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APPRAISAL OF AIRPORT ALTERNATIVES IN GREENLAND BY THE USE OF RISK ANALYSIS AND MONTE CARLO SIMULATION

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ABSTRACT

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

1 INTRODUCTION

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

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

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

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

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

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

2 THE GREENLAND CASE

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

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

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

Figure 1. Map of Greenland with the two important cities Nuuk and Kangerlussuaq

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

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

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

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

3 THE DETERMINISTIC CALCULATION

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

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

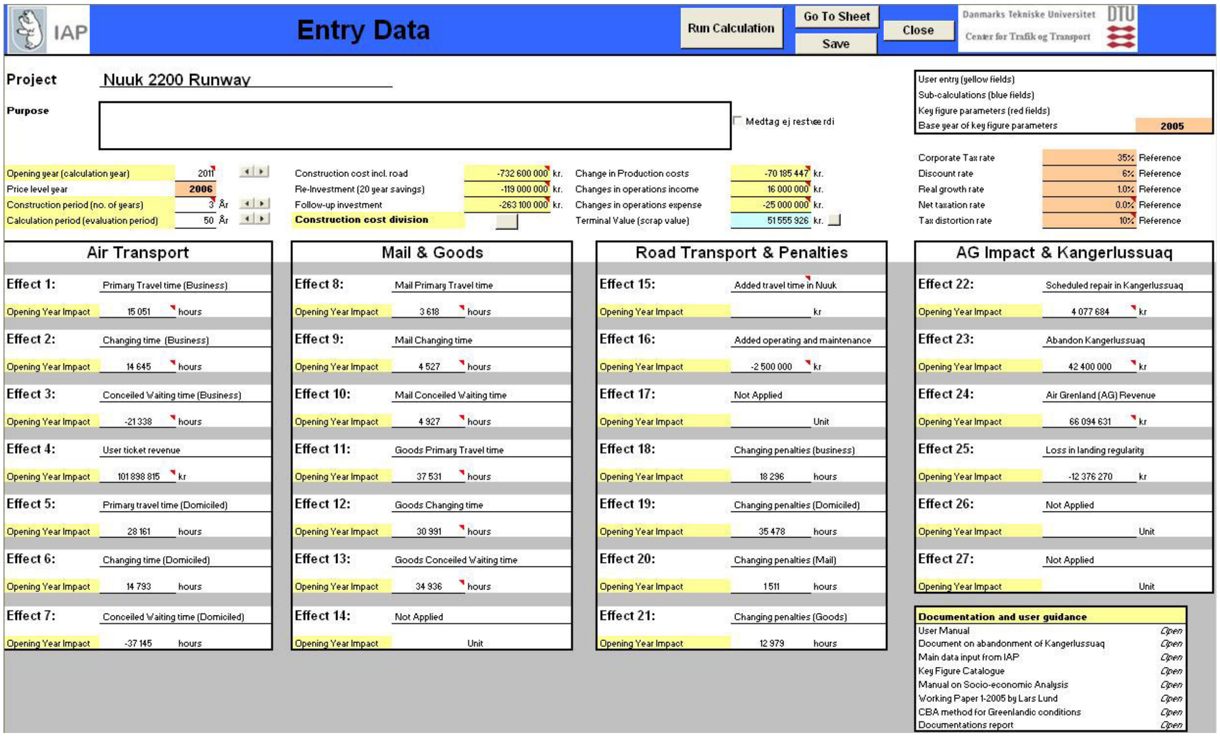


Figure 2: Overview of the Entry data sheet from CBA-TGB, the Nuuk 2200m Runway Alternative

