MODELLING OF TRANSPORT PROJECT UNCERTAINTIES: RISK ASSESSMENT AND SCENARIO ANALYSIS

Kim Bang Salling[(a)], **Steen Leleur**[(b)]

[(a), (b)] Department of Transport
Technical University of Denmark (DTU)
Build. 115, DTU, DK 2800 Kgs. Lyngby
Denmark
[(a)]kbs@transport.dtu.dk, [(b)]sl@transport.dtu.dk

ABSTRACT

This paper proposes a new way of handling the uncertainties present in transport decision making based on infrastructure appraisals. The paper suggests to combine the principle of Optimism Bias, which depicts the historical tendency of overestimating transport related benefits and underestimating investment costs, with a quantitative risk analysis based on Monte Carlo simulation and to make use of a set of exploratory scenarios. The analysis is carried out by using the CBA-DK model representing the Danish standard approach to socio-economic cost-benefit analysis. Specifically, the paper proposes to supplement Optimism Bias and the associated Reference Class Forecasting (RCF) technique with a new technique that makes use of a scenario-grid. We tentatively introduce and refer to this as Reference Scenario Forecasting (RSF). The final RSF output from the CBA-DK model consists of a set of scenario-based graphs which function as risk-related decision support for the appraised transport infrastructure project.

Keywords: decision support, risk analysis, reference class forecasting, reference scenario forecasting

1. INTRODUCTION

This paper sets out a new methodology for examining the uncertainties relating to transport decision making based on infrastructure appraisals. The approach proceeds by combining the principle of Optimism Bias, which depicts the historical tendency of overestimating transport related benefits and underestimating investment costs, with a quantitative risk analysis based on Monte Carlo simulation and by using a set of exploratory scenarios. The analysis is carried out by using the CBA-DK model representing the Danish standard approach to socio-economic cost-benefit analysis. Specifically, the paper proposes to supplement Optimism Bias and the associated Reference Class Forecasting (RCF) technique with a new technique that makes use of a scenario-grid. We tentatively introduce and refer to this as Reference Scenario Forecasting (RSF).

The paper is disposed as follows. In Section 2 a description is given of Optimism Bias and Reference Class Forecasting. Section 3 presents the applied Greenland case study and the calculations carried out in the CBA-DK model together with a set of altogether nine scenarios. For one of the scenarios, the Reference Scenario 5, the input probability distributions based on RCF are described and the results from a model run are given. In the following Section 4 the principles of Reference Scenario Forecasting are presented and illustrated by a set of model runs. These RSF results consist of a set of scenario-based graphs which function as risk-related decision support for the appraised transport infrastructure project. The final Section 5 gives a conclusion and a perspective on the further research.

2. OPTIMISM BIAS AND REFERENCE CLASS FORECASTING

The Optimism Bias approach is dealt with by using a well-established technique named Reference Class Forecasting (RCF). The theoretical background is made up by prospect theory developed by Kahneman and Tversky in 1979 (Daniel Kahneman received the Nobel prize in Economics in 2002 for his work in collaboration with Amos Tversky (1937-1996)). Prospect theory describes decisions between alternatives that involve risk, i.e. alternatives where the general outcome is uncertain but the associated probabilities are known. 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 and COWI 2004).

Reference Class Forecasting is established on the basis of information from a class of similar projects. The classification of reference classes have been explored in Flyvbjerg and COWI (2004), pp. 13-14, where three main groups of projects has been statistically tested for similarities, namely roads (highways and trunk roads), rail (metro, conventional rail and high speed rail) and fixed links (bridges and tunnels). Hence, RCF does not try to forecast specific uncertain events that will affect the particular project, but instead it places the project to be evaluated in a statistical distribution of outcomes from this class of reference projects. Flyvbjerg et al. (2003) have built a large pool of reference class projects divided into three types of transport-related infrastructure investments, namely road, rail and fixed links projects. From the latter Salling (2008) has performed a data analysis uncovering a set of probability distributions that fit the data from Flyvbjerg et al. (2003) associated with transport infrastructure assessments see Table 1.

