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Modelling of Transport Project Uncertainties: Feasibility Risk Assessment and Scenario Analysis

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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 functions as risk-related decision support for the appraised transport infrastructure project. The presentation of RSF is demonstrated by using an appraisal case concerning a new airfield in the capital of Greenland, Nuuk.

Keywords: Quantitative Risk Analysis, Scenario Analysis, Socio-Economic Analysis, Transport Infrastructure Appraisal, Reference Class Forecasting, Reference Scenario Forecasting, Airfield Case

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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 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 methodology is demonstrated on an appraisal case concerning a new airfield in the capital of Greenland, Nuuk.

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The presence of uncertainty in transport infrastructure appraisals is a commonly treated subject throughout literature (Back et al., 2000; Flyvbjerg et al., 2003; Priemus et al., 2008; Salling, 2008). This paper deals with uncertainties as part of a quantitative risk analysis approach embedding transport related impacts such as construction costs and travel related benefits with a probability distribution function, thus, applying Monte Carlo simulation to accommodate the uncertainties. Accordingly, a sub-division regarding the nature of uncertainty has been included separating the aleatory (stochastic) uncertainties and the epistemic uncertainties into so-called variability and uncertainty (Salling and Banister, 2010). A schematic representation has been illustrated in Figure 1 depicting the difference between the mentioned two major sources of uncertainty.

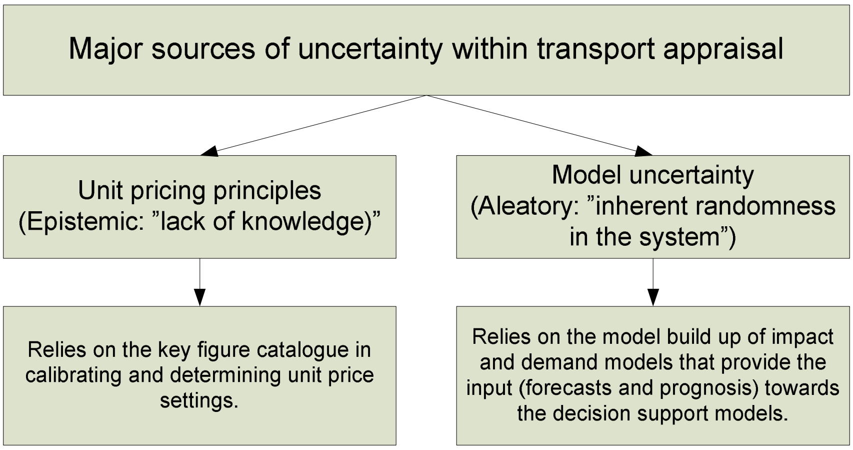

Figure 1. Schematical overview illustrating the two major sources of uncertainty embedded within transport infrastructure assessment (adapted from Vose (2002; 2008))

Figure 1 denotes firstly the underlying uncertainties embedded within any demand or impact model and secondly, the uncertainties inherent in any CBA pricing strategy (pricing strategy is referring to the pricing principles set out by the Danish Ministry of Finance which are determining and hence assigning unit price figures to various transport related impacts). Vose (2002; 2008) suggest separating these two issues into variability uncertainty (aleatory) and uncertainty (epistemic) in order to capture the total uncertainty of a specific problem. The epistemic uncertainty occurs when pricing strategies are defined as knowledge imperfections, which may be reduced by more research and empirical analysis. The aleatory uncertainty (modelling deficiency) is due to the inherent variability of the system, which is especially applicable in human and natural systems, concerning social, economic, and technological developments (Salling and Leleur, 2011). Figure 1 is clearly not a complete list of the uncertainties present in transport infrastructure appraisal; many other uncertainty groups are present such as the determination of which qualitative and quantitative impacts to include, the choice of methodological approaches to the decision making process, the various input parameters to the impact, demand and traffic models, etc. However, the embedded approach to transport decision making proposed in this paper is merely concentrating on two major sources of uncertainty. Mackie and Preston (1998); Vose (2002); de Jong et al. (2005) and Vose (2008) provide an in-depth treatment of the subject matter.

The paper is structured 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 presents 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). Optimism Bias is particularly applied within transport project evaluation schemes and covers the general tendency of overestimating benefits and underestimating costs. This prospect, thus, leads to wrongful decision support foundation, in particular when it comes to the appraisal of the transport project. Thus, several transport related projects have led to huge cost overruns and/or traffic demand underruns (Flyvbjerg et al., 2003).

