Transport assessment and risk analysis: the case of the 2nd fixed link across the Danube River

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Abstract

The scope of this paper is to present a new methodology for appraising transport infrastructure projects. Conventionally, transport infrastructure appraisal is conducted by the use of cost-benefit analyses (CBA) in order to produce aggregated single point estimates. However, new research has proved that the embedded uncertainties within traditional CBA such as ex-ante based investment costs and travel time savings are of high significance. This paper investigates the latter two impacts in terms of the Optimism Bias principle which is used to take account of the underestimation of construction costs and the overestimation of travel time savings. By extending this principle into stochastic modelling where a quantitative risk analysis (QRA) is applied, so-called feasibility risk assessment is provided by moving from point (deterministic CBA) to interval (stochastic QRA) results. Hereby, decision support as illustrated in this paper will aim to provide assistance in the development and ultimately the choice of action, while accounting for the uncertainties surrounding transport appraisal schemes. Evidently, the methodological approach is illustrated by a case example from the Northern region of Bulgaria.

Keywords

Cost-benefit Analysis, Decision Support Model, Optimism Bias, Quantitative Risk Analysis, Monte Carlo Simulation

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Introduction

Project appraisal is the process of comparing virtues and deficiencies of a project. The task is to find the consequences of a project and to handle this knowledge. It is obvious that a project is only feasible if the virtues compensate for the deficiencies and that the best project is the one where the so-called net gain is the greatest. The challenge is to find a method to describe the criteria in a way that makes them comparable and to find a rational and trustworthy method to compare the criteria. Traditionally, cost-benefit analysis (CBA) is applied leading to a set of investment criteria that can be further exploited. However, this set of deterministic single point output criteria are based upon "best guess" estimates of each input variable to the assessment scheme. Thus, the CBA depicts more of a most likely value of the transport project rather than the actual value. To distinguish the latter, various combinations for each input variable is normally selected creating a set of worst and best case scenarios. These combinations of possible values around the best guess are commonly referred to as "what if" scenarios or sensitivity tests. However, the assessment of transport projects increasingly requires a greater understanding of the complexity of alternatives and the underlying transportation impacts. Hence, the number of "what if" scenario combinations increases rapidly, making these type of analyses very confusing for decision-makers and stakeholder. This paper sets out to explore the latter in terms of two supplementary methodological approaches respectively by the Optimism Bias principle and a quantitative risk analysis (QRA) technique.

The Optimism Bias principle is defined as the percentage difference between ex-ante (before) estimates of the appraisal and ex-post (after) values from the final outturn of the projects (MacDonald, 2002; Flyvbjerg et al., 2003) These levels of uncertainty can be applied in ex-ante based project appraisal studies, but they are currently more or less disregarded in transport appraisal schemes in Denmark (Salling, 2008). This approach has been applied as so-called uplifts to the construction costs where varying degrees of acceptable Optimism Bias has been determined. The second approach relies on QRA by the use of Monte Carlo simulation, which is very similar to a traditional sensitivity analysis, as it generates a large number of possible scenarios. However, the simulation procedure goes one step further by generating a large set of values that each input variable can take and weighs each scenario by the probability of occurrence. Consequently, instead of receiving single point results, the decision-makers receive interval results in terms of an output probability distribution. An advantage of this approach is the possibility of incorporating expert opinions in terms of choosing the most suitable probability distributions and the determination of appropriate limits (intervals).

The remaining parts of the paper will be structured as follows. Following this introduction a description of the case study concerning the second fixed link across the Danube River is discussed. Hereafter, a brief introduction is made to the decision support model of CBA-DK. The model consists of the two types of analyses, as described above, resulting in feasibility risk assessment. For each method a sub-section in the paper is provided, together with detailed definitions all relating to the case study of the fixed link connection of Danube River. Furthermore, the analysis makes use of a so-called reference class forecasting (RCF) technique in terms of Optimism Bias. Finally, a set of conclusions and a perspective are presented.

The Case Study

Consequently, as a missing part of a vital transport corridor in the Eastern part of Europe (Corridor # 4), lies the fixed link across the Danube River between the two towns of Vidin (Bulgaria) and Calafat (Romania). Being the connection of Europe with the Middle East, during the last years, Bulgaria is trying to reconstruct the existing connection in terms of a new road and railroad link, in order to improve the local, regional and long-distance traffic between the two countries. The decision to build a bridge at that place of the river is due to the need for better integration of the continent and the actual consumption of transport. Figure 1 is presenting a map of Bulgaria with the major roads and highways – where the red mark is depicting the location of the second fixed link over the Danube River and the green mark is illustrating the location of the existing bridge between Rousse (Bulgaria) and Giurgiu (Romania) – Friendship Bridge, which is a part of transport Corridor #9 (the 1st fixed link across the Danube River).