Table 1: Fitted distributions from Salling (2008)

Impact	**Distribution**
Travel time savings	Beta-PERT
Construction costs	Erlang

The two distributions depicted in Table 1 have been fitted against reference class projects concerning travel time savings (traffic demand forecasts) and construction costs. These two impacts make up the key components in most transport evaluation schemes (Leleur 2000), for which reason the following case study applies these distributions for a risk assessment study in Greenland.

3. THE GREENLAND CASE STUDY

The paper makes use of information comprised in Leleur et al. (2007), Salling (2008) and Salling and Banister (2009) in which an examination of a new international airport in Nuuk is presented by three project alternatives. These consist of two alternatives replacing the existing runway in Nuuk, i.e. increasing the current runway length to either 1799 metre (m) or 2200m, and as the third alternative the construction of a new, relocated airport to the south with a 3000m runway, consequently leading to a closing of the existing airport. Results from this study clearly pointed towards either of the two extension alternatives leaving the Nuuk 3000m alternative infeasible from a societal perspective. Finally, an article posted on the website of the Home Rule Authorities in Greenland, October 2007 outlined that the Nuuk 2200m alternative has been selected for implementation (Kristensen 2008). In light of this information, this paper examines the robustness of this decision based on combining a set of scenarios with risk analysis.

3.1. The CBA-DK Model

The CBA-DK model combines deterministic calculation based upon conventional cost-benefit analysis (CBA) with a stochastic calculation based on a quantitative risk analysis (QRA). This model is in accordance with the socio-economic analysis guidelines provided by the Danish Ministry of Transport (DMT 2003). It 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 which implements a standardized Monte Carlo simulation (Palisade 2007; Salling 2008). The deterministic calculation from CBA-DK produces the following decision criteria for the Nuuk case as shown in Table 2.

Table 2: Decision criteria from a deterministic CBA model run for Nuuk 2200m (Salling and Banister 2009)

Construction costs	1,059 MDKK
Benefit cost ratio (BCR)	2.5
Internal rate of return (IRR)	13.8%
Net present value (NPV)	1,706 MDKK
First year rate of return (FYRR)	19.8%

These criteria values show clearly that the 2200m alternative produces very good societal results with a significantly higher NPV (1€ ≈ 7.5 Danish Kroner (DKK)). However, the results only depict one set of possible outcomes. To provide strategic decision support the CBA-DK model is used on a set of exploratory scenarios that express external economic factors e.g. a deregulation regime combined with a specific socio-geographic development e.g. Nuuk getting higher importance as centre.

3.2. Scenarios

The scenarios in this study have been set up with respect to two main types of regimes: Three global regimes which deal with the overall international economic development and three regional/local regimes describing the future importance of Nuuk as centre

Global economic development

Nuuk importance as centre and regional growth pole in Greenland

	Deregulation	Regulation	Stagnation
Clearly higher	Sc. 1	Sc. 4	Sc. 7
Moderately higher	Sc. 2	**Ref sc. 5**	Sc. 8
Same	Sc. 3	Sc. 6	Sc. 9

Increasing uncertainty →

Increasing uncertainty ↑

Figure 1: Scenario-grid for imagined futures representing possible and plausible development

(adapted from Leleur et al. 2004). The regimes vary as depicted in Figure 1 where the horizontal axis outlines the global economic development and the vertical axis outlines the importance of Nuuk as centre and regional growth pole in Greenland. Uncertainty tendencies as relating to the regimes have also been indicated.

Altogether nine scenarios have been formulated, which are expected to have different influences on the feasibility of the Nuuk airport investment. The set of scenarios is expressing a range of possible and plausible developments, each of which could prevail as the context of the appraisal study. The influences are discussed below relating these both to the deterministic and stochastic CBA-DK calculations.

3.3. Reference scenario 5

To enhance the understanding of the uncertainties involved a Monte Carlo simulation is performed (Vose 2002; Salling 2008). Selecting appropriate probability distributions to acknowledge the embedded impact uncertainties presents the critical part of this calculation procedure. As previously presented in Table 1 two underlying transportation impacts are implemented in terms of an Erlang distribution and a Beta-PERT distribution.