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

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

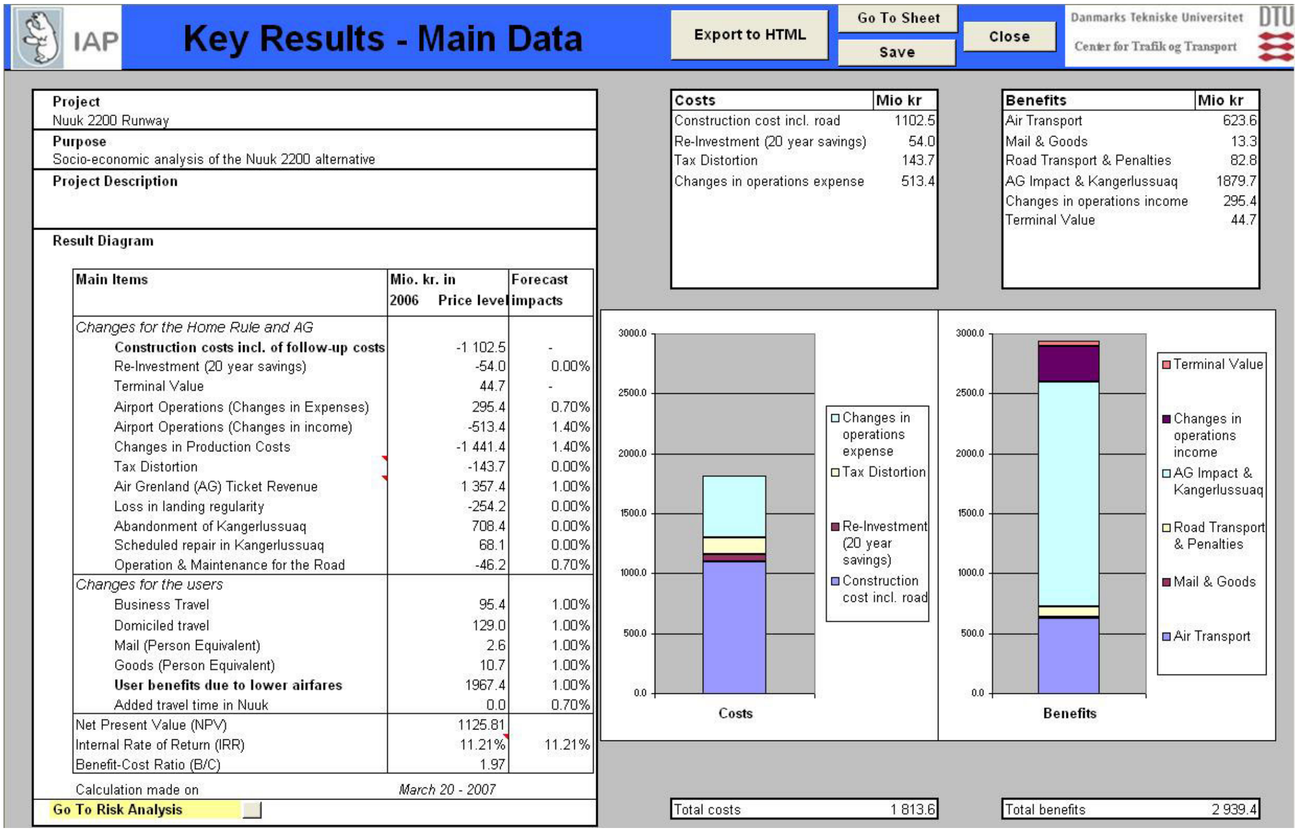
The resulting evaluation criteria for all three alternatives are listed in Table 1 together with their investment costs in present values[i].

Table 1: Overview of results for the three alternatives

	Nuuk 1799	**Nuuk 2200**	**Nuuk 3000**
Investment	759.3 Mkr	995.7 Mkr.	2432.1 Mkr
NPV	701.2 Mkr	1125.8 Mkr	-814.2 Mkr
IRR	10.8%	11.2%	4.4%
B/C-ratio	1.80	1.97	0.72