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. Evidently, it is argued that general errors of judgment are often systematic and hence predictable rather than randomly passed errors or biases. Thus, human judgment, including forecasts e.g. on construction cost schemes, is biased. The theoretical foundation from prospect theory was therefore translated into so-called reference class forecasting, which generally is a method for unbiasing forecasts or in other words dealing with the errors from human judgments (Kahneman and Tversky, 1979; Flyvbjerg, 2006). A reference class denotes a pool of past projects similar to the one being appraised. Herein a systematical collection of past errors is gathered for a range of projects comparing the deficiencies at the planning stage (Flyvbjerg et al., 2003). Experience from past projects is then collected and compared so that "planning fallacy" can be avoided (Buehler et al., 2003; Koole and Spijker, 2000).

Reference Class Forecasting (RCF) is established on the basis of information from a class of similar projects. The classification of reference classes has been explored in Flyvbjerg and COWI (2004), pp. 13-14, where three main groups of projects were 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 the methodology 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 link projects. Based on the latter Salling (2008) has performed a data analysis uncovering a set of probability distributions that fits the data from Flyvbjerg et al. (2003) associated with transport infrastructure assessments, see Table 1.

Table 1. Fitted probability distribution functions (Salling and Banister, 2009)

Impact	Distribution
User benefits	Beta-PERT
Construction costs	Erlang

The two distributions depicted in Table 1 have been fitted against reference class projects concerning traffic demand forecasts which ultimately lead to the user derived benefits in terms of travel time savings, ticket revenues etc. and construction costs (Flyvbjerg et al., 2003). These two impacts make up the key components in most transport evaluation schemes (Leleur, 2000), for which reason the following case study applies the presented 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 means of three project alternatives. A new overall transportation plan was needed, firstly in order to accommodate the increasing tourist demands, secondly to prepare Greenland for airline competition (currently, only the Scandinavian Airline Service, SAS and AirGreenland are serving Greenland) and finally, more urgently, to accommodate the phasing-out of the current Dash 7 aeroplanes. The current runways would be too short to handle newer aeroplanes such as the Dash 8. For example, the current runway length in Nuuk is 1200 meters, whereas the Dash 8-400 needs at least 1600 meters to land. Secondly, this case study investigates the possibility of moving the international airport from Kangerlussuaq to Greenland's capital, Nuuk. Naturally, the various stakeholders are all interested in maximizing their benefits, and this has resulted in several project proposals for new infrastructure investments in Greenland.

