lower BCR and visa versa. Note that for the descending cumulative curves with the probability on the y-axis and the rate of return on the x-axis more reliable data will lead to steeper curves.

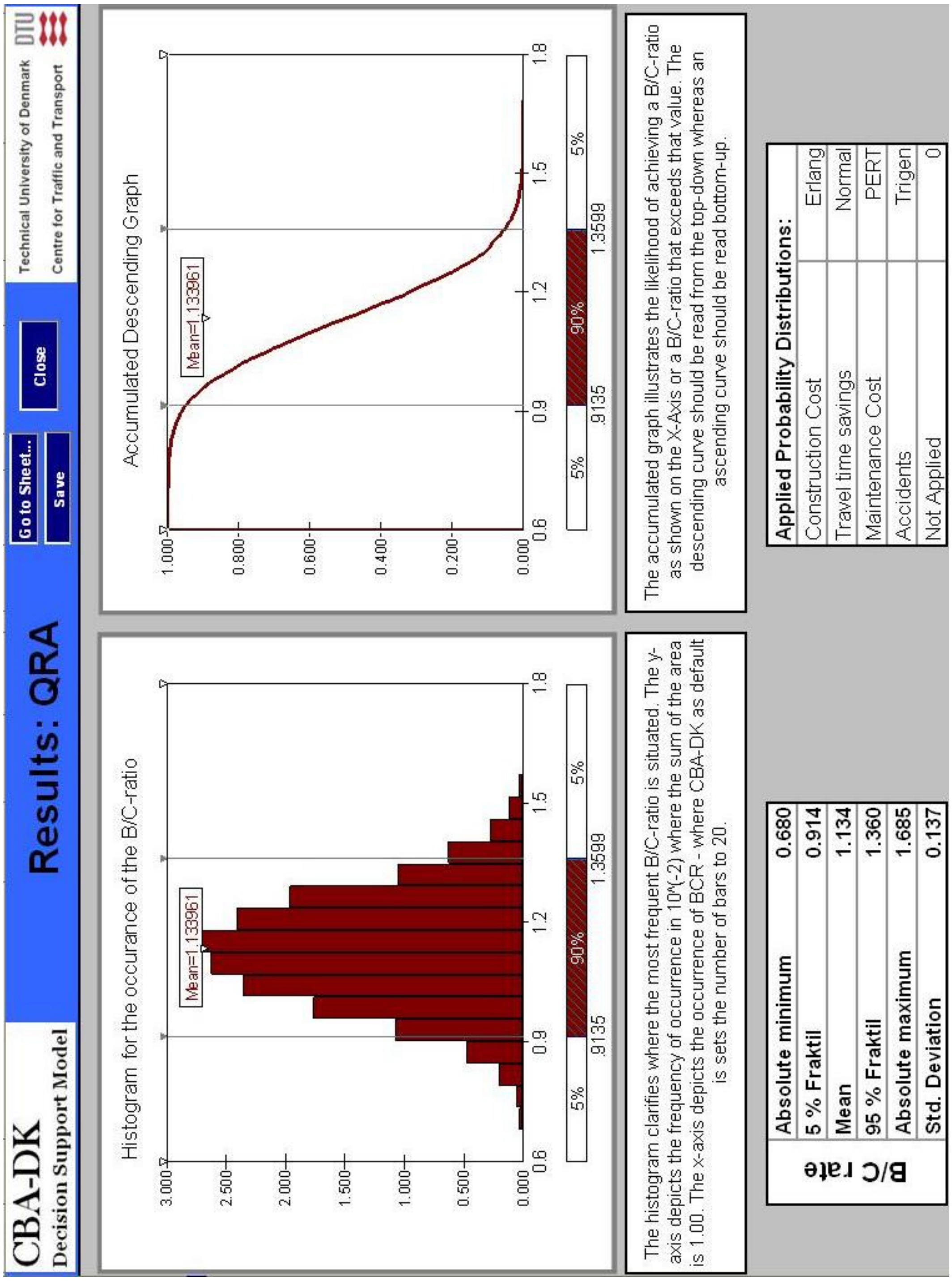


Figure 36. Result sheet from a fixed Monte Carlo simulation in CBA-DK.