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

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



Main Items	Mio. kr. in 2006 Price level	Forecast impacts
Changes for the Home Rule and AG		
Construction costs incl. of follow-up costs	-1 102.5	-
Re-Investment (20 year savings)	-54.0	0.00%
Terminal Value	44.7	-
Airport Operations (Changes in Expenses)	295.4	0.70%
Airport Operations (Changes in income)	-513.4	1.40%
Changes in Production Costs	-1 441.4	1.40%
Tax Distortion	-143.7	0.00%
Air Grenland (AG) Ticket Revenue	1 357.4	1.00%
Loss in landing regularity	-254.2	0.00%
Abandonment of Kangerlussuaq	708.4	0.00%
Scheduled repair in Kangerlussuaq	68.1	0.00%
Operation & Maintenance for the Road	-46.2	0.70%
Changes for the users		
Business Travel	95.4	1.00%
Domiciled travel	129.0	1.00%
Mail (Person Equivalent)	2.6	1.00%
Goods (Person Equivalent)	10.7	1.00%
User benefits due to lower airfares	1967.4	1.00%
Added travel time in Nuuk	0.0	0.70%
Net Present Value (NPV)	1125.81	
Internal Rate of Return (IRR)	11.21%	11.21%
Benefit-Cost Ratio (B/C)	1.97	

Costs	Mio kr
Construction cost incl. road	1102.5
Re-Investment (20 year savings)	54.0
Tax Distortion	143.7
Changes in operations expense	513.4
Total costs	1 813.6

Benefits	Mio kr
Air Transport	623.6
Mail & Goods	13.3
Road Transport & Penalties	82.8
AG Impact & Kangerlussuaq	1879.7
Changes in operations income	295.4
Terminal Value	44.7
Total benefits	2 939.4

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

4 THE STOCHASTIC CALCULATION

The methodology used within the stochastic calculation is Monte Carlo simulation (MCS) where appropriate probability distributions are applied on the uncertain parameters and variables. The results derived from Figure 3 give a clear identification of the main input variables that have the strongest effect on the overall framework model. It is clear that one of the key impacts is the investment costs (construction costs). Several studies have tried to determine the magnitude of uncertainty in the determination of the transport infrastructure project costs. In Salling & Leleur (2006) it is suggested to use the Lichtenberg's principle (Lichtenberg 2000) together with an Erlang distribution to illustrate the uncertainty of the construction costs. Furthermore, the travel time savings and especially the user benefits due to lower airfares are of significance. In the CBA-TGB framework this impact is treated with a normal distribution "describing" the uncertainties within the underlying traffic- and passenger flow model. The results are presented graphically using three different assumptions regarding the probability distribution: (1) only applying the Erlang distribution, (2) only applying the normal distribution and (3) a combination of the two.

4.1 Construction costs (investment costs)

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

Back et al. (2000) propose four conditions to be satisfied when assigning a probability distribution, a.o. that the distribution must be able to have a greater freedom in its tales as skewness must be expected. Further investigation show that the Gamma distribution converted to an Erlang distribution fulfills this condition (Salling & Leleur 2006). An adjusted method of the succesive principle is embedded within the CBA-TGB framework by the use of a triple estimation producing a mean (μ) on the basis of the ex-ante estimated investment costs (most likely *ML*), the minimum occurrence of investment cost (*min.*) and the maximum occurrence (*max.*) as illustrated by formula (1) (Lichtenberg 2000).

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

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

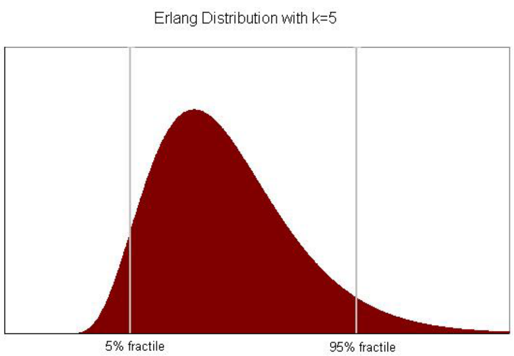


Figure 4: The Erlang distribution implemented for the construction costs with skewness parameter *k*=5

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

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

The construction costs are seen as influenced by ontological uncertainty stemming from the inherent randomness in the modeling system (variability). This type of uncertainty depicts the flaws within any modeling system ultimately resulting in a type of randomness. Further simulations/calculation do not lead to a significant decrease of uncertainty thus a change in the existing framework would be recommended (Salling & Leleur 2006). In this light the following simulation only applying the construction cost denotes the variability of the CBA-TGB modeling system i. e. illustrated by the steepness of the curves.