3.3.1. Construction costs (Erlang distribution)

Construction costs for large infrastructure projects have a tendency to be underestimated, which means that socio-economic analyses become overoptimistic. These misinterpretations of ex-ante based costs, deliberate or otherwise, result in budget overruns. From the data derived from Flyvbjerg et al. (2003) a sample collection of 57 rail type projects revealed that 88% of the infrastructure projects experienced costs overruns. It has been assumed that the empirical results from rail projects can be applied to airport infrastructure projects. In the database no separate section on airport infrastructure projects was available but rail projects were judged to be the most suitable project class. Thus, the dataset as concerns rail infrastructure projects resulted in input parameters towards the Erlang distribution with a shape parameter of 9 and a scale parameter estimated on the data set (Lichtenberg 2000; Salling and Banister 2009). The worst observation from the data sample, with a cost overrun of 100% has been used as upper limit while a best case observation, cost underrun, occurred with -15% as a lower limit. In this context, a cost overrun of 100% means that the ex-ante based construction cost estimate in reality was exceeded by 100%.

3.3.2. Travel time savings (PERT distribution)

Typically, travel time savings are calculated on basis of current traffic flows provided by a traffic and forecast model. Hereby, future traffic flows are determined based upon a forecast rooted in e.g. past data information, expert judgments, empirical evidence, etc. However, such a futuristic demand forecast is extremely troublesome to make (Priemus et al. 2008). The same data material reveals a comparison between 27 rail projects depicting the inaccuracy for traffic demand forecasts. The overestimation of demand forecast, and hereby mis-calculations in terms of travel time savings, occurs in almost 85% of the cases. The worst observation from the data sample, with a demand underrun of -95% has been used as lower limit while a best case observation, with a demand overrun, occurred with 75% as an upper limit. In this context, a demand underrun of -95% means that the ex-ante developed forecast was under-exceeded by 95%.

3.3.3. Results

The CBA-DK model provides the deterministic point results as illustrated in Table 2 including a stochastic calculation which enhances the point results into interval results allowing for the decision-makers to explore their risk aversion towards the appraised scheme. The latter is performed through a Monte Carlo simulation with the Optimism Bias based input. The results of the focal reference scenario 5 are presented as an accumulated descending graph (ADG), see Figure 2. The shown ADG delivers information with regard to the probability of achieving a BCR higher than or equal to the x-axis value. Hence, the ADG is important as a means to involve decision-makers and support strategic decision-making based upon their revealed risk aversion.

The ADG pictured in Figure 2 shows that for approximately 80% of the cases the reference scenario 5 gives a feasible result with the BCR > 1.0. However, decision-makers with risk aversion would probably take into account that in 20% of the simulation runs scenario 5 gives an infeasible result.

The remaining 8 scenarios take the basis from the focal reference scenario 5. By using the two different types of regimes, the input parameters for the two probability distributions are set according to an assessment of the uncertainties as they are perceived under the specific scenario. This is carried out by using the principles of Reference Scenario Forecasting (RSF) as outlined below.

4. REFERENCE SCENARIO FORECASTING

In order to operationalise the use of scenarios in CBA-DK the previous technique of Reference Class Forecasting based on the Optimism Bias has been combined with Monte Carlo simulation and scenario analysis.

The reference scenario 5 will form the basis (focal scenario) for RSF and the related 8 scenarios will be set by assessing the development in expected travel time related benefits. It has been assumed that in the actual case the construction cost effect is independent of the regimes, for which reason the input parameters to the Erlang distribution remain as presented in section 3.2.1.