2.11 @RISK from Palisade

@RISK from Palisade version 4.5 and 5.0 is add-in products to Microsoft Excel which integrates completely with the spreadsheet (Palisade 2002; 2007). The software relies on quantitative risk analysis seeking to determine the outcome of a given decision situation as a probability distribution. Making an analysis with @RISK can be divided into three steps: Develop and setup the QRA model, identify and simulate the uncertainties and finally, analyze and interpret the model outcome. Version 5.0 was released ultimo 2007, thus, all previous case related calculations are performed using version 4.5. However, the new version has been adapted and implemented in a new case (Salling and Banister 2008).

Setting up the model

The setup of the risk analysis model is made in Figure 26 where all variables and parameters are transferred. In the CBA-module of the CBA-DK model, the most important variables can be determined (deterministically). Conversely, the nature of the variables included in the QRA needs to be described in terms of uncertainty. This is done by the use of probability distributions, which give both the range of values that the variables could take (e.g. minimum and maximum), and the likelihood of occurrence of each value in the given range. A common bias in any model setup is the distinction between independent and dependent variables. The cases presented in the Ph.D. study set out in the papers 1-6 all relies on independent variables. However, @RISK can make the distinction by implementing a correlation matrix ranging from -1 to 1 in values. A value of 0 indicates there is no correlation between the two variables, which is the default value in the CBA-DK model. A value of 1 is a complete positive correlation between the two variables and a value of -1 is a complete inverse correlation (Vose 1996, p. 194).

Sampling methods in @RISK

The two available sampling methods in @RISK is the Monte Carlo sampling and the previously mentioned Latin[30] Hypercube Sampling (LHS) methods. The Monte Carlo sampling is the original and least sophisticated method. It is derived from a uniform distribution [0;1] where a random value x is chosen. This method gives you an equal probability to pick a number in the interval between 0 and 1. The drawback of this sampling method is that there is not any memory assigned. It is possible to choose the same number over and over again, somewhat like a lottery where you pick a ball remembering the number and then place the ball back in the bowl again.

The other sampling method used in @RISK is Latin Hypercube sampling. This method is similar to the Monte Carlo sampling concerning the variation of the distribution area [0;1]. However, in Latin Hypercube sampling there is implemented a memory such that the distortion of a distribution can be taken into account. When sampling with the Latin Hypercube method values with higher probability are chosen before values with a low probability. This method is therefore known as a stratified sampling technique based on the uncertain parameter's probability distribution being divided into equal sized intervals. In this way an interval already chosen is stored in a memory and this interval will not be chosen again. The method "economises" with regard to the number of iterations.

Analyzing the results

Finally, the output variable chosen for simulation i.e. the BCR is determined by a probability distribution. The decision-makers now must interpret this distribution and make their decisions. Traditionally, in a single-valued result the decision-makers would compare the result with a set of minimum requirements or acceptance levels. If the output result is determined to be at least as good as the standards the results would be accepted. However, most often the decision-makers recognizes the uncertainty involved in a single-valued result hence they manipulate their acceptance level in terms of making some allowances for risks. Furthermore, when more alternatives or initiatives are proposed and all exceeds the acceptance level then the analysis is trivial. The decision-makers must on this basis determine if the expected and "best case" value are good enough to

[30] A Latin square is defined where the sample only consists of one value for each row and column hence LHS ensures per definition variation of sampling where the ensemble of random numbers from the input distribution is a "valid" representation.

outweigh the "worst case" value i.e. the "worst expected best" case (Palisade 2007).