TRANS-EUROPEAN CORRIDOR IV

Figure 1. Illustration of the 2nd fixed link across the Danube River (UNECE, 2004)

The bridge, as a part of the European Corridor Number 4 (according to the second Pan-European transport Conference, March 1994[1]), is representing an important connection between Europe and the Middle East. The lack of fixed links across the Danube River, the need for faster connections between Western Europe and Istanbul, as well as the desire for improvements in the infrastructure and the necessity for economical development in this part of the Balkans have led to the proposal of constructing this second link across the Danube River. Today, it is extremely troublesome to make the journey from Bulgaria to Romania, since the existing ferry line runs very unscheduled and slow.

Construction of the bridge in the region will attract investors and tourists, and thus will have a major impact on the economy in the Northwest Bulgaria, considered as the poorest regions in the country. Several factors have played an important role in determining the location of the bridge. The desire to replace the low capacity ferry line with a fixed link connection has been the main reason for this new infrastructure project. Construction of a combined bridge at this place of the river will improve the travel times and at the same time create a link between the three various transport modes - road, rail and water. Transport Corridor 4 provides a direct

[1] The Pan European Transport Corridor IV is a working group within the European Commission. Details can be found on http://www.tinavienna.at/corridor4/.

connection from the port of Thessaloniki to the Danube River and from there - to the inland parts of Europe. Locating the bridge at this place will play an important role in the stability of the region, for the economical development and integration, not only for Bulgaria, but for Romania and the other neighbouring countries as well. Building a fixed link Vidin - Calafat will be a symbol of a new stage of the European integration of Bulgaria. Expectations of people living in the region are high. The bridge will play the role of catalyst for socio-economic development throughout the region.

Three kinds of problems accrue with the project: *technical problems*, which represent the difficulties appearing during the construction such as material specification, changes in the project, implementation, etc.; *organizational problems*, connected with the co-operation and funding between Bulgarian and Romanian governments, companies, organizations, etc. and final *administrative problems* which mainly are due to the different legalizations in the two countries. The overall length of the link is approximately 2 kilometres and it will ultimately have 2 tracks in each direction together with an emergency lane and a bicycle and pedestrian lane. The estimated construction cost in current prices (2008) is set to €106.3 mio. Currently, Bulgaria has no unique guidelines on how to perform socio-economic analyses, thus; fixed unit prices together with other standard measures are not directly available. Hence, this paper will apply Danish standards combined with various coefficients and parameters from the European commission, e.g. the IMPACT study (CE Delft, 2008) and TEN CONNECT (TEN CONNECT, 2008).

The main data for the fixed link project is collected from the Bulgarian Ministry of Transportation and other local authorities. These are the travel time savings, vehicle operating costs, construction costs etc. The information related to external effects such as noise, pollution, etc. on the other hand, is not directly accessible. Hence, correspondence with local and regional authorities together with relevant companies is made in order to access reliable data and parameters. Finally, the assessment of freight train operation and ultimately unit prices are currently not accessible. However, future developments as part of a master thesis project elaborate upon this impact by incorporating it into a so-called multi-criteria analysis (Mudova, 2009). Applying a standardized methodological approach such as CBA and QRA with regard to transport appraisal has to the authors knowledge never been implemented within Bulgaria before. This first attempt to render visible a new approach to assessing transport projects in Bulgaria will hopefully take part in the start-up process of a transport assessment manual corresponding to the Danish (DMT, 2003).

The CBA-DK decision support model

The CBA-DK model consists of two modules – 1) a deterministic module, which includes the CBA, and 2) a stochastic module or Risk Analysis Module taking the various uncertainties into account. A schematic view of the model is presented on Figure 2. The CBA is following the guidelines created by the Danish Ministry of Transportation (DMT, 2003) and the future investments are calculated and assessed by the use of single point estimates.