The travel time savings, however, will no doubt change as a consequence of the economic development. Clearly, deregulation and high economic growth will mean more people that travel both as tourists, residents

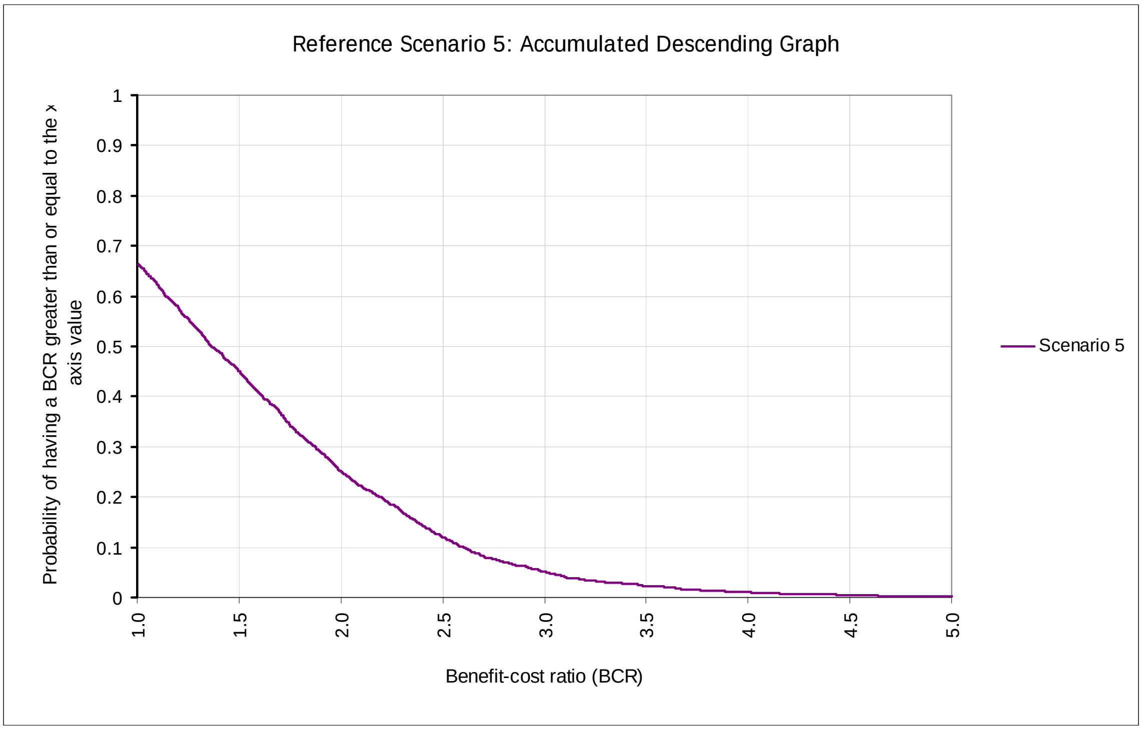

Figure 2: Resulting accumulated descending graph (ADG) for the focal scenario 5: the y-axis values for BCR = 1.0 indicate the certainty levels of the scenario

and business travellers. The opposite tendency will turn out in the case of stagnation or financial crisis. All trips will then be at a minimum and the travel time savings effect will decrease due to the lower passenger number.

The variation between scenarios is systematically explored and related to the scenario-grid (Figure 1). The specific scenario input concerning the Beta-PERT distribution is assessed by making use of the triple estimation technique in a “backward way” compared to its intended use (Lichtenberg 2000) and by anchoring its initial parameter-setting with the values for the focal scenario 5.

4.1. Triple values for the focal scenario 5

The main idea of Reference Scenario Forecasting is based on assessing the most likely (ML), the maximum (MAX) and the minimum (MIN) values under the various scenario conditions. The assessment is carried out based on knowledge of these values under the focal scenario 5, where the triple set values have been determined as follows with all values in mio DKK (1):

$$(MIN5, ML5, MAX5) = (10, 170, 300) \qquad (1)$$

The assessment is based on this anchoring information being available and interpreting how the values will change under the changed scenario conditions. The importance of anchoring information has been treated by Goodwin and Wright (2004, pp. 309-325), while the value of using triple estimates for exploring uncertainty has been examined by Lichtenberg (2000, pp. 119-132) and Vose (2002, pp. 272-278). In the following we will exemplify some of the deliberations that have been used of to set the values shown in Table 3.