The QRA present the output distribution towards the decision-makers with a complete picture of all the possible outcomes. This is a tremendous assistance compared with the above "worst expected best" case considerations. Furthermore, by rigorously defining the associated uncertainty with every input variable an exhausted range of possible outcomes can be determined. The second advantage is the illustration of probability of occurrence, thus, a relative measurement of each possible outcome. The contribution to the decision support can be seen in the shift from the single-valued comparison between desirable outcomes and undesirable outcomes to the recognition that some outcomes are more likely to occur than others.

Ultimately, the risk associated with the analysis is to be interpreted by various decision-makers. The same results given to different individuals may be interpreted differently and lead to different courses of action. Risk averse decision-makers, for instance, prefer a small spread in possible results with most of the probability associated with desirable results. On the other hand, if you are a "risk taker" then you will accept a greater spread or possible variation in you outcome distribution.

Limitations

The quantitative risk analysis that @RISK relies on has gained incredible popularity with decision-makers. Unfortunately, many people have mistakenly assumed that this technique reveals all the correct answers just by pushing the simulation button. It is important to bear in mind that the latter technique is a tool to assist the decision-makers to arrive at the most informative decision. Like any other tools, @RISK can be used to good advantage by skilled practitioners or to create havoc in the hands of the unskilled. It is especially important to keep in mind, that by changing a deterministic variable into a stochastic probability distribution, you just shift the possible errors to make.

Features of @RISK version 4.5 and 5.0

The following small passage describes some of the features of @RISK version 5.0. The new version reminds much about the previous version in which this section easily can be transferred into the cases described within the main report of the Ph.D. thesis.

The major quality of @RISK is that it functions as add-in to Excel which makes it run in almost any given environment. The user is presented with a number of icons in the top bar of Excel and an extra scroll down menu. Figure 37 shows the icon bar of @RISK which is very similar to that of version 4.5.

Figure 37. Features of @RISK version 5.0 embedded within Excel.

Generally, are most of the icons self-explanatory in which guidance is available when pushing the button. Users who need to explore the @RISK software beyond the features embedded within CBA-DK should start by defining the probability distribution that is the top button on the far left. Figure 38 shows an example on how the define distribution function works in a given case example.