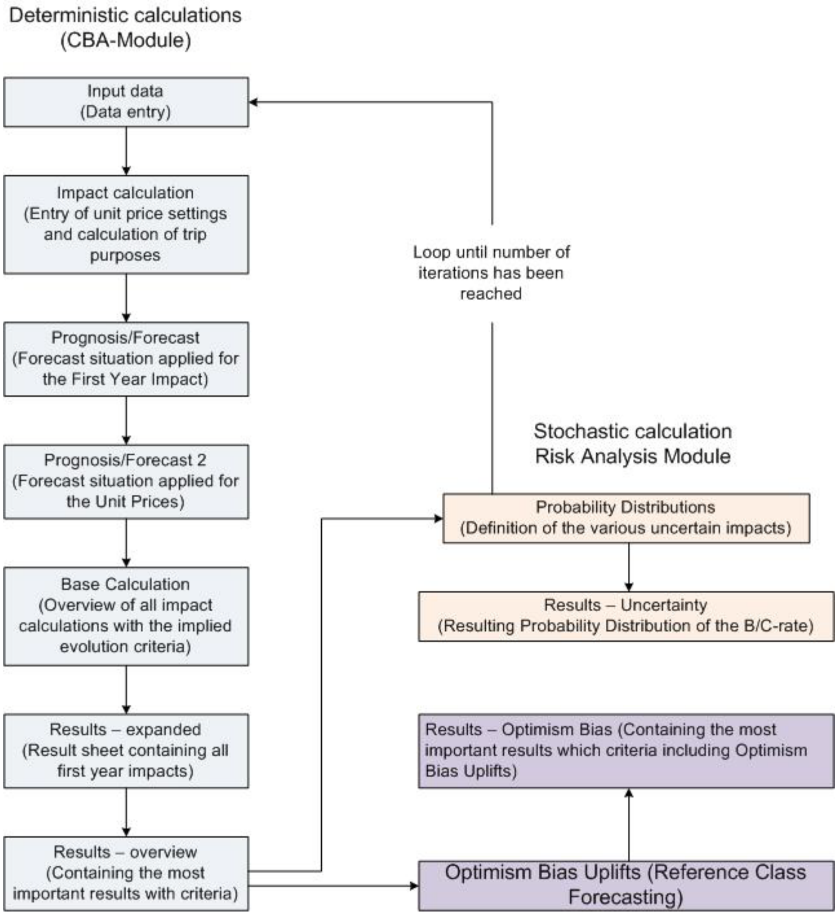

Figure 2. The module structure of CBA-DK shown by the various worksheet (adapted from Salling, 2008)

The remaining part of the paper contains information with regard to a preliminary calculation within CBA-DK for the case project regarding the second fixed link across the Danube River.

Cost-benefit analysis

The purpose of the CBA is to determine whether or not a project should be realized by analyzing all the costs and the benefits that result from the project. The CBA module (deterministic) for the investigated project is divided onto four categories: Passenger Cars, Passenger trains, Freight Trains and External Effects. The first two categories summarize information on current traffic and future expectations, considering impacts as travel time savings, vehicle operating costs, congestion and changing traffic. The rule-of-a-half method (RoH) is used in order to determine the volume of the changing traffic. Currently, the Freight Train's is missing data, hence the travel time savings etc., is not implemented within this paper (it is, however, intended to include this information in the finalized Master thesis project). Finally, the changes in revenue have been determined based upon ticket prices from the existing ferry line and the existing bridge connection (Danube Bridge I). This impact corresponds to the highest benefit since it depends on the increase in traffic. Additional information needed for the analysis, such as: construction cost, operating and maintenance cost, evaluation period, discount rate, etc. is shown in the top of the input data sheet (Figure 3).

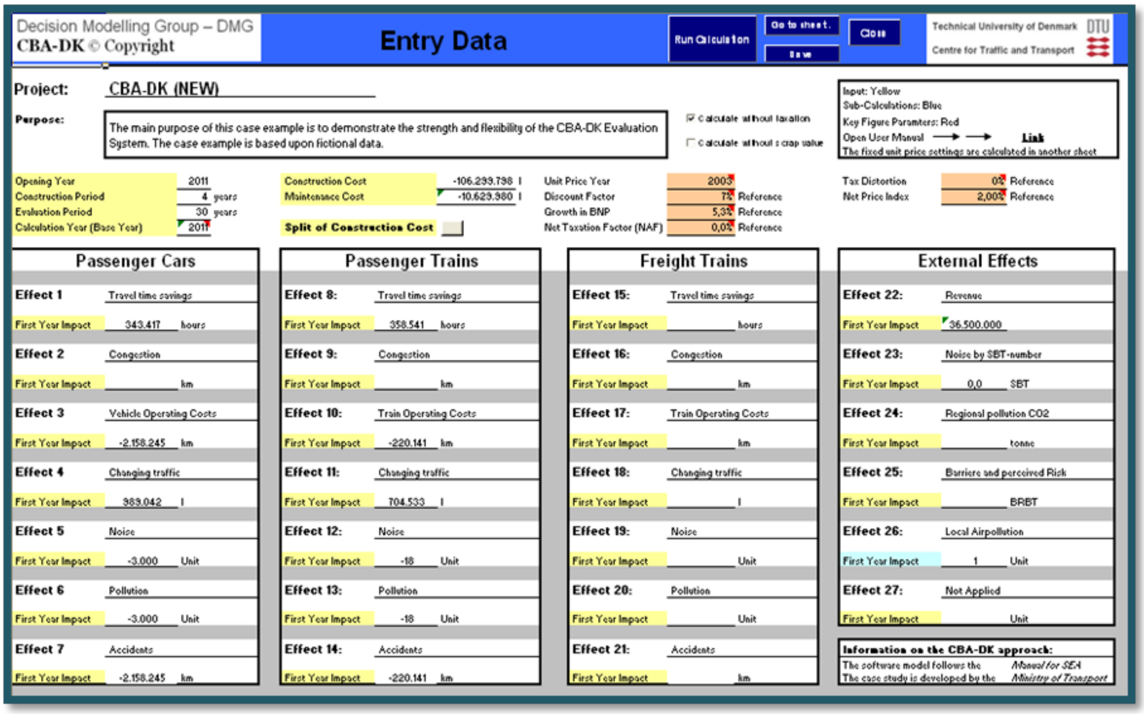

Figure 3. Input data sheet form CBA-DK (Mudova, 2009)

The following gives a detailed description of the different parameters, included in the CBA-DK input data sheet, as well as an explanation on how the values are derived.

