DTU Library

A New Approach to Feasibility Risk Assessment within Transport Infrastructure Appraisal

Salling, Kim Bang

Link back to DTU Orbit

26th IPMA World Congress, Crete, Greece, 2012

A New Approach to Feasibility Risk Assessment within Transport Infrastructure Appraisal

Kim Bang Salling[*]

Technical University of Denmark, Department of Transport, Bygningstorvet 116V, 2800 Kgs. Lyngby, Denmark

Abstract

This paper introduces a new approach of applying feasibility risk assessment within transport project infrastructure appraisal. The procedure is based upon quantitative risk analysis and Monte Carlo simulation in combination with conventional cost-benefit analysis converting deterministic benefit-cost ratios (BCRs) into stochastic interval results. Recent research has proven that particularly input based impacts such as construction cost and demand forecasts (travel time savings) often are respectively underestimated and overestimated creating so-called Optimism Bias. Decision-makers and stakeholders are, hereby, often basing their decisions on wrongful material. The presented approach to transport infrastructure appraisal is to include uncertainties and risks in the evaluation. Correspondingly, the handling of uncertainties and risk within transport project assessment are often made up by sensitivity tests producing deterministically based output values. Research has proven that traditional sensitivity analysis seldomnly captures the total variability especially as concerns the costs and demands estimated in the pre-stage of the evaluation. Therefore, this paper introduces an approach to decision support based upon so-called reference class forecasting using historical information from similar past projects. The scheme is made evident through a brand new database sample (UPD: the UNITE Project Database) which contains almost 200 specific European transport infrastructure projects. Hence, the approach will be tested and further explored upon a fixed case example depicting a new fixed link between Elsinore (Denmark) and Helsingborg (Sweden) revealing a severe decrease in economical return including relevant UPD information. Finally, a conclusion and perspective of the further work will be discussed.

[*] Corresponding author. Tel.: +45 4525 1548; fax: +45 4593 6412.
E-mail address: kbs@transport.dtu.dk.

doi:10.1016/j.sbspro.2013.03.047

1. Introduction

Providing suitable decision support for strategic transport decision making is a topic of growing concern. Therefore, assessments that explore the robustness of upcoming infrastructure investment decisions in relation to the uncertainty in construction costs and transport prognoses - referred to as the transport demand estimates - are critical (Flyvbjerg *et al.*, 2003). Current research have disclosed a consistent tendency towards the overestimation of transport demand and underestimation of costs showing the presence of the estimation problems in the assessments i.e. the decision basis carries embedded uncertainties from the analysis to the final outcome of the decision support system (Flyvbjerg *et al.*, 2003; Salling, 2008, Canterelli *et al.*, 2010). Many cases have been documented where the poorly executed estimation of both impacts have led to investments that later on turned out to be less than satisfactory (Priemus *et al.*, 2008).

Transport appraisal in many countries is primarily based on Cost Benefit Analysis (CBA), where the advantages and disadvantages of particular investment alternatives are assessed in terms of their relative importance for society (Haezendonck, 2007). Traditionally in terms of the handling of uncertainties the CBA will undergo national standardized sensitivity tests, where e.g. individual impacts and/or input criteria such as the discount ratio or growth in GDP (Gross Domestic Product) are treated in order to determine how much the output might vary before the project is rejected. However, there is a growing concern about the inadequacy of such a traditional approach and an increasing recognition that the scope of project evaluation should be extended even further to account for the overestimation of benefits and underestimation of investment costs (Salling & Banister 2009; Ševcíková *et al.*, 2011; Herder *et al.*, 2011; Beukers *et al.*, 2012). As noted already, the variability relating to the construction costs and the transport demand, which are two central impacts in any transport infrastructure assessment, will dominate and have high importance as regards the long-term socio-economic return or feasibility of the investment. Thus, better estimation of costs and benefits, the latter highly correlated with the transport demand, is of major importance to the usefulness of CBA in terms of robust decision making.

The scope of this paper is to apply quantitative risk analysis (QRA) in order to depict the totality of any future sensitivity outcomes in terms of Monte Carlo simulation (MCS). Thus, the QRA introduces probabilities into the decision-making process, depicted as feasibility risk assessment (FRA) linking traditional appraisal approaches with risk analysis and Monte Carlo simulation. Consequently, instead of receiving single point results, decision-makers receive interval results in terms of an output probability distribution.