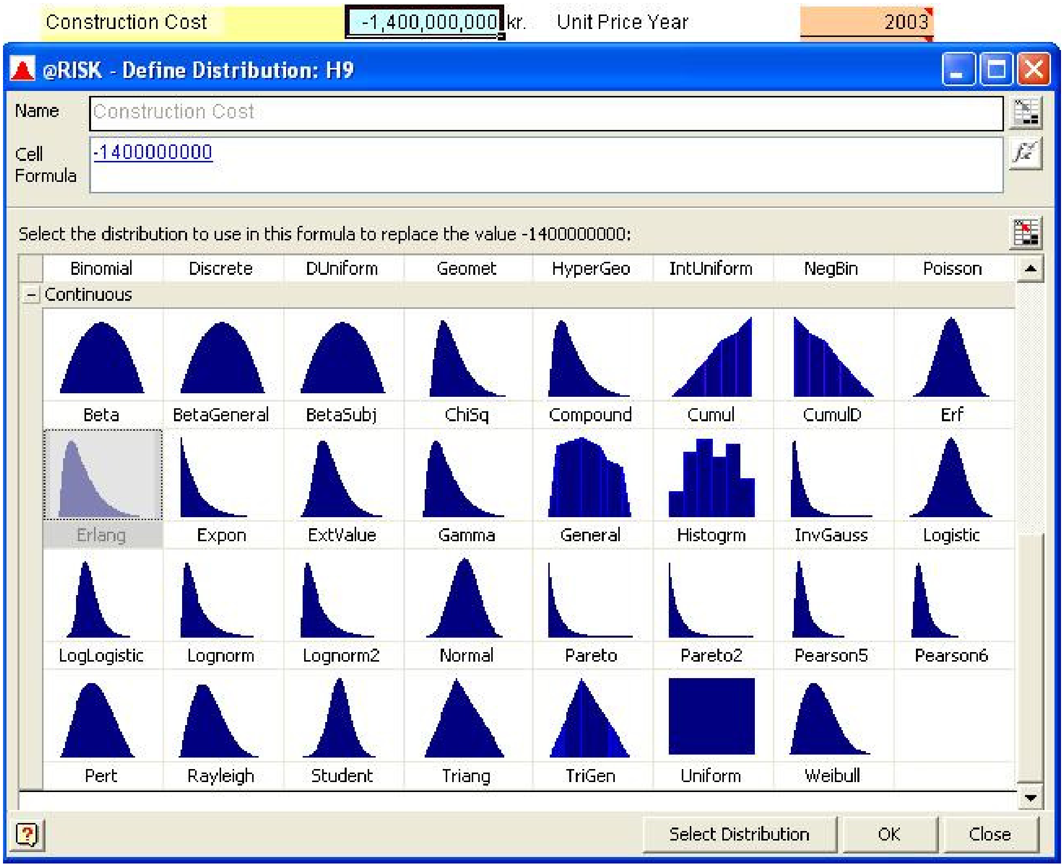


Figure 38. Continuous distribution function palet of @RISK.

It can be seen from Figure 38 that a number of various distributions are embedded within the software program. If the user chooses to accept the Erlang distribution as shown above, Figure 39 appears in which new input parameters are needed in order to make the simulation work. A new feature of the software model is the ability of overlaying two distributions for comparison reasons. This would be relevant for input parameters with low level of knowledge in which two or more distributions could be of relevance. Figure 39 is only illustrated for the example in which an Erlang distribution and PERT distributions is showed.

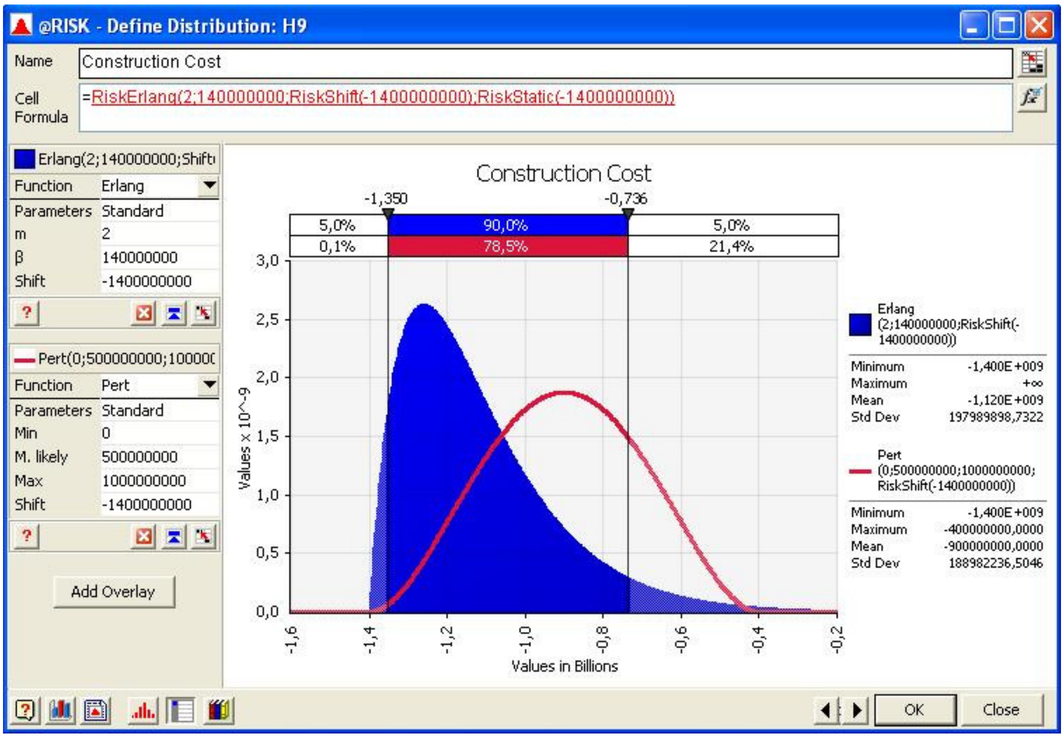


Figure 39. Illustration of possible features when applying the Erlang or PERT distribution.