4.2. Triple values for scenario 2, 4, 6 and 8

In scenario 2 optimism in the global economy and deregulation lift the ML5 value to ML2 = 220 mio DKK. At the same time uncertainty is perceived to be decreasing, as indicated in Figure 1, which gives a higher MIN-value and a higher MAX-value. Hereby we obtain the following triple set for scenario 2 in mio DKK (2):

$$(MIN2, ML2, MAX2) = (50, 220, 330) \qquad (2)$$

More or less the same tendency occurs with respect to Scenario 4 where the importance of Nuuk as a centre is growing. However, the uncertainty is increasing compared to the focal scenario 5, leaving the MIN5 more or less unchanged but giving a clearly higher MAX-value. Hereby, we obtain the following triple set values for scenario 4 in mio DKK (3):

$$(MIN4, ML4, MAX4) = (25, 200, 350) \qquad (3)$$

The triple values for Scenario 8 are derived by taking into account that the global economy is stagnating, which leads to increasing uncertainty and a lower assessment of ML8 to 145 mio DKK. It has been assumed that the benefits from the travel time savings cannot be lower than 0 (lower boundary). In this way the following triple set has been arrived at for scenario 8 in mio DKK (4):

$$(MIN8, ML8, MAX8) = (0, 145, 300) \qquad (4)$$

Finally, the triple set for scenario 6 is assessed based on the uncertainty being lower than under the conditions in the focal scenario. Nuuk as centre and growth pole is the same as today with a regulated regime. Thus, ML6 is lowered to 150 mio DKK with the following set of MIN and MAX values in mio DKK:

$$(MIN6, ML6, MAX6) = (10, 150, 285) \qquad (5)$$

4.3. Triple values for the remaining scenarios

The remaining four scenario values have been found by using the triple sets assessed for scenario 2, 4, 6 and 8. As depicted in Figure 1, the highest uncertainty relates to scenario 7, while the most certain scenario is scenario 3. Table 3 shows the outcomes of the assessment of the nine scenarios from Figure 1 with the triple values in absolute terms (mio DKK).

Table 3: Summary of the triple values applied for the Reference Scenario Forecasting (mio DKK)

Scenario	**MIN**	**ML**	**MAX**
Scenario 1	50	250	400
Scenario 2	50	220	330
Scenario 3	25	175	325
Scenario 4	25	200	350
Scenario 5	**10**	**170**	**300**
Scenario 6	10	150	285
Scenario 7	0	170	315
Scenario 8	0	145	300
Scenario 9	0	100	250

In this context the triple values for the different scenarios have been set in accordance with discussion amongst the authors and mainly for the purpose to illustrate the approach of RSF. In a real-world application the values should be set by people with a thorough knowledge (stakeholders) of the project examined based on their assessment of the conditions that may influence them.

Consequently, a future task in this respect is to implement the use of a decision conference (DC) as part of the RSF approach. Essentially, a DC brings together decision analysis, group processes and information technology over an intensive two or three day session (Goodwin and Wright 2004, pp. 323-325). The DC makes it possible for the various stakeholders relating to the specific decision task to affect the course of action. Principally, a decision conference involves a set of stakeholders with all different perspectives towards the problem represented. For this demo-case, stakeholders could be representatives from the Home Rule authorities in Greenland, people from the Municipality of Nuuk, aviation experts, economists, etc. Their main challenge is to produce the triple set values under the different scenarios based on their knowledge and their assessment of the scenario conditions. Hereby the set of triple estimates in Table 3 may be changed into more realistic values.

4.4. RSF results for the Greenland case

Model runs in CBA-DK making use of the values in Table 3 produce 8 additional accumulated descending graphs (ADGs), see Figure 3.

The main output from the RSF is that none of the scenarios produces an ADG with 100% probability of achieving a BCR above 1.00. Scenario 1 returns a 95% certainty level that the Nuuk 2200 meter alternative is feasible whereas scenario 9 returns a 45% certainty