Finally, in terms of operationalising the FRA approach a database is currently under construction which scrutinizes historical information with regard to construction costs and demand forecast. This frame of reference, the UNITE Project Database (UPD), evidently include various risk-based information with regard to the before and after situations e.g. project name, project type (reference), year of acceptance and year of opening, country, initial cost and actual cost of project (converted into 2010 price level) and initial demand and actual demand of infrastructure project. Herein, percentage deviations are produced from initial to actual state, delivering input to the Monte Carlo simulation.

The paper, thus, is disposed as follows. Section 2 introduces the software and decision support model, UNITE-DSS, consisting of respectively a CBA and QRA part facilitating the overall frame of feasibility risk assessment. Moreover, the case study is presented exploring the possibility of a new fixed link across the Oresund connecting Denmark to Sweden. Section 3 elaborates further on the UPD database information where actual data fitting is performed on respectively a sample from the cost and demand side. Section 4 presents a fixed model run within the UNITE-DSS model and a set of findings are presented and finally in section 5 a conclusion and perspective of the further work is given.

2. The UNITE-DSS decision support model

The UNITE-DSS decision support model is designed to bring informed decision support, both in terms of single aggregated estimates such as the Benefit Cost Ratios (BCRs), and also in terms of interval results by accumulated probability curves (or accumulated descending graphs ADG). The current interaction between the deterministic and the stochastic parts of the UNITE-DSS model is made up by the feasibility risk to be investigated when assessing transport infrastructure projects (Salling, 2008). The deterministic part encompasses the CBA calculations where monetary impacts are treated against socio-economic criteria such as discount ratio, growth in GDP, evaluation period, etc. The stochastic part treats the QRA calculations enabling the analyst or modeler to *enhance* the deterministic results into probabilistic outputs. The main purpose of this module is 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 following depicts the case study calculations upon an appraisal study concerning a new fixed link connecting Denmark to Sweden in the Northern part of Zeeland (Elsinore) with Helsingborg in Sweden.

2.1. The Elsinore-Helsingborg (HH) connection

The Oresund Fixed Link connecting the greater area of Copenhagen with Malmo in Sweden opened in July 2000, cf. dotted circle on Figure 1. Today, ten years after the opening, the railway line of the link is close to its capacity limit resulting in delays and discomfort for the travelers. The case of this paper concerns a new complementary fixed link connection between Denmark and Sweden between the cities of Elsinore (Helsingor) and Helsingborg, HH-Connection, see the full circle on Figure 1.
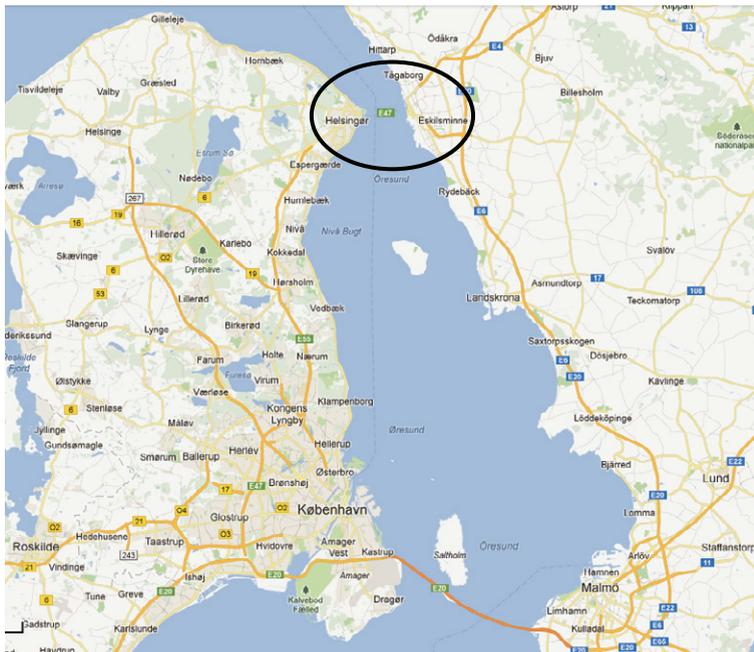

Fig. 1. The proposed new fixed link between Elsinore (Helsingor - Denmark) and Helsingborg (Sweden): the HH-Connection (from Google Maps)

Regionally, the proposed connection is expected to create a substantial increase in trade, education and work place related benefits. Ultimately it is expected that a fixed link with increased commuter traffic across the border will result in a common labor and residence market. In addition, the recent decision to construct the Femern Belt fixed link connecting Denmark with Germany will increase the number of travelers and especially the amount of freight movement from central Europe through Denmark to the rest of Scandinavia (Sweden, Norway and Finland). Currently, the HH-connection is operated with ferry service which in the following is referred to as the base scenario whereas each of the proposed alignments will substitute the ferries with a fixed link with four alternatives being considered, see Table 1.