The following icons are self explanatory in which the second from the left denotes the add output parameter or in other words your output parameter (BCR). Thirdly, you can define possible correlations in which a so-called correlation matrix appears. This feature is currently under development for the CBA-DK model but users who wish to use this function can do so in the @RISK window. The fourth button from the left is the fit distribution icon. In the main report this function is used in order to fit distribution functions onwards empirical data sets from Flyvbjerg et al. (2003). It is only possible to use this feature if the analyst has data available to be analysed. The fifth button from the left is the model window (earlier denoted as the input/output window in version 4.5). Herein @RISK opens a window showing all the applied features in the worksheet that is input distributions and output variables.

The buttom panel of Figure 37 is now to be assessed. The first button from the left is the simulation settings. Herein the user is allowed to change the number of iterations, sampling procedure, result display etc., see Figure 40.

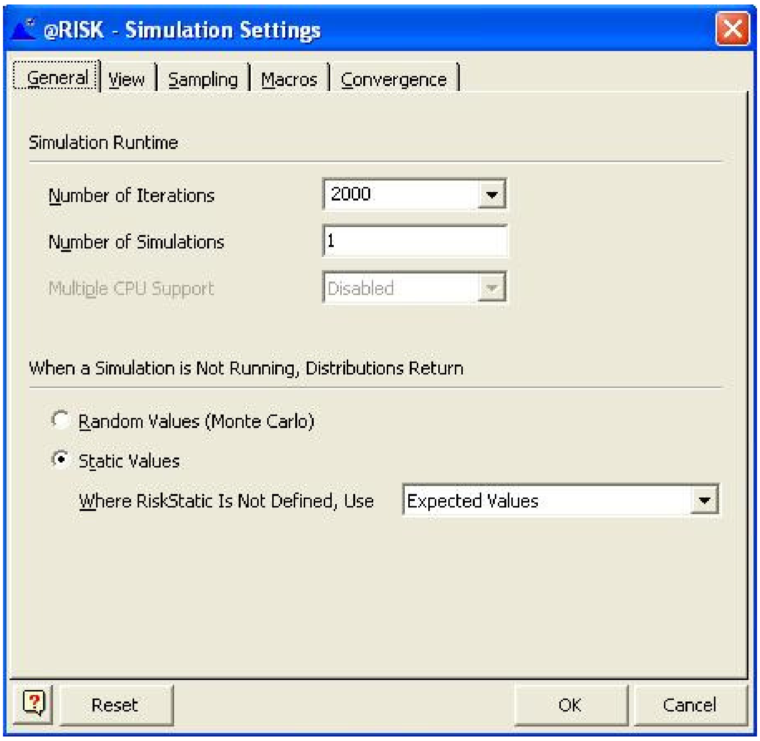


Figure 40. Simulation settings from @RISK.

When the user is finished with the possible changes made it is possible to run the simulation again. This is done by pushing the sixth button from the top in which Figure 41 most often appears (depends on the choice in simulation settings).