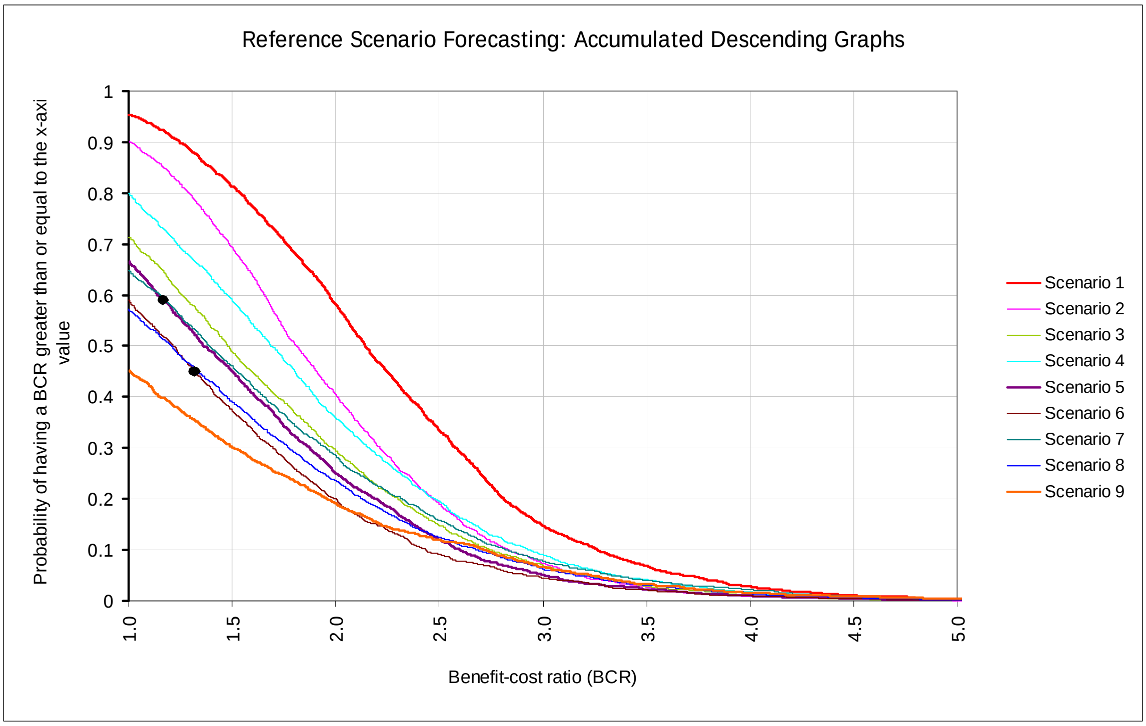

Figure 3: Resulting accumulated descending graphs (ADGs) from Reference Scenario Forecasting: the y-axis values for BCR = 1.0 indicate the certainty levels of the scenarios

level. Attention could be paid to scenario ADGs that intersect each other. Thus, scenario 8 crosses scenario 6 at a 46% threshold whereas scenario 7 crosses the reference scenario at 60%. Furthermore it can be noted that the flatness of the ADG corresponds to the degree of uncertainty assigned each scenario, i.e. a flatter ADG depicts a higher uncertainty.

Risk aversive decision-makers would probably accept the project under scenario 1, 2 and 3, where less risk aversive decision-makers would also include scenarios 4, 5 and 7. Under the condition of scenario 9 the project will probably not be accepted whereas scenarios 6 and 8 are more difficult to interpret. A next step towards a decision could be to estimate the probability of each scenario to get closer to a final decision. We foresee that making use of a decision conference will help qualifying the deliberations of the involved decision-makers.

5. CONCLUSION AND PERSPECTIVES

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 paper 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 appraisal 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.

By combining Optimism Bias and Monte Carlo simulation, the CBA-DK model makes a more explicit consideration of risk possible as concerns the probability of implementing a non-feasible project or for that sake of not implementing a feasible one. The concept of Reference Scenario Forecasting (RSF) has been introduced as a possible way of making operational use of scenarios, and its principles have been demonstrated by applying a case study from Greenland.

Altogether nine scenarios have been set out and assessed resulting in a set of graphs illustrating the influence on the appraisal result. These graphs allow the decision-makers to debate and decide on the basis of a risk-oriented feasibility approach within transport infrastructure appraisal. Currently, this new RSF approach uses two main types of regimes leading to the robustness valuation of the appraisal result. Further research will explore the application of more refined scenario descriptions with additional scenario information and the formulation of a decision conference set-up with the purpose of estimating the triple set values under the different scenario conditions.