Table 1. The proposed four alternatives for the HH-Connection with construction costs in million DKK in 2010 price level (Salling *et al.*, 2010) *(note that 1 million DKK ≈ €130,000)*

HH-Connection alternative	Description of alternative (Alignment of connection)	Cost (billion DKK)	BCR	NPV (billion DKK)
Alternative 1	Tunnel for rail (2 tracks) person traffic only	7.7	1.51	5.6
Alternative 2	Tunnel for rail (1 track) goods traffic only	5.5	0.18	-6.5
Alternative 3	Bridge for road and rail (2x2 lanes & 2 tracks)	11.5	2.72	28.4
Alternative 4	Bridge for road (2x2 lanes)	6.0	3.09	18.0

Moreover a socio-economic cost-benefit analysis (CBA) has been carried through incorporating changes in respectively benefits or costs such as travel time savings, vehicle operating costs, ticket revenues, air pollution, etc. (Salling *et al.*, 2010). The results from the CBA depict three feasible alternatives, 1, 3 and 4 whereas alternative 2 only allowing railway freight to use the link produces infeasible results seen from a socio-economic point of view. The two bridge solutions (alternative 3 and 4) clearly perform the best with high BCRs whereas alternative 2 with only one track for railway goods is performing poorly. Furthermore, for alternative 3 and 4 it should be noticed that with regard to the NPVs alternative 3 performs the best, while as concerns the BCRs alternative 4 performs the best.

2.2. Feasibility Risk Assessment (FRA)

Even though a key advantage of using cost-benefit analysis 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 a single aggregated value, e.g. net present values or benefit cost ratios. The quantification of "non-market" effects such as accidents saved, air pollution and other externalities present a practical measurement problem. Finally, two superior sets of uncertainties are identified in any assessment of transport infrastructure projects; the underlying model uncertainties embedded within any traffic or impact model and the uncertainties in any CBA pricing strategy illustrated in terms of the unit prices associated with each of the prior transport related impacts (Salling, 2008).

By adding to the conventional CBA through the adoption of a quantitative risk analysis, the probabilities of occurrence of particular risk factors can be incorporated, and decision-makers and analysts can make use of their expertise. The technique used is Monte Carlo simulation which involves a random sampling method (in this case in terms of a Latin Hypercube sampling approach) concerning each different probability distribution selected for the actual model set-up. 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 & Banister, 2009; Vose, 2008).

The following introduces the UPD database which sets off to produce input data to the feasibility risk assessment and Monte Carlo simulation in terms of selecting an appropriate probability distribution.

3. The UNITE Project Database (UPD)

The UNITE Project Database (UPD) has been intialised as a consequence to the increasing demand for informed and risk-based decision support within transport infrastructure appraisal. The general idea is to gather all possible and available information regarding implemented transport investment projects in Scandinavia and other Western Europe countries, which can be used as frame of reference for any future evaluations. Such historical derived information adopted for future analyses has through literature been named Reference Class Forecasting (RCF) i.e. sources that contain historical derived data in this case in terms of estimated construction costs and demand forecasts (that lays the foundation for the combined effect of travel time savings) set against actual/realized construction costs and traffic loads (Kahneman & Tversky, 1979; Flyvbjerg & COWI, 2004). Thus, the database (denoted reference classes) contain information in percentages of respectively over- or underruns which in the following are assumed to construct the input distributions to the UNITE method of appraisal together with the mean percentage over/underrun (Ambrasaite *et al.*, 2012). In order to adopt the RCF technique vast amount of data is needed in order to make the data fitting and thereby derive suitable input probability distributions (PDs). Salling (2008) fitted a set of PDs from the database collected in Flyvbjerg *et al.* (2003) proving that an Erlang distribution is representing the inaccuracies as concerns construction cost estimates and a Beta-PERT (Program and Evaluation Review Technique) or Normal distribution representing the inaccuracies as concerns the demand forecast estimation.