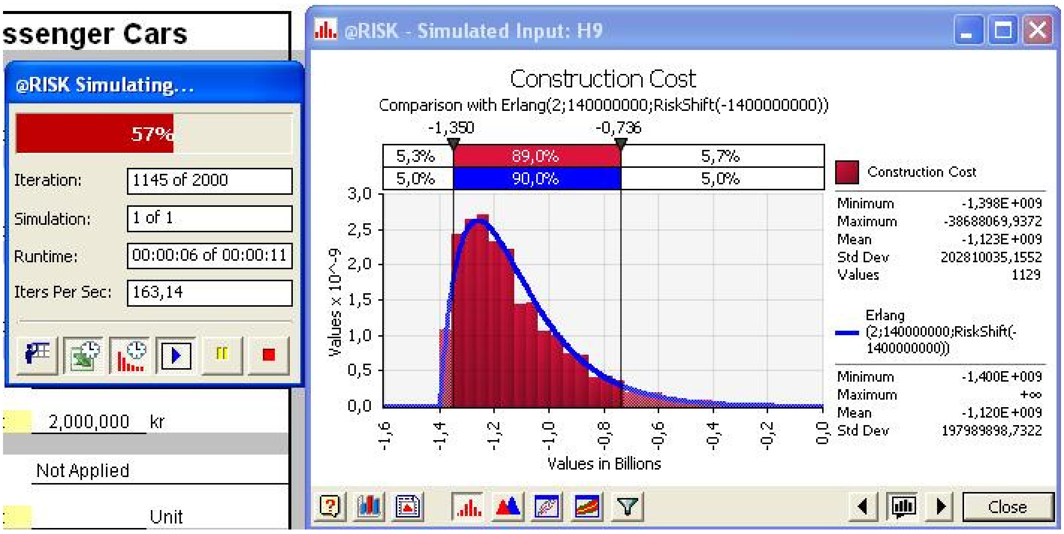


Figure 41. Simulation with 2000 iterations and one input distribution.

Figure 41 shows on the left the performance window in which the run procedure can be followed. Herein the user can see the number of iterations, run time and iterations per second. The illustrated example gives a good impression of the benefits in using Monte Carlo simulation in which an expected runtime for 2000 iterations is only 11 seconds. The window on the right depicts how well the simulation performs compared with the mathematical function. Each iteration is recorded and illustrated as bars whereas a curve is fitted onwards.

Finally, the output results summary window can be assessed in which Figure 42 appears.