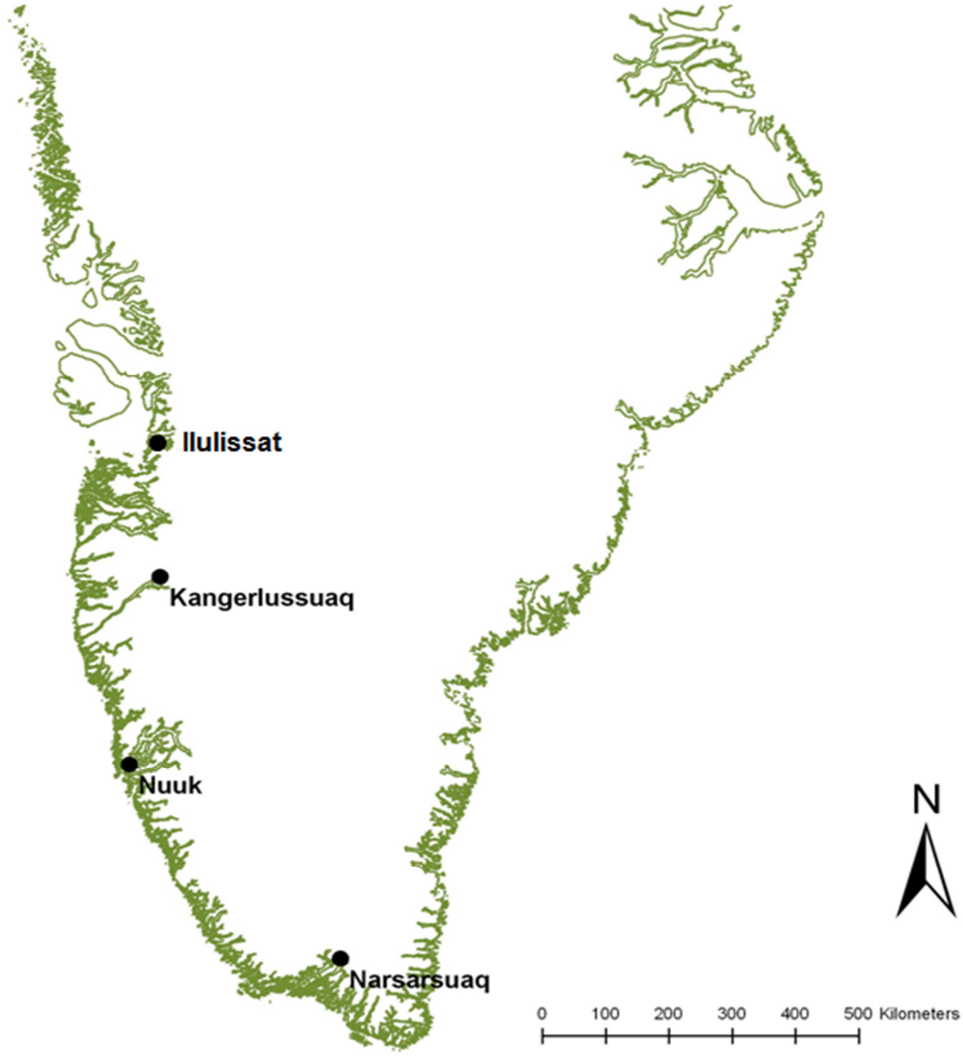

Figure 2. Location of the four main airports in Greenland (Salling and Banister, 2009)

The overall transport plan covered a huge variety of various scenarios/alternatives (Leleur et al., 2007) all covering, among others, three different runway length alternatives in the three major cities of Nuuk (the capital), Ilulissat and Narsarsuaq. Approximately 70% of all foreign (and domestic) travellers have in fact their final destination set to Nuuk; however, since the only international airport is situated in Kangerlussuaq, all travellers have to make a stop-over there (Nielsen et al., 2007). Figure 2 depicts the current cities of interest where Kangerlussuaq is the major international airport constructed by the Americans during and after the Second World War.

The case study made use of in this paper, however, only looks into the alternatives in Nuuk. They consisted of two alternatives replacing the existing runway in Nuuk (1200 metres), i.e. increasing the current runway length to either 1800 metres (m) or 2200 m, and a third alternative the construction of a new, relocated airport to the south with a 3000 m runway, consequently leading to the closing of the existing airport. For more elaborate information concerning the case study and the runway alternatives in particular, refer to Leleur et al. (2007). Table 2 depicts the three types of runway lengths, their estimated construction costs together with possible airplanes (excluding the old Dash-7) that are able to use the runways.

Table 2. Alternative runway lengths, costs and possible aeroplanes

Type of Runways	1800 metre	2200 metre	3000 metre
Cost (DKK in 2006 prices)	496 mDKK	733 mDKK	2169 mDKK
Reinvestments (2006 prices)	97 mDKK	119 mDKK	169 mDKK
Types of airplanes	Dash-8 (100 PAX) Boeing 757 (180 PAX) Boeing 737 (120 PAX)	Dash-8 (100 PAX) Boeing 757 (180 PAX) Boeing 737 (120 PAX) Airbus 330-200 (245 PAX)	Dash-8 (100 PAX) Boeing 757 (180 PAX) Boeing 737 (120 PAX) Airbus 330-200 (245 PAX)

Results from this study pointed towards the 1800 or 2200 metres runway extension alternatives (Leleur et al., 2007; Salling and Banister, 2009), thus, in light of this information, the following examines the robustness of the 2200 metre alternative on combining a set of scenarios with risk analysis and optimism bias.

3.1 Construction cost estimate

The impact with the highest overall significance on any given appraisal study is the construction cost. For transport authorities to prepare accurate future budget programmes for transport projects, reliable and valid cost estimates are of vital interest. Future funding is obviously never known as it depends on shifting governments etc. The difficulties in this respect are 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 e.g. due to strategic reasons (the theory of strategic misrepresentation), etc. (Wilmot and Cheng, 2003; Osland and Strand, 2010). A literature review was conducted by Cantarelli et al. (2010) uncovering the causes and explanations specifically to construction cost overruns. The authors claim that the reason for cost overruns can be divided into four categories as depicted in Figure 3.

Even though the explanations depicted in figure 3 make explicit efforts to derive and hence explain the four various causes to cost overruns, no suggestions have been formulated in order to find a way to model and thus minimise construction cost overruns. In the following an effort is made firstly to accommodate the technical causes of cost overruns by formulating adequate probability distribution functions and secondly to discuss and qualitatively indicate the final three 'strategic' causes in terms of applying reference classes from past data. The paper, thus, seeks to reduce the probability of both Optimism Bias and the overestimation of benefits and underestimations of costs.