The convention used in the database sample was defined as the difference between actual and estimated costs and demands in percentage terms. Thus, the ex-post values are referring to the real accounted cost or demands determined at the time of completing the project, whilst the ex-ante values are found within the budgeted costs or estimated demands at the time of decision to build (Flyvbjerg, 2007; Ambrasaite *et al.*, 2012), as presented through the following formula (1):

$$U = \frac{\left(\left(X_a - X_f\right) \times 100\right)}{X_f} \tag{1}$$

Where U is the percent inaccuracy, X_a is the actual traffic or realized costs after the project is opened and X_f is the forecasted traffic or estimated construction cost on the time on decision to build (Salling & Leleur, 2012).

3.1. Demand Forecasts and Travel Time Savings inaccuracies

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).

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 (DTU Transport, 2011) where frequent updates are made. It is clear 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. In order to captivate and produce time saved in e.g. vehicles or trains TTS relies on valid traffic forecasts or in traditional terms demand forecasts. Thus, demand prognosis lays the basis for calculating travel time savings stemming from transport infrastructure projects. The embedded uncertainty in deriving these forecasts depends among others on the time and effort put into data collection and traffic modeling.

Ambrasaite *et al.* (2012), conclude that generally, traffic forecasts within road projects are within a threshold of -80% to 160% accuracy with an average underestimation of -10.4%, however with a high standard deviation on 50%, see Figure 2.
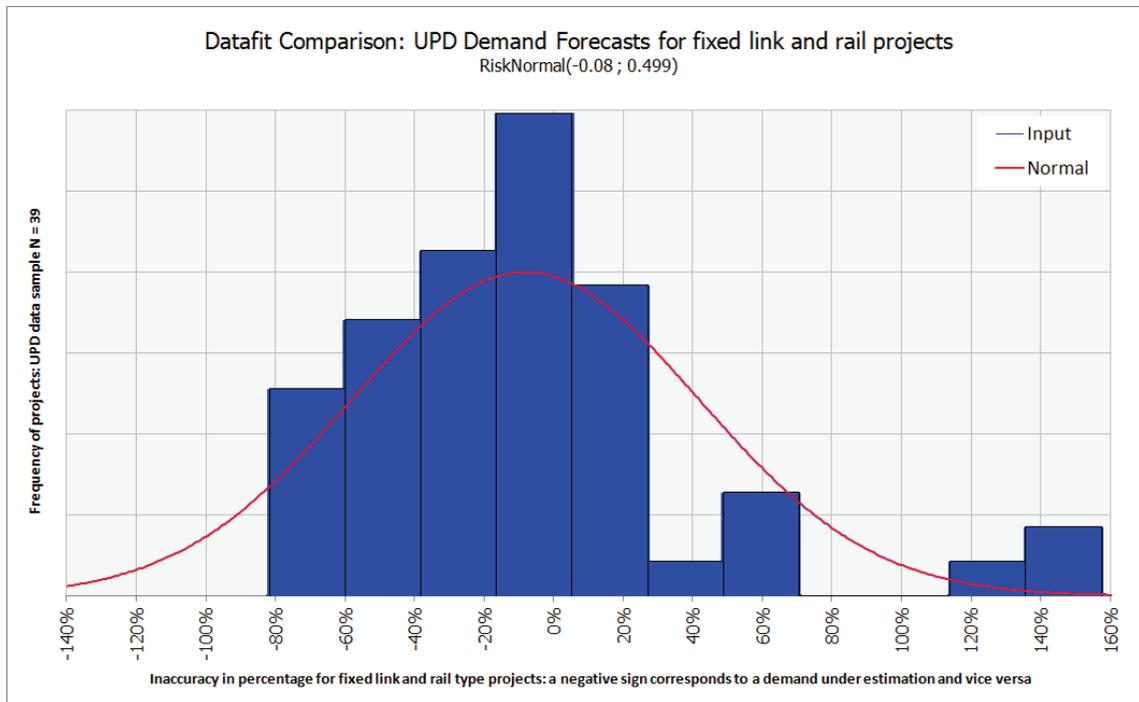

Fig. 2. Inaccuracies of demand forecasts for roads in 39 projects (average -10.4%). Inaccuracy is measured as actual minus forecast traffic in percentage of forecast traffic, thus, a negative sign refers to lower actual demand than predicted and vice versa (Ambrasaite *et al.*, 2012)

Figure 2 furthermore presents the initial data fit for 39 projects available in the UPD database. It should be noted that due to data availability the two types of projects namely fixed link and rail projects have been placed within the same type of reference class. By taking rail projects as an exemplar may at worst over emphasis the uncertainties embedded. Thus, the data sample illustrated in Figure 2 depicts that a Normal distribution with the mean of 0.08 and standard deviation of 0.499 is suitable.