In an ongoing research project about "Uncertainties in transport project evaluation" 2009-2012, funded by the Danish Strategic Research Council, the presented methodology will be further developed.

REFERENCES

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, United Kingdom.

Flyvbjerg, B. and COWI Consult, 2004. Procedures for Dealing with Optimism Bias in Transport Planning. *Guidance Document*, prepared for the British Department for Transport, United Kingdom.

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

Kahneman, D. and Tversky, A. 1979. Prospect Theory: An Analysis of Decision under Risk. *Econometrica*, 47 (2), 263-292.

Kristensen, K., 2007. *Atlantic airport in Nuuk saluted*. Home Rule Authority, Greenland. Available from: http://sermitsiaq.gl/indland/article19110.ece [accessed 14 November 2008]

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

Leleur, S., Holvad, T., Salling, K.B. and Jensen, A.V., 2004. Development of the CLG-DSS Evaluation Model, *CLG-Report task 9*, Centre for Traffic and Transport, Technical University of 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 (in Danish).

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

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

Priemus, H., Flyvbjerg, B. and Wee, B. van, 2008. *Decision-making on Mega-Projects: Cost-Benefit Analysis, Planning and Innovation.* Transport Economics, Management and Policy, General Editor: Kenneth Button, George Mason University, USA.

Salling, K.B., 2008. *Assessment of Transport Projects: Risk Analysis and Decision Support*. Thesis (PhD), Department of Transport, Technical University of Denmark.

Salling, K.B. and Banister, D., 2008. Assessment of large transport infrastructure projects: the CBA-DK model. *Proceedings of the International Conference on Infrastructure Systems*. November 10-12, Rotterdam, the Netherlands.

Vose, D., 2002. *Risk Analysis – a quantitative guide*. 2nd ed., John Wiley and Sons, United Kingdom.

BIBLIOGRAPHY

KIM BANG SALLING is currently employed as an assistant professor at the Department of Transport at the Technical University of Denmark. He defended his PhD thesis entitled: *Assessment of Transport Projects: Risk Analysis and Decision Support*, November 2008. He furthermore holds a Master's degree in Engineering within socio-economic evaluation methodologies and decision support systems with special emphasis on cost-benefit analysis and Risk Analysis. The Ph.D. project concerned a decision support model for assessing transport projects. By use of the developed CBA-DK software a new risk-oriented methodology for feasibility risk assessment is developed. Recently, he has been part of the Centre for Logistics and Freight (CLG) project where he co-developed a new Decision Support System applied for large scale infrastructure projects, under the CLG task 9 project. He has also been working on a software program for a composite evaluation model called COSIMA-VEJ for the Danish Road Directory. Furthermore, he has been involved in a large transport appraisal study in Greenland evaluating the overall transport system and a customized decision support model for the Rail Net Denmark in order for them to optimize asset management and project ranking. Currently, he is co-managing a large-scale research project for the Danish Strategic Research Council over the next four years entitled: *Uncertainties in Transport Project Evaluation*.

STEEN LELEUR is professor of decision support systems and planning at the Department of Transport at the Technical University of Denmark and the head of the Decision Modelling Group. Recently, he was, among other things, involved in research on topics about systems analysis and evaluation methodology in the Centre for Logistics and Goods Transport. His most recent book "Systemic Planning – Principles and Methodology for Planning in a Complex World" examines the issues of uncertainty and complexity as relating to strategic planning and evaluation problems. Previously, he has published textbooks in Danish and English about traffic planning and highway engineering. He received his M.Sc. in engineering in 1972 at the Technical University of Denmark and defended his doctoral dissertation at the same university about investment planning in 1984. From 1972 until 1986 he worked in the Danish Highway Agency. From 1986 until present Steen Leleur has been employed by the Technical University of Denmark, where he is responsible for the specialisation in traffic planning and highway engineering within the Master Programme "Transport and Logistics". For several years he was associated with the Copenhagen Business School, where he taught courses in systems science and planning theory. Over the years Steen Leleur has been involved in many international transport planning and evaluation research projects, among others several within the European Commission's strategic transport research programmes.