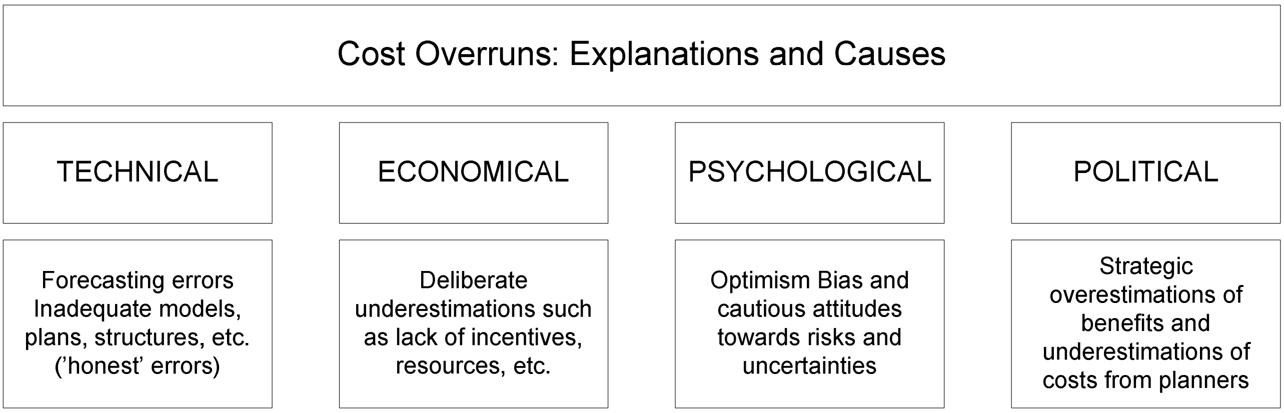

Figure 3. Categorising of the four types of explanations to cost overruns and their causes (adapted from Cantarelli et al. (2010)

3.1.1 Deriving a suitable probability distribution function

Cost underestimation at the planning stage is often explained by planners in terms of the dynamic development of the project over time. In the pre-construction phase projects are normally based upon traditional impacts of construction works e.g. for 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 (the technical causes are shown in Figure 3). Thus overall construction costs tend to rise during the implementation period. 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 not acceptable and more precise construction cost estimates are needed in order to make recommendations that are valid and provide trustworthy decision support.

Traditionally, such cost estimations are oriented towards a deterministic approach failing to address the inherent variability of the real world problems as explained above. Thus, a stochastic approach is better suited to address the risks and uncertainties embedded within standard deterministic approaches to cost estimation. Back et al. (2000) propose to apply range estimation techniques rooted in probability distribution functions and Monte Carlo simulation. The choice of probability distributions have been scrutinized and are determined to follow the properties listed below:

1. For a given construction cost estimate, an upper and lower limit exists – from where it is reasonable to assume that no values will exceed those estimators. Consequently, a close-ended distribution is desirable
2. The distribution should be continuous. It must be assumed that the construction cost estimate can have any value within the pre-defined upper and lower limits
3. It is found that the probability of occurrence of an event (construction cost estimate) decreases as the upper and lower limits are reached. Thus, it is preferred that the probability distribution is convex rather than concave
4. The distribution should be unimodal. This is particular relevant for construction costs as it must be assumed to have a most likely value

5. Since actual costs are more likely to be higher than lower than predicted, skewness should be expected to influence the probability distribution

Following the 5 points literature shows that specifically three types of distribution functions are suitable in order to address the uncertainty of cost data, namely, triangular (Back et al. (2000), Beta-PERT (Vose, 2008) or Erlang distributions (Lichtenberg 2000). A theoretical review and statistical tests are performed in Back et al. (2000) supporting the fact to apply triangular distributions with skewness, however, as illustrated in table 3 other types of probability distribution functions are applicable in order to fulfil the above mentioned 5 criteria.

Table 3. Candidate probability distributions and their properties (adapted from Back et al., 2000)

		Desired properties	
Continuous distribution (2)	**Bounded (1)**	**Unimodal (4)**	**Skewness (5)**
Normal	No	Yes	No
Lognormal	At one end	Yes	Yes
Uniform	Yes	No	No
Gamma	At one end	Yes	Yes
Triangular	Yes	Yes	Yes
Beta	Yes	Yes (most of cases)	Yes

Salling (2008) argues to apply a Gamma (Erlang) distribution to accommodate the uncertainties within the construction cost estimation. In this respect, it has been assumed to follow previous literature concerning successive calculation and triple estimation (Lichtenberg, 2000), where it has been proven that an Erlang distribution is fully applicable to represent the uncertainties of cost estimation.

3.2 Travel time savings and ticket revenue (TTS-TR)

Travel time savings (TTS) are by far the largest contributor of direct benefits from any given transport project. Benefits originating from this category often make up about 70-90% of the overall user benefits (Mackie et al., 2001). Specifically within public transportation such as air transport infrastructure projects ticket revenues (TR) play a vital role in the assessment of benefits for society. The latter is conceived through user benefits due to lower air fare tickets. Consequently, due to the relocation of a new central international airport in Nuuk, passengers and cargo must expect lower airfares through a more direct routing and increased competition between different airline companies. Currently, passengers must transfer to alternate routes in Kangerlussuaq when arriving internationally, resulting in higher ticket prices and longer travel times.