3.2. Construction Costs inaccuracies

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 kilometer highway of a predefined road type. 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% or more (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 trustworthy decision support.

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. Ambrasaite *et al.* (2012) and Flyvbjerg *et al.* (2003) both agrees on the tendency which is clearly right skewed - where cost overruns are commonly occurring. In fact an average of 20.2% cost overrun among the 62 fixed link and rail projects are derived (Ambrasaite *et al.*, 2012). Figure 3 are illustrating the inaccuracies within cost estimation of large transport infrastructure projects. 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.
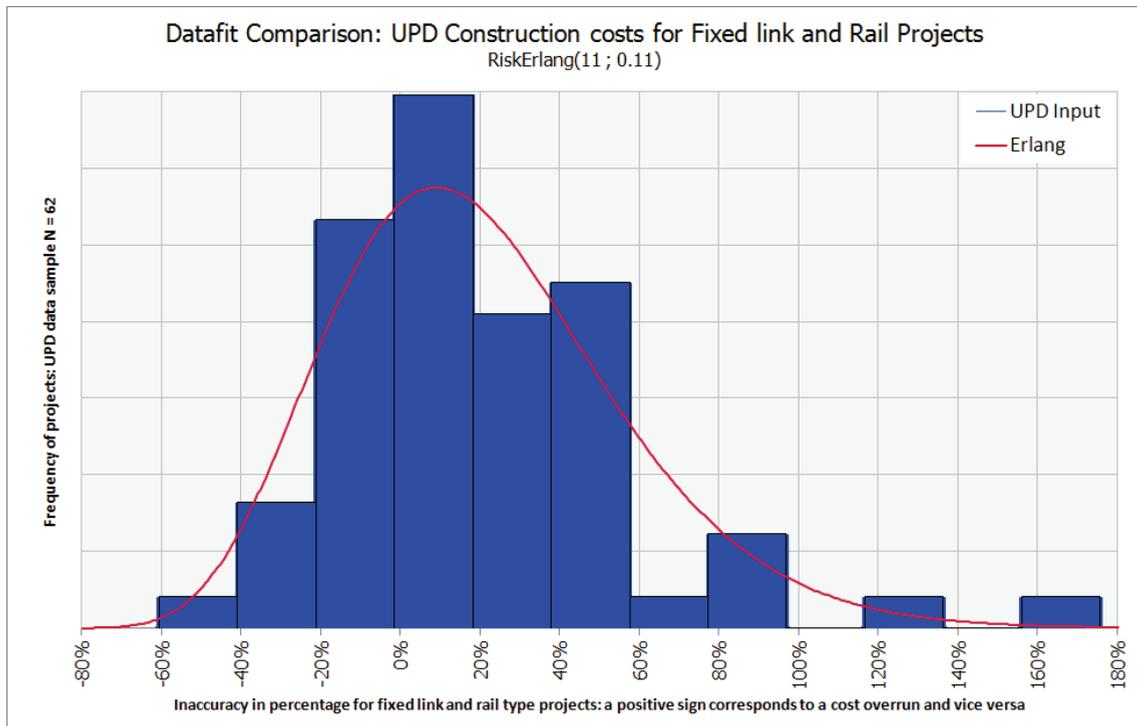

Fig. 3. Inaccuracies of cost estimates for fixed link and rail projects (UPD data sample of N = 62 and average 20.4%). The figure show the percentage distribution of projects with respect to cost over/underrun (constant prices), thus, a positive sign refers to estimated costs are underestimated (Ambrasaite *et al.*, 2012)

Figure 3 furthermore presents the initial data fit depicting an Erlang distribution with the shape $k = 11$ and the scale $\theta = 0.11$. Hence the data fit conducted adjacent to the UPD findings support the previous PDs (Salling, 2008) where it was concluded that an Erlang distribution with $k = 8$ and $\theta = 0.09$ and a Normal distribution with the standard deviation of 0.15 would be applicable to represent the uncertainties for respectively the construction costs and demand forecasts.