Construction Cost
The construction cost estimate is one of the most significant effects, as it has the greatest impact in the evaluation of the projects. It is important to make accurate forecasts for the costs of the future infrastructure project and based on them to calculate the funding and to determine the overall budget of the construction. Unfortunately, however, that budget is often exceeded, since the latter e.g. relies on changing governments, administrative and technical problems encountered during construction, and alteration of the material prices. Another very important factor that influences the budget of a project is the manner such projects is amended in time. When designing the equipment, attention is paid to the traditional impacts, such as type of construction, pavement, materials, etc. In the process of actual construction, must often, arise changes dictated by the current situation, the appearance of new methods or changes in the surrounding environment. They require a change in the price and that change is impossible to take into consideration in the design phase.

In Bulgaria, when a raw budget is done the length of the facility and unit price per kilometer of the bridge, including all costs, is taken into account. When the project is approved a more accurate pricing is done, taking appropriate quantity of material to be used in the building stages, multiplied by the unit price and the length of the bridge. Additional costs such as labour; design; supervision, etc is also taken into consideration before calculating the final budget.

The construction cost for the project is equal to the sum of the implementation cost plus the price paid for the bridge supervision. Thus, the construction cost for the CBA calculations is estimated to be €106.3 mio. Maintenance cost in Bulgaria is usually taken as 10% of the construction cost, which in this case equals €10.6 mio (Mudova, 2009).

Discount ratio and Gross Domestic Product
In the CBA calculation the discount ratio and the growth in Gross Domestic Product (GDP) is used. According to the Central Intelligence Agency (CIA) report for Bulgaria the discount ratio for the country is determined to be 5.77 % (CIA, 2009). This ratio is very similar to the one applied in Denmark (6%) where a general rule of thumb is to apply 6% if taxes and other subsidies are implemented and 7% if they are disregarded. For this case study, a discount ratio of 7% has been applied since no common ground has yet been set with regard to the taxation rules.

Another factor, needed for the socio-economic analysis, is the current as well as the estimated future growth in GDP. While "traditional" Western European countries have relatively constant growths each year, Bulgaria is experiencing a rather explosive growth per year. This is due to the fact that after the end of the Communism, the economy of Bulgaria is in the process of development and every year major changes occur. In order to complete the CBA calculations the average value of GDP from the last 5 years is taken, namely 5.3%, see Figure 4. For comparison reasons a GDP growth of 2% is applied in Denmark.

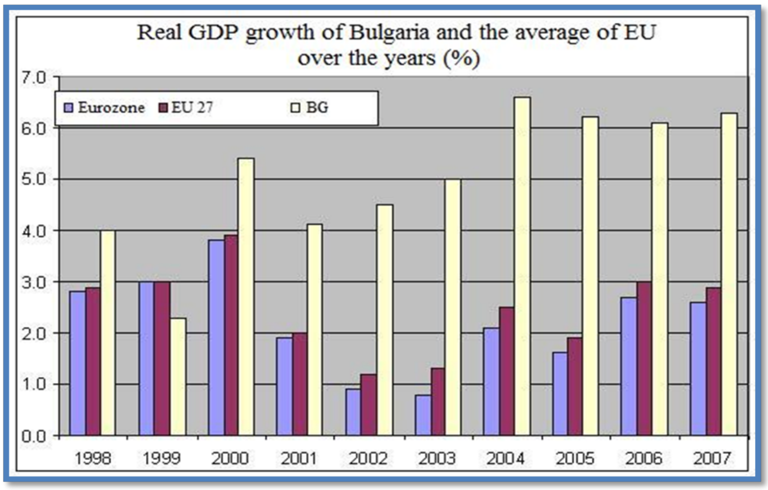

Figure 4. Growth in GDP for Bulgaria and EU (www.broker.bg, 2008)

Figure 4 shows the changes occurred in the GDP value since 1998 for three different groups – Euro zone, the 27 European Union members and Bulgaria. The last four years have shown explosive growths in Bulgaria with annual rates above 6%.

Travel Time Savings
One of the key advantages of constructing a new transport infrastructure or reconstructing an existing one is the reduction of travel time. In many cases the benefits of travel time savings (TTS) reaches 70-90% of the total benefits (Leleur 2000, p.108). TTS for this project represents the annual amount of hours that are saved by the drivers from crossing the bridge compared to the time required to cross the same distance, but with a ferry.

Presently the connection between Vidin (Bulgaria) and Calafat (Romania) is realized by ferry line. Time required for traveling from one bank to the other is approximately 40 minutes with 20 minutes of sailing and 20 minutes of loading[2]. After constructing the new link it is expected that distance will be overcome approximately in 5 minutes (the bridge speed is set to 100 km/h and the total length is 1,971 km, however, payments etc. must be taken into

[2] The 20 minutes time for loading is an averaged value where the ferry will depart whenever it is fully loaded. Thus, cases occur when it takes 1 hour before departure.

account). Hence, it follows that the time the driver will save on travel, after the construction of the fixed link is approximately 35 minutes. Opening the bridge will increase the traffic on the link with 2-3 times or even more, depending on the economical growth in the region.