Such benefits are normally estimated by the use of traffic models that simulate future traffic flows given a certain predictive forecast. Evidently, the TTS-TR relies on two types of submodels: a demand model and a traffic model that together predict the induced demand (increase of travelers). Næss (2011) explores a set of environmental impact assessment (EIA) reports where it is actually revealed that some traffic models not even include the induced traffic. These observations lead to the adoption of so-called pessimism bias against the no-build alternative, thus, politicians were 'persuaded' into the construction of a road scheme based upon wrongful assumptions concerning induced traffic. This was also further explored by Nielsen and Fosgerau (2005) claiming that, at best, induced traffic is in fact normally underestimated or fully ignored when it comes to Danish motorway cases.

Traffic model research is very extensive especially in the area of model uncertainties and bias. Thus, recently conducted research has proved that the underlying uncertainties of generalized travel time savings measured as hours per year follow a normal distribution (de Jong et al., 2005). Unfortunately, the real magnitude of uncertainties related to the traffic model outputs has not been tested in the Greenland case. Hence, it has been decided not to include the transferred bias from the traffic model calculations.

On the other hand, the demand forecast models that lay the foundation for traffic models, have proven to be overestimating future traffic demands leading to benefit underruns (Flyvbjerg et al., 2003). We therefore tend to overestimate the TTS-TR impact which ultimately can lead to wrongful decisions. Evidently, demand forecasts of road projects are fairly accurate with an average inaccuracy of only 9% measured in respect to the following formula (Ibid.):

$U = \frac{\left((X_a - X_f)\times 100\right)}{X_f}$, where U is percent inaccuracy, X_a is the actual traffic after the project is opened and X_f is the forecasted traffic on the decision to build. Moreover, a recent research study completed for Norwegian road projects actually proved that especially for tolled road projects road planners are in fact very accurate with an inaccuracy mean of -2.5% (meaning that the actual traffic is 2.5% less than forecasted on average). However, on toll free roads the inaccuracy increases substantially to 19% which means that the actual traffic is 19% higher than forecasted on average (Welde and Odeck, 2011). On the other hand, rail projects are depicting a very high inaccuracy with an average of U = 39% (Flyvbjerg et al., 2003, p. 26).

Unfortunately, no observations were made for air transport schemes and the inaccuracies of passenger flows. Thus, in order to apply uncertainty measures to the Greenlandic case project, it is found reasonable to apply the data concerning rail project inaccuracies (Salling and Banister, 2009). Even though the use of rail projects as an exemplar add variation to the inputs, similarities towards air transport projects and particularly infrastructure projects can be drawn, e.g. both types of projects are 'relatively unconventional (scarce)' and of large scale (explains the similarities in cost overruns). Moreover, particularly covering quantification of non-transport related benefits (i.e. not included in a conventional CBA) effects such as network, mobility, accessibility, land use etc., are all substantially inherent in both types of project types (Leleur et al., 2004; Leleur et al., 2007; Banister and Thurstain-Goowin, 2011). Secondly, both types of projects are subdivided among various groups of stakeholders/actors – namely users (passengers), operators (airline carriers) and providers (government, municipalities, etc.) explaining the demand forecast biases. From the latter it was concluded that at worst the rail exemplar would overemphasise the problem (ibid.).

To elaborate on the two latter uncertainty aspects a decision support model has been adopted for transport project appraisal, namely the CBA-DK model (Salling, 2008).

3.3 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 4.

Table 4. Decision criteria from a deterministic CBA model run for Nuuk 2200 m (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%

The criteria values clearly show that the 2200 m alternative produces very good societal results illustrated by a high NPV (1€ ≈ 7.6 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 a centre. Considerable work in order to improve the methods from which we appraise transport infrastructure investments has been made. The first steps were taken in the late 1990s where the Standing Advisory Committee on Trunk Road Assessment (SACTRA) made evident that standardized cost-benefit methods were lacking wider economic impacts (benefits), thus, underestimating the total economic benefits (SACTRA 1999). Accordingly, several authors have tried to produce a set of exploratory regulative scenarios (regimes) putting focus upon the wider economic benefits relating to transport infrastructure investments (Venables, 2007; Vickerman, 2007; 2009).