4. Findings and discussion

Enhancing the deterministically found BCRs into probabilistic accumulated descending graphs is made through anchoring the CBA results and hereafter assign distributional information on the uncertain impacts. Herein, so-called certainty graphs are derived depicting the certainty of feasibility i.e. a probability of a particular project to obtain a BCR equal to or higher than 1.00 (Salling *et al.*, 2010).

Thus, a fixed model run in the UNITE-DSS model produce the following set of certainty graphs for each of the four selected alternatives of the HH-Connection project, see Figure 4.
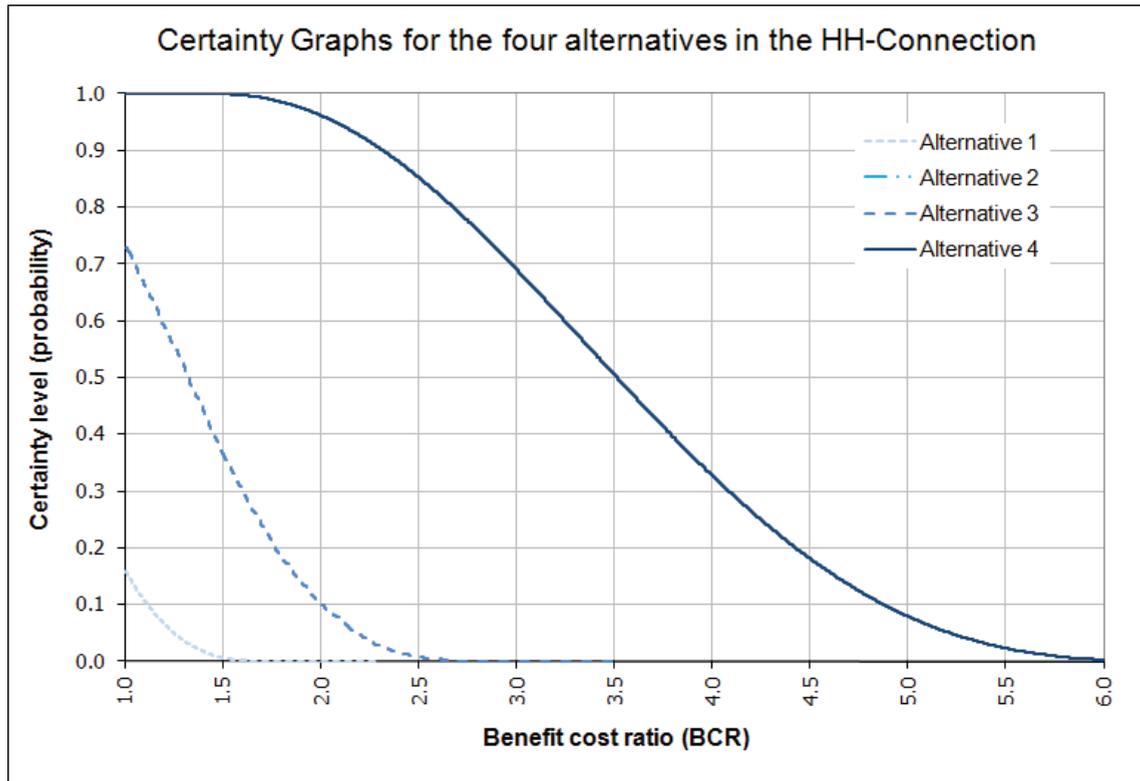

Fig. 4. Certainty graphs for the four alternatives of the HH-Connection.

Figure 4 illustrates the certainty given respectively an Erlang distribution describing the estimation uncertainty of the construction cost and a Normal distribution describing the uncertainty in demand forecasting. Thus, Alternative 4 which in Table 1 delivered the highest BCR also produces the most certain results with a certainty of 100% of achieving a feasible project. However, Alternative 3, which in Table 1 entailed the highest NPV only produces feasible BCRs in 80% of the simulations. Thus, Alternative 3 allows for 20% infeasible results which for many decision-makers, given the large amount of money invested, would either be rejected or at least subjected to further scrutiny. Obviously, Alternative 1 and 2 should be rejected immediately due to their low certainty of feasibility - even though Alternative 1 actually produced feasible results in the CBA.

5. Conclusions and perspective

A new approach to risk-based decision support, UNITE, has been outlined for the purpose of undertaking risk analysis with regard to the socio-economic feasibility of large transport infrastructure investments. In recent years as briefly reviewed, this is a topic that has been examined by several researchers based on using reference class forecasting, which led, among other things, to uplift factors and new software considered to be an improvement compared to conventional sensitivity analysis.

The development of an UNITE approach, aiming at assisting informed decision making under the perspective of comprehensive consideration of the main uncertainties has been found to be related to obtaining reliable estimates for construction costs and transport demand. In the paper the focus has been on transport costs and demands exemplified by the new fixed HH-Connection. Specifically, a quantitative risk analysis has been made use of in combination with Monte Carlo simulation, establishment of a new, enlarged project database (UPD), data fitting and spread sheet modeling by the use of the UNITE-DSS decision support model.

Based on the findings and work carried through so far it can be concluded that the need for risk-based decision support is of huge relevance. Specifically, from the case study findings, Alternative 1 and 3 produce clear feasible results given the CBA, however, embedding the uncertainties presented in terms of respectively the Erlang and Normal distributions, it is made evident, that the certainty is merely 80% for Alternative 3 and 20% for Alternative 1 - leaving much debate for the decision-makers and stakeholders whether to pursue such alternatives or not.

The UPD database described is still at an early stage for which reason, the findings must be taken with some precaution. The UNITE research project will continue until the end of 2013 and it is expected to be able to present results based on more cases and empirical analysis. A major foundation here will be the fully-established project database made in collaboration between the partners in the UNITE project. Moreover, in order of determining the extreme boundaries for the distributions new and further explorations are made in terms of decision conferencing and overconfidence theory elaborating further on group decisions and psychology.

References

Ambrasaite, I., Leleur, S., Nicolaisen, M. S., & Salling, K.B. (2012). UPD - the UNITE Project Database: Collection of reference class information. *Database concerning cost and demand inaccuracies,* database developed as part of the UNITE (Uncertainties in Transport Project Evaluation) project funded by the Danish Council for Strategic Research (2009-2013).

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

Beukers, E., Bertolini, L., & Te Brömmelstroet, M. (2012). Why Cost Benefit Analysis is Perceived as a Problematic Tool for Assessment of Transport Plans: A Process Perspective. *Transportation Research Part A*, 46(1), pp. 68-78.

Cantarelli, C. C., Flyvbjerg, B., van Wee, B., & Molin, E. J. E. (2010). Cost overruns in large-scale transportation infrastructure projects: Which explanations can be given. *European Journal of Transport Infrastructure Research*, 10(1), pp. 5-18.

DTU Transport (2011). Key Figure Catalogue: Unit prices for use in the socio-economic analysis on the transport area. *Unit prices for transport impact assessment*, Spread sheet model, www.transport.dtu.dk.

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

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

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

Haezendonck, E. (2007). *Transport Project Evaluation*. (Eds.) Cheltenham: Edward Elgar Publishing.

Herder, P.M., de Joode, J. & Ligtvoet, A. (2011). Buying Real Options - Valuing Uncertainty in Infrastructure Planning. *Futures-the Journal of Policy Planning and Futures Studies*, 43(9), pp. 961-969.

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

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 prepared for the Department of Transport, London, United Kingdom.

Priemus, H., Flyvbjerg, B. & van Wee, B. (2008). *Decision-Making on Mega-Projects: Cost-Benefit Analysis, Planning and Innovation*. Cheltenham: Edward Elgar Publishing.

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

Salling, K. B., & Banister, D. (2009). Assessment of large Infrastructure Projects: the CBA-DK model. *Transportation Research part A: Policy and Practice*, 43(9-10), pp. 800-813.

Salling, K. B., Leleur, S., & Skougaard, B. Z. (2010). Reference Scenario Forecasting: A new approach to Transport Project Assessment. Presented and in Proceedings of the *10th World Conference on Transport Research* (WCTR), Paper ID no. 03325, Lisbon, Portugal.

Salling, K. B., & Leleur, S. (2012). Modelling of Transport Project Uncertainties: Risk Assessment and Scenario Analysis. *European Journal of Transport Infrastructure Research*, 12(1), pp. 21-38.

Ševcíková, H., Raftery, A. E., & Waddell, P. A. (2011). Uncertain Benefits: Application of Bayesian Melding to the Alaskan Way Viaduct in Seattle. *Transportation Research Part A*, 45(6), pp. 540-553.

Vose, D. (2008). *Risk Analysis - A quantitative guide*. (3rd ed.), John Wiley & Sons Ltd., UK.

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