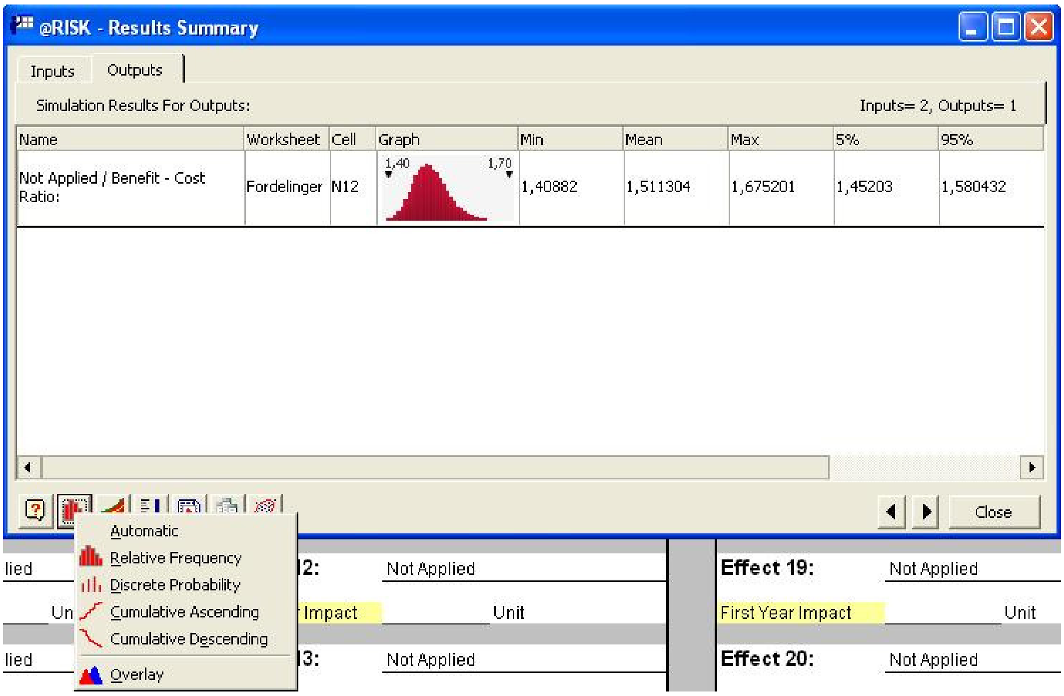


Figure 42. Output summary window from @RISK.

From this window the user is able to create numerous output statistics and graphs suitable for the needs required. The CBA-DK makes use of the accumulative descending graph which has been embedded as the output from the model. Furthermore, different functions exist such as tornado graphs where quantiles are depicted for the output parameter.

3. Summary

Building customized decision support models has turned out to be a challenging task. This documentation report has been created to assist users or analysts in customizing their needs and hereby translating "virtual" matters into organized variables. The CBA-DK decision support model has been designed to bring informed decision support towards decision-makers. The model makes use of conventional cost benefit analysis based upon manual work set-out by the Danish Ministry of Transport. The final evaluation criteria is determined by aggregated single point values in terms of net present values, internal rate of returns and benefit cost rates (BCR). These aggregated point results depicts in many ways a most likely (mode) value for the respective project. By implementing quantitative risk analysis to comprehend with the various model and pricing uncertainties embedded within the analyses, interval results is produced.

These interval measures corresponds to the decision-makers risk aversion or preference towards the given project alternative and its feasibility. The way the latter has been applied is by the use of Monte Carlo simulation where different input probability distributions have been assigned pre-determined input parameters such as construction costs and time savings. A large concern with respect to the CBA-DK model has been to assign relevant and trustworthy distributions covering the uncertainty in the best possible manner. Literature and conference attendance has clarified some issues relevant in choosing the most optimal distribution. Furthermore has the UK Department for Transport introduced so-called Optimism Bias uplifts within transport project evaluation where construction cost estimates are uplifted in the range between 15% and 45% corresponding to the risk aversion of the decision-makers.

In the context of this documentation report, the CBA-DK model is facing new implementation schemes in order to verify and validate the model. Currently the model does not handle inter-dependencies (correlations) between one or more variables. Especially, as concerns external effects does the modelling framework lack the prospect of correlations. However, the recent publication of @RISK version 5.0 allows for more in depth analyses of the latter including the possibilities of making best fit probability distributions on past data sets.

References

Back, W. E., Boles, W. W. & Fry, G. T. (2000). Defining Triangular Probability Distributions from Historical Cost Data. *Journal of Construction Engineering and Management*, Vol. 126, No. 1: 29-37.

Banister D. and Berechman J. (2000). *Transport Investment and Economic Development*. UCL Press, London, United Kingdom.

Danish Ministry of Transport (2003). *Manual for socio-economic analysis – applied methodology in the transport sector*. Copenhagen, Denmark (in Danish).

Danish Ministry of Transport (2004). The socio-economic analysis – case studies, illustration of the procedure in a socio-economic analysis. *Technical Report*, Copenhagen, Denmark (in Danish).

Danish Ministry of Transport (2006). *Key Figure Catalog for use in socio-economic analysis on the transport area*. Revised June 2006, Copenhagen, Denmark (In Danish).

De Jong, G., Pieters, M., Miller, S., Daly, A., Plasmeijer R., Graafland, I., Lierens, A., Baak, J., Walker, W. & Kroes, E. (2005). Uncertainty in traffic forecasts: literature review and new results for the Netherlands. *Working Paper* prepared for AVV Transport Research Centre - RAND Europe.