4. Risk and Scenario Analysis: 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 (Leleur et al. 2004). Exploratory scenarios are often made use of when representing uncertainty reflections upon long time planning. The effort and scenarios set up below are building upon studies from the Netherlands (van Wee and van der Hoorn, 2001) and from Great Britain (Headicar, 2009). Thus, the scenarios in this study have been set up with respect to two main types of regimes: One regime which deals with the overall international economic development and one regional/local regime describing the future importance of Nuuk as a centre (adapted from Leleur et al. (2004) and Headicar (2009, pp. 408-431). The regimes vary in a 3x3 grid as depicted in Figure 4 where the horizontal axis outlines the global economic development and the vertical axis outlines the importance of Nuuk as a centre and regional growth pole in Greenland. Uncertainty tendencies 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 both to the deterministic and stochastic CBA-DK calculations.

4.1 Reference Scenario 5 (the focal scenario)

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 (Salling and Banister, 2009).

Global economic development

Nuuk importance as centre and regional growth pole in Greenland

	High growth	Moderate growth	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 4. Scenarios for imagined futures representing possible and plausible developments

4.1.1 Construction Costs (Erlang distribution)

As stated, construction costs for large infrastructure projects have a tendency to be underestimated, which means that socio-economic analyses become overoptimistic. 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 cost overruns. It has been assumed that the empirical results from rail projects can be applied to airport infrastructure projects. Salling and Banister (2009) argued to apply the dataset regarding rail infrastructure projects which resulted in input parameters for the Erlang distribution with a shape parameter of 9 (Salling and Banister 2009).

4.1.2 Travel time savings and ticket revenue (Beta-PERT distribution)

Secondly, Flyvbjerg et al. (2003) furthermore investigated 27 rail projects depicting the inaccuracy for traffic demand forecasts. The overestimation of demand forecasts, and hereby miscalculations in terms of user benefits, 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%. Salling (2008) provided a data analysis from the 27 rail projects illustrating that the inaccuracies from the demand forecasts were very skew to the right following a Beta distribution. Furthermore, the PERT (Program Evaluation and Review Technique) distribution was scrutinized through several studies where it especially proved its usefulness in terms of modelling expert data (Lichtenberg, 2000; Vose, 2002). Thus, the Beta-PERT distribution only requires inputs as to minimum, maximum and most likely values, respectively.

4.1.3 Results

The CBA-DK model provides the deterministic *point results* as shown earlier in Table 4 including a stochastic calculation which transforms the point results into *interval results* allowing 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 5.