It is expected that the construction induces a substantial amount of traffic in this part of the Eastern European Corridor. Hence, three forecast scenarios have been adopted based on the economic development in the region after improving the accessibility and mobility. The first forecast scenario corresponds to a low macro-economic growth in the region where the traffic increases with 3,000 ADT (annual daily traffic) which correspondingly is applied within the CBA calculations. The second scenario sets out on a moderate economic growth with a traffic increase of 5,000 ADT and the third scenario with a high economic development increases the traffic with 10,000–12,000 ADT (Evtimov, 2004). The constructed CBA for this paper is based on the lowest traffic forecast, namely 3,000 ADT. Hence, the TTS effect will generate a net yield towards the society of approximately 350.000 hours per year. The construction period set out in the contract is equal to 4 years and the official start of the project was 2007, hence the opening year is 2011 (BMT, 2007).

Given that the traffic flow is expected to be 3000 vehicles per 24-hours (in the case of a low economic development in the region), the TTS is calculated to be 343 417 hours per year. The TTS for passenger trains is calculated the similar way as the passenger cars travel time savings. According to the traffic data it is expected that 18 passenger trains will pass the bridge for 24 hours time period. At the moment there is no train connection between the towns of Vidin and Calafat. Hence, TTS for passenger trains is estimated to be 358 541 hours per year.

Changing traffic
Most often the amount of induced or changing traffic is calculated by use of various traffic models. However in the Bulgarian case, the *rule of a half* (RoH) principle is applied stating that the changing traffic only receives 50% of the overall travel time benefits and the existing users receive 100% of the travel time savings. Hereby the changing traffic associated with vehicle transport in the first year of operation results in a benefit of nearly €1 mio whereas the changing traffic corresponding to passenger trains results in €705.000. It has been assumed that the newly generated amount of passenger trains is set to approximately 1 per hour except from 12AM to 6AM, or 18 passenger trains (Mudova, 2009).

Revenue
The revenue is very close connected with the travel time savings effect in which this impact relies on the amount of traffic using the bridge. The general impact is made up by a simple comparison between the ex-ante based costs of using the ferry line service and the ex-post based costs (tolls) of crossing the bridge. Thus, the toll is based on the current bridge across the Danube River between Rousse and Giurgiu (Danube Bridge I) as presented in Table 1. The current state of the data available from the second fixed link across the Danube River is not segmented between transport modes, i.e. an average has been made between cars and trucks.

Type of vehicle	Size (tonne)	Fee on the Bulgarian Border
Car	> 3.5	€6.00
Truck	3.5 -7.5	€12.00
Truck	3.5 -7.5	€18.00
Buss	7.5 -12.0	€25.00
Truck	>12.0	€37.00

Table 1. Taxes paid to gross Rousse – Giurgiu Bridge (Mudova, 2009)

Thus, the average fee is calculated to be 20 €/vehicle. The total revenue per year is calculated to be €21.9 mio.

Vehicle/train operating cost
In order to determine vehicle/train operating costs, several components are taken into account, such as fuel consumption, engine oil consumption, tyre wear, maintenance costs, depreciation, vehicle capital costs, etc. Based on the latter a unit price can be derived as shown in the Key Figure Catalogue (DMT, 2006). This unit price setting is used in the CBA calculations by multiplying it with the amount of respectively vehicle and train kilometres. For the vehicles it is estimated to be approximately 2 mio km and for the passenger trains it is 220.000 km.

External Effects
The three types of external effects embedded within this case specific calculation are noise, pollution and accidents. The accident savings and noise savings are taken as the sum of the kilometres travelled by the vehicle multiplied by a unit price (DMT, 2006). The pollution impact is split into local pollution consisting of pollutants such as, NO_x, SO_2, particles, etc. and a regional pollution consisting of CO_2 emission. Traditionally, this impact is calculated based upon the amount of pollution (kg/€) however, since the data material was sparse, this impact has been calculated based on kilometres driven €/km.

CBA Results
A fixed model run in CBA-DK produces a result sheet as shown in Figure 5. The set of decision criteria are presented in terms of a Benefit-Cost Ratio (BCR), Net Present Value (NPV), Internal Rate of Return (IRR) and First Year Rate of Return (FYRR). The left side of the sheet shows the main impacts, after applying the net changes, as well as the main criteria. The investigated case project produces a feasible result towards society with a BCR of 1.68 and a NPV of €112 mio. On the right hand side a graphical view of the costs and the benefits is presented. The most significant benefits from the assessment scheme stems from the revenue and the travel time related savings.