DTU-Transport and COWI Consult (2008). Transport Economical unit prices – for socio-economic analyses version 1.0. Deparment of Transport, Technical University of Denmark, February 2008 (in Danish).

Flyvbjerg, B., Bruzelius, N. & Rothengatter, W 2003. *Megaprojects and Risk – An anatomy of Ambition*. Cambridge University Press, United Kingdom.

Knudsen, M. A. (2006). Evaluation of uncertainty in traffic models – a theoretical and practical analysis of the Naestved model, *Master Thesis*, Technical University of Denmark, Lyngby (In Danish).

Leleur, S. (2000). *Road Infrastructure Planning – A Decision-Oriented Approach*. 2nd Edition, Lyngby: Polyteknisk Press, Denmark.

Leleur, S., Holvad, T., Salling, K. B. & Jensen, A. V. (2004). ”Development of the CLG-DSS Evaluation Model”, *Midterm Report*, Centre for Logistics and Goods Transport (CLG) at CTT-DTU, April 2004.

Lichtenberg, S. (2000). ”*Proactive Management of Uncertainty using the Successive Principle*”. Polyteknisk Forlag, Lyngby, Denmark.

Palisade (2002). “*@RISK version 4.5 - advanced risk analysis for spreadsheets*”. Palisade Corporation.

Palisade (2007). *“@RISK version 5.0 - advanced risk analysis for spreadsheets*”. Palisade Corporation, NY USA.

Rosenstand, K. (2007). A socio-economic analysis of the road connection between Sisimiut and Kangerlussuaq with a special emphasis on construction cost and uncertainty. *Master Thesis*, Technical University of Denmark (in Danish).

Salling, K.B. (2003). The socio-economic consequences of the Øresund Fixed Link – an ex-post study. *Master Thesis*, Centre for Traffic and Transport, Technical University of Denmark (in Danish).

Salling, K.B. (2006). Calculating the Net Taxation Factor and Tax Distortion in Denmark. *Unpublished note available with the software solution of CBA-DK version 1.0*, Centre for Traffic and Transport, Technical University of Denmark.

Salling, K.B. & Leleur, S. (2006). Transport Appraisal and Monte Carlo Simulation by use of the CBA-DK Model. Proceedings of the WSC ’06, Monterey, CA-USA, submitted for publication in *Transport Policy.*

Salling, K.B., Leleur, S. & Jensen, A.V. (2007). Modelling Decision Support and Uncertainty for Large Transport Infrastructure Projects: The CLG-DSS Model of the Øresund Fixed Link. *Decision Support Systems*, Vol. 43, issue 4, 1539-1547, Elsevier.

Salling, K.B. & Banister, D. (2008). Assessment of large transport infrastructure projects: the CBA-DK model. *Accepted for presentation* at the International Conference on Infrastructure Systems (NGInfra), Rotterdam, the Netherlands, November 2008.

Vose, D. (1996). ”*Quantitative Risk Analysis: A Guide to Monte Carlo Simulation Modelling*”. John Wiley & Sons.

Vose, D. (2000). *Risk Analysis – a quantitative guide*. 2nd ed., John Wiley and Sons, London, UK.

Walker, W.E., Harremöes, P, Rotmans, J., Van Der Sluijs, J.P., Van Asselt, M.B.A., Janssen, P. and Krayer Von Krauss, M.P. (2003). Defining Uncertainty –

A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Journal of Integrated Assessment*, Vol. 4, No. 1 pp. 5-17, Swets & Zeitlinger.

Wilmot, C. G. & Cheng, G. (2003). Estimating Future Highway Construction Costs. *Journal of Construction Engineering and Management*, Vol. 129, Issue 3, pp 272-279.

The Department performs research and provides education on traffic and transport planning. It advises the Danish Government's Departement for Transport on infrastructure, economic appraisals, transport policy and road safety and collects data on the transport habits of the population. The Department collaborates with companies on such topics as logistics, public transport and intelligent transport systems.

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