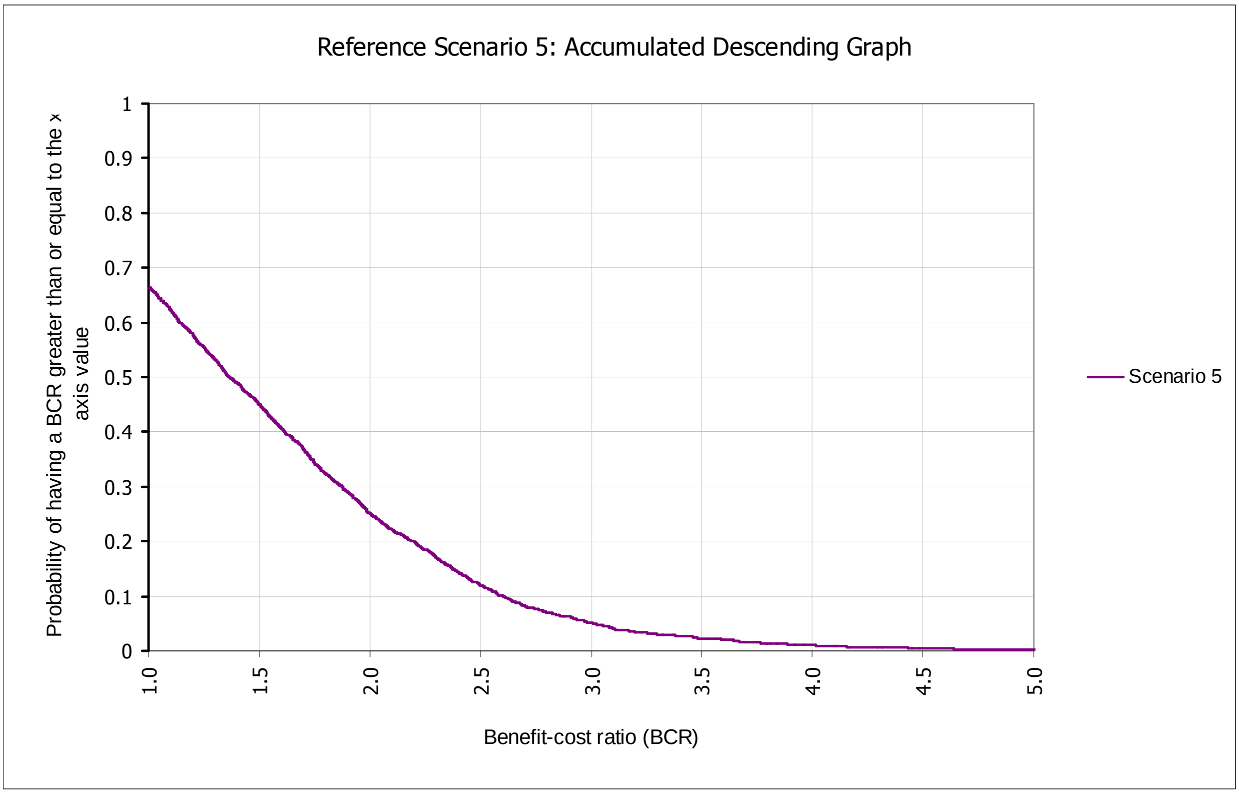

Figure 5. Resulting accumulated descending graph (ADG) for the focal scenario 5: the y-axis values for BCR = 1.0 indicate the certainty levels of the scenario

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 5 shows that for approximately 65% 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 35% of the simulation runs scenario 5 gives an infeasible result.

The remaining 8 scenarios use the focal reference scenario 5 as their basis. 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.

4.2 Reference Scenario Forecasting (RSF)

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 3.5.1.

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 travelling both as tourists, residents and business travellers. The opposite tendency will be the result 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.

4.2.1 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 mDKK (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 to set the values shown in Table 5.

4.2.2 Triple Values for scenarios 2, 4, 6 and 8

In scenario 2 optimism in the global economy indicated by deregulation lifts the ML5 value to ML2 = 220 mDKK. At the same time uncertainty is perceived to be decreasing, as indicated in Figure 1, which gives a higher MIN-value and higher MAX-value. Hereby we obtain the following triple set for scenario 2 in mDKK (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 mDKK (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 mDKK. 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 mDKK (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 a centre and growth pole is the same as today with a regulated economic condition. Thus, ML6 is lowered to 150 mDKK with the following set of MIN and MAX values in mDKK:

(MIN6, ML6, MAX6) = (10, 150, 285) (5)

4.2.3 Triple Values for the remaining scenarios

The remaining four scenario values have been found using the triple sets assessed for scenarios 2, 4, 6 and 8. As depicted in Figure 4, the highest uncertainty relates to scenario 7, while the most certain scenario is scenario 3. Table 5 shows the outcomes of the assessment of the nine scenarios from Figure 4 with the triple values in absolute terms (mDKK).

Table 5. Summary of the triple values applied for the RSF (mDKK)

Scenarios	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 (focal)	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 upon deliberations among the authors and mainly for the purpose of illustrating the approach of RSF. In a real-world application the values should be set by people with a thorough knowledge (i.e. local officials, planners, key stakeholders and decision-makers such as politicians) 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 (Phillips, 2007). 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 5 may be changed into what may be argued as more realistic values.

Another major benefit from decision conferencing as presented above is the minimisation of the strategic misrepresentation represented in the political explanation of Optimism Bias (Figure 3). Strategic misrepresentation occurs as planners and analysts are employed, hence, representing various types of organisations with economic interest in the final throughput of the project. Hereby, strong competition often exists for the scarce public resources resulting in strategically misrepresented projects, i.e. *the survival of the unfittest* projects (Osland and Strand, 2010). However, if projects at an early stage accommodate a DC and RSF with participants scattered between stakeholders, planners, analysts and other key actors strategic misrepresentation can be 'caught' at an early stage of the project.

4.3 RSF Results for the Greenland case

Model runs in CBA-DK making use of the values in Table 5 produce 8 additional accumulated descending graphs (ADGs), see Figure 6.

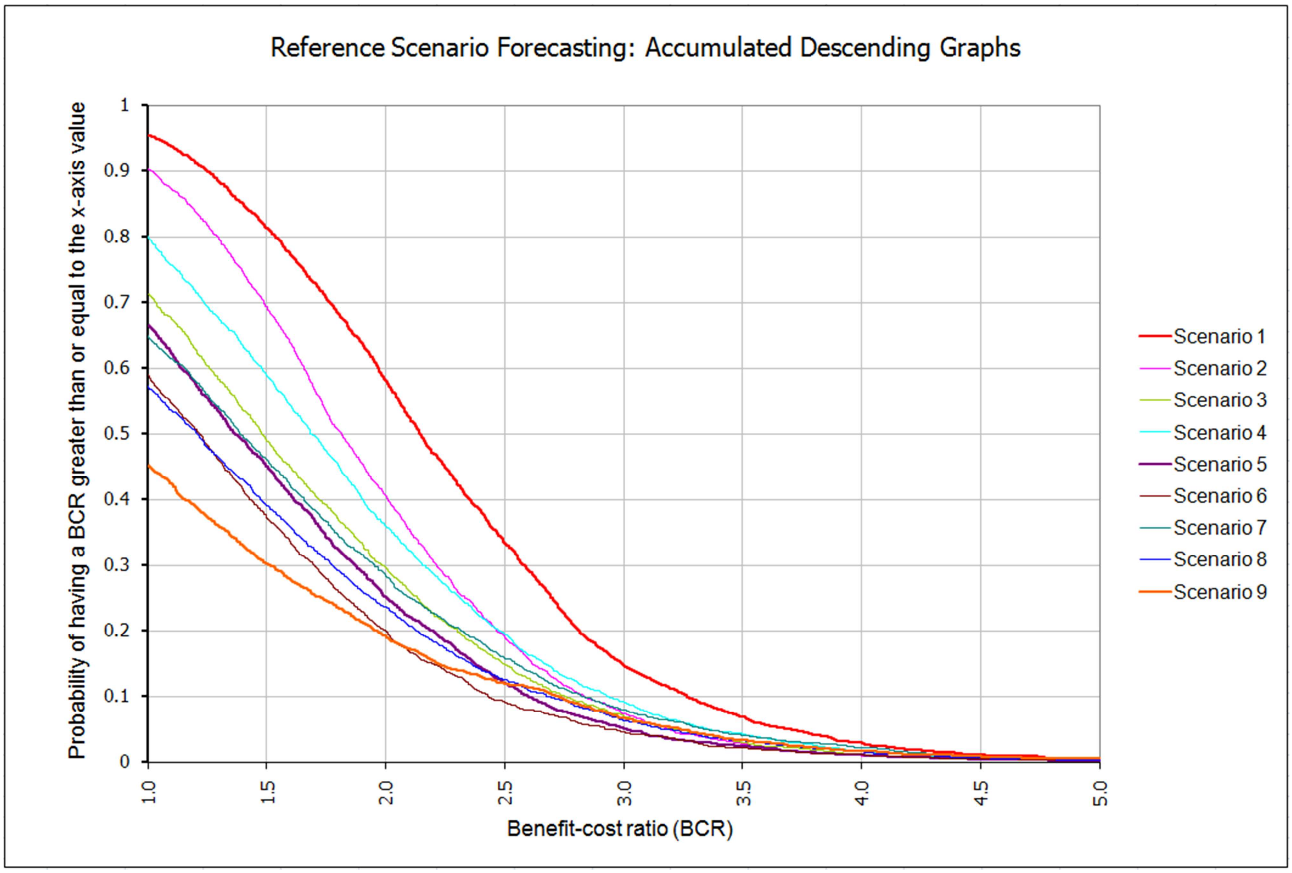

Figure 6. Resulting accumulated descending graphs (ADGs) from Reference Scenario Forecasting: the y-axis values for BCR = 1.0 indicate the certainty levels of the scenarios

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 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 to each scenario, i.e. a flatter ADG depicts a higher uncertainty.

Risk aversive decision-makers would probably accept the project under scenarios 1, 2 and 3, whereas 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. We foresee that making use of a decision conference will help qualifying the deliberations of the involved decision-makers. Evidently, the introduction of decision conferences as part of transport infrastructure planning increases the transparency of the problem and furthermore holds the perspective of creating ownership to the project. The benefit from applying scenarios and RSF is to view a full span of outcome probabilities, thus, in the case of the Nuuk 2200 metre runway proposal decision-makers and stakeholders are able to indulge further courses of action based upon probability ranges from 45% to 95% of the project being feasible. These new results surely questions the original BCR of 2.5 for the Nuuk 2200 metre alternative in which care must be taken at the level of information and ultimately the decision support provided.

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 applying Monte Carlo simulation and Reference Class Forecasting, the CBA-DK model allows a more explicit consideration of risk 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. The graphs allow 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.

Accordingly, the boundaries as well as the most likely values in Table 4 are set by discussions among the authors. New insight to range estimation indicates, however, that individuals tend to estimate too narrow intervals especially with respect to the 'unknown'. In literature, such estimation fallacies are denoted overconfidence theory and have been particularly explored within financial markets as planners, stakeholders and authors tend to produce too narrow ranges of forecasts ultimately leading to inaccurate predictions (de Venter and Michayluk, 2008). Hence, new research in the area of overconfidence within uncertainties in transport project evaluation will be undertaken in order to explore the range estimation bias produced in the RSF methodology (Leleur et al., 2011).

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 explored and developed.

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