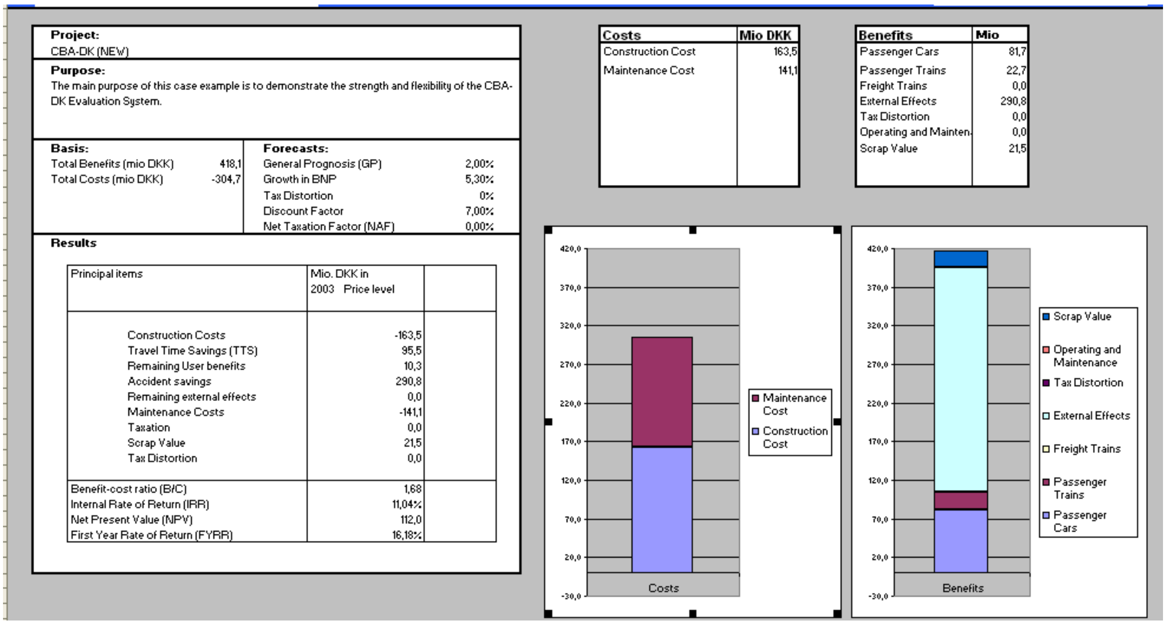

Figure 5. The most important case result from CBA-DK (Mudova, 2009)

The decision criteria point estimates depict the profitability of the case. However, it is increasingly a requirement within model based decision support to map and communicate the uncertainty underlying such estimates. The following section depicts two supplementary ways of addressing the uncertainties involved in making transport infrastructure appraisal namely by applying the Optimism Bias principle in terms of uplift parameters or by applying a quantitative risk analysis (QRA) resulting in feasibility risk assessment..

Optimism Bias

A clear tendency throughout the deterministic CBA calculation reveals that the two impacts of travel time savings and construction costs are the most important impacts within the analysis. The travel time savings follows the prognosis laid out in Evtimov (2004) where forecast models are described. Evidently, a large-scale literature and data study has proved that these two impacts holds substantial amounts of bias, in terms of underestimating the construction costs and overestimating the demand forecasts (Flyvbjerg et al., 2003). This comparative study relied upon a technique named reference class forecasting (RCF) in collecting ex-ante based and ex-post based data sets from different transport related projects covering rail, road and fixed link projects (Flyvbjerg, 2007). The theoretical background to RCF originates in prospect theory developed by Kahneman and Tversky in 1979[3] (Kahneman and Tversky, 1979). A reference class denotes a pool of past projects similar to the one being appraised. A systematic collection of differences between forecast and actual values is gathered for a range of similar projects, the deficiencies in the forecast process (for costs and demand) are compared, and this evidence is then used to improve current decisions. Experience from past projects is then collected, compared and used so that "planning fallacy" can be avoided (Buehler et al., 1994).

The research findings in e.g. Flyvbjerg et al. (2003) made the first attempt in empirically deriving data concerning transport infrastructure projects both ex-ante as well as ex-post. Hence, the general overstating of benefits and understating the costs were introduced as so-called Optimism Bias (Mott MacDonald, 2002). These assumptions tend to increase the feasibility of the transportation scheme, thus, a false sense of optimism is applied in the decision-making process.

From the range of data collected as part of the reference classes the resulting outcome can be determined in terms of so-called Optimism Bias uplifts, which are then related to the preliminary construction cost predictions. The uplifts should be applied to the estimated budget costs at the time of the decision to build. Thus, uplifts are referred to as the cost overruns calculated in fixed prices. Table 2 shows some of the uplifts applicable within transport infrastructure projects, for different levels of certainty ranging from 50-90% (Flyvbjerg and COWI, 2004).

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

Table 2. Applicable capital expenditure uplifts for selected percentiles applied to constant prices (adapted from Flyvbjerg and COWI, 2004)

[3] Daniel Kahneman received the Nobel prize in Economics in 2002 for his work in collaboration with Amos Tversky (1937-1996).

The Optimism Bias uplifts shown above are classified according to the risk aversion of decision-makers in terms of cost overruns. If a group of decision-makers for instance decides that the risk of a cost overrun must be less than 20% for a road type project, the construction cost estimate must be uplifted by 32%. Thus, if the initial budget estimate was 100 million DKK the final budget taking into account the Optimism Bias at an 80% probability level would be 132 million DKK. It is assumed that the acceptance levels of respectively 50% and 80% are to be applied in the following. The 80% acceptance level illustrates decision-makers with relatively low risk aversion whilst the 50% acceptance level depicts decision-makers with high risk aversion.

Results including the Optimism Bias Uplifts

Recalculating the case alternatives incorporating the Optimism Bias uplift in respective a 50 and 80% acceptance level, the following decision variables are determined (Table 3).

	Investment Original	Investment 23%	Investment 55%	BCR, 23%	BCR, 55%
Danube River case	106.3 mio	130.7 mio	165 mio	1.24	0.83

Table 3. Investment cost with Optimism Bias uplifts and the respective BCR (Mudova, 2009)

A summary of the construction cost and the percentage uplifts added to it, as well at the BCR changes with regards to the new investment is presented in Table 3. As it can be seen from the table, it is evident that by increasing the construction cost the BCR is getting reduced, which in the case of 55% uplifts leads to an unprofitable project. It is illustrated that actually by introducing Optimism Bias uplifts the project with a BCR of 1.68 decreases to 1.24 with a low level of acceptable Optimism Bias and 0.83 with a high level of acceptable Optimism Bias. Even though the uncertainties within the CBA are addressed, the general outcome is still produced in single point estimates, where decision-makers are confronted with three BCRs to base their decision. The following addresses this issue by introducing probability distributions instead of single point estimates in terms of a Monte Carlo simulation.

Quantitative Risk Analysis

Risk and uncertainties are key features of most business and government problems and need therefore to be assessed before any decisions are implemented. The essence of the traditional risk analysis approach is to provide the decision-maker with a mean to treat the totality of any future outcome. The advantage of using the QRA approach is the possibility of differentiating the feature of risk information in terms of outcome criteria such as the BCR by applying parameter related probability distributions (Hertz & Thomas, 1984).

In order to examine the risk (in our terminology risk refers to the uncertainty of making a wrongful or inadequate decision support) of the studied fixed link over the Danube River a set of suitable distributions has been determine. A common mistake within risk analysis is to apply wrong or inadequate[4] probability distributions. This common type of bias is the distinction between actual data fit and "expert opinion" in the derivation of distribution functions. Thus, a ground rule when assessing the uncertain parameters or variables are if the uncertain parameter more or less is defined in literature or by data, *parametric distributions* should be applied, e.g. normal, gamma and beta. If, the uncertain parameter relies on experts to judge the uncertainty, *non-parametric distributions* should be assigned, such as triangular and uniform (Vose, 2002, p. 273).

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

Given the available data, two distributions are selected and tested in @RISK:

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

The PERT distribution is used to analyze the risk concerning the TTS for passenger cars and trains and the revenue whilst the Erlang distribution is used in the testing of the risk regarding the construction cost of the infrastructure project.

Travel time savings
The impact concerning travel time savings (TTS) is based upon the future demand within the transport system. Several attempts have been made in order to judge and determine demand forecasts as accurate as possible. However, recent research has proved, that even though a vast amount of funds are being omitted to the development and determination of accurate demand forecasts, transport infrastructure projects have a tendency to be overestimated when it comes to the future demands. Whether this is intentional, strategic or modelling deficiencies are left un-said, however, this modelling bias clearly affects the overall appraisal in terms of over-stating the travel time savings resulting in inadequate decision support (Flyvbjerg et al., 2003; Flyvbjerg and COWI, 2004).

A data fit has been conducted in Salling (2008) elaborating upon the current overestimations of demand forecasts (demand underrun). This study proved that the Beta-PERT distribution was well-suited in interpreting and ultimately describing the uncertainties involved in predicting the future traffic flows. The characteristics concerning the Beta-PERT distribution is very similar to a triangular distribution in which analysts are to apply a minimum and maximum threshold boundary together with a most likely value (mode).

Table 4 shows the threshold values concerning the three groups of uncertainty namely $TTS_{Passenger\ cars}$, $TTS_{Passenger\ trains}$ and $Revenue_{Total}$. Currently, the revenue is aggregated from the expenditure categories shown in Table 1. Note that a negative sign corresponds to overestimation of demand forecasts whereas a positive sign corresponds to underestimations.

Impact	Min	Mode	Max
$TTS_{Passenger\ cars}$	-40%	0	+20%
$TTS_{Passenger\ trains}$	-60%	0	+10%
$Revenue_{Total}$	-40%	0	+20%

Table 4. Input parameters to the Beta-PERT distribution (Mudova, 2009)

The Beta-PERT distribution is illustrated together with a triangular distribution in Figure 6. Herein, the advantage of applying the Beta-PERT distribution is illustrated by the smoothness of the curve which places much more emphasis on the mode value compared to the outer boundaries.

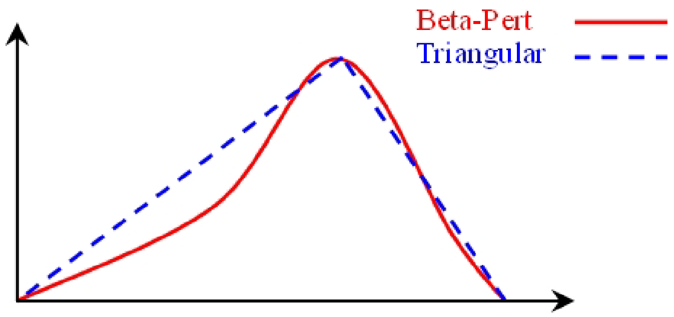

Figure 6. Illustration of the Beta-PERT distribution compared with the triangular distribution (adapted from Salling, 2008)

Construction Cost

Experience gained from large infrastructure projects on a global level, such as the Channel tunnel and the Great Belt link, shows that the overrun of the construction cost is a common phenomenon and the difference between actual and estimated cost typically ranges from 50 to 100%. The risk of exceeding the construction cost is significant and can not be totally eliminated, but can be moderated. When calculating the construction cost, impacts such as building the bridge, pavements, materials, labour are taken into account, but the main reasons for cost overrunning are due to incorrect calculation of the price as a result of lack of realism in forecasting, the inability to foresee delays and the losses caused by them, possible future changes in the project are not taken into account, as well as the weather impact, the geological risks, etc. To take a proper decision on whether the new bridge over the Danube River are to be realized, it is necessary to assess the risk arising from the changes in the construction cost. Problems with the implementation of the fixed link have actually already occurred: a 6 month delay due to administration and bureaucracy, thus, the initial cost estimates is already on the verge of being exceeded.

Current research, thus, states that construction cost estimates for large public procurements tend to be underestimated, which means that appraisals seem to be over optimistic with regard to the project's costs (Flyvbjerg et al., 2003). Mis-interpretation of ex-ante based costs, deliberate or otherwise, results in budget overruns. During literature studies it is clear that estimating construction costs has assigned a relatively high degree of uncertainty. Studies conducted in the US, UK and Denmark all contributes to the fact of interpreting and in some cases measuring the uncertainty of ex-ante based construction cost derivation (Mott MacDonald, 2002; Flyvbjerg et al., 2003; Flyvbjerg and COWI, 2004; Back et al., 2000; Lichtenberg, 2000).

The handling of the uncertainties with respect to these current construction costs underrun is made by the Erlang distribution. The Erlang distribution is a special case of the gamma distribution with integer values for the shape parameter, thus, the implementation of this distribution is considered parametric (Vose, 2002). The Erlang distribution resembles the PERT distribution in terms of relevance and structure with respectively closed and open ended tales. Decision-makers are left with the same process as determining limits in which an absolute *min* and approximated *max* value is obtained. The difference, however, lies in the interpretation of the mean value where a so-called triple estimation technique based upon successive calculation is applied (Lichtenberg, 2000, p. 125). (1) illustrates the differences in determining the mean values from respective a triangular, PERT and Erlang distribution:

$$\mu_{Triang.} = \frac{\min + \text{mode} + \max}{3}, \mu_{PERT} = \frac{\min + 4 \cdot \text{mode} + \max}{6}, \mu_{succ.} = \frac{\min + 2.9 \cdot \text{mode} + \max}{4.9} \quad (1)$$

The properties of the Erlang distribution requires a shape (k) and a scale (θ) parameter. From the above mean value a scale parameter (θ) is found by: $\theta = \frac{\mu}{k}$. The applicability of the Erlang distribution is related to the variation of the scale parameter. By conducting a parameter fit from the data derived in Flyvbjerg et al. (2003) a set of shape parameters are assessed respectively concerning road, rail and fixed link projects (Salling, 2008). Herein, it is found that a shape parameter of 9 fits the current data describing construction cost overruns concerning fixed link projects. Furthermore, a $\mu_{succ.}$ can be set to approximately €120 mio based upon the triple estimation technique and the scale parameter θ is determined to €13 mio.

Results from a QRA using Monte Carlo simulation

The purpose of this stochastic QRA calculation is to provide the decision-makers with a mean to widen their assessment of the possible BCR. The results obtained from @RISK are presented in terms of an accumulated descending graph (ADG) that illustrates the "certainty" of achieving of certain BCR or better (Palisade, 2007; Salling, 2008). Thus, the results presented are of particular importance in the case where a choice among several alternatives has to be made. To determine the risk for the project and establish the possible boundaries of the BCR, the PERT distribution with respect to the travel time savings for passenger cars and trains, as well as for the revenue is run in @RISK together with the Erlang distribution concerning the construction cost. The ADG presented in Figure 7 depicts a BCR greater then 1.00 occurring in 84% of the simulation runs.