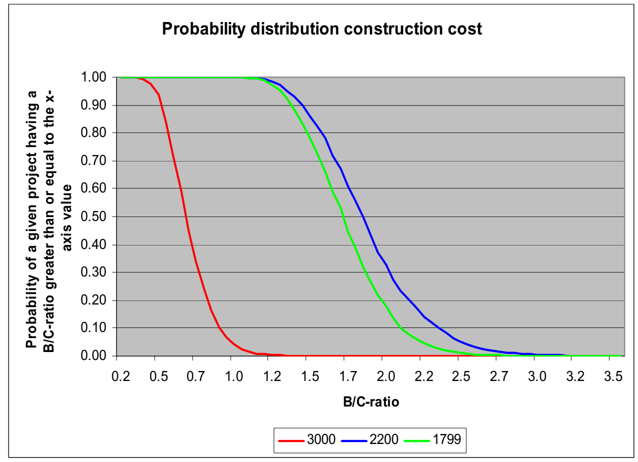


Figure 5: Resulting accumulated probability distributions of the three Nuuk alternatives for the construction costs

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

4.2 Travel time savings

Traditionally, when predicting future traffic flows various techniques can be used if historical performance data in addition to current traffic flows are accessible. This could be accomplished using methods such as exponential smoothing, regression analysis and curve fitting (Vose 2002). The historical data in the Greenlandic case, however, creates a major challenge because of low and fluctuating traffic at present and in the past. The net changes of passengers after the implementation of a new airport due to the induced traffic lead to such changes that historical data will be of less value. Uncertainty within the future passenger flows must therefore be expected determined in the following as epistemic uncertainty due to "lack of knowledge" (Walker et al. 2003).

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

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

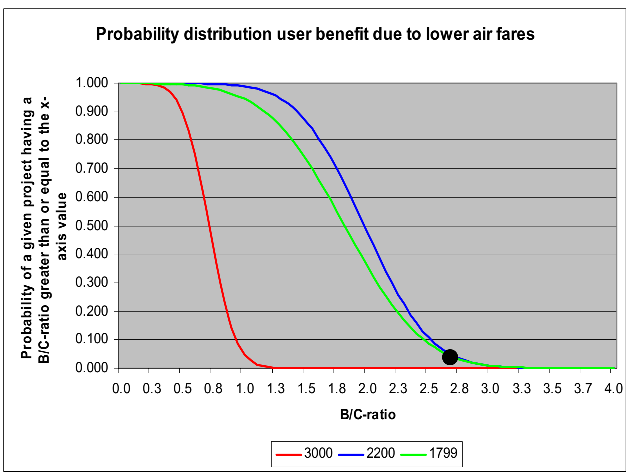


Figure 6: Resulting probability distributions of the three Nuuk alternatives for the user benefits due to lower airfares

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

4.3 Overall results

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

In Figure 7 the overall results are illustrated.

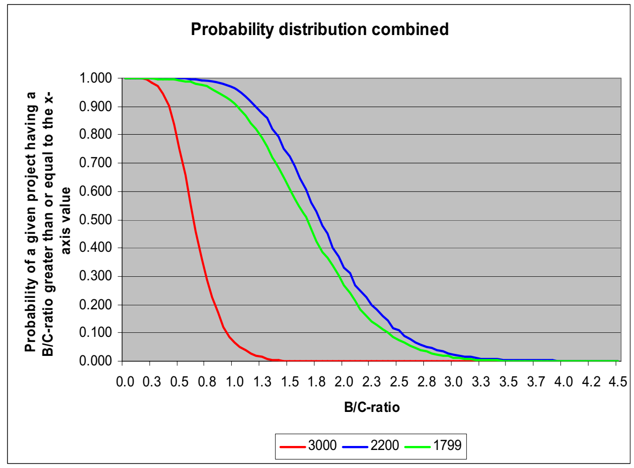


Figure 7: Resulting graphs of the B/C-ratio implementing both Erlang- and normal distributions

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

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

5 CONCLUSION AND PERSPECTIVE

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

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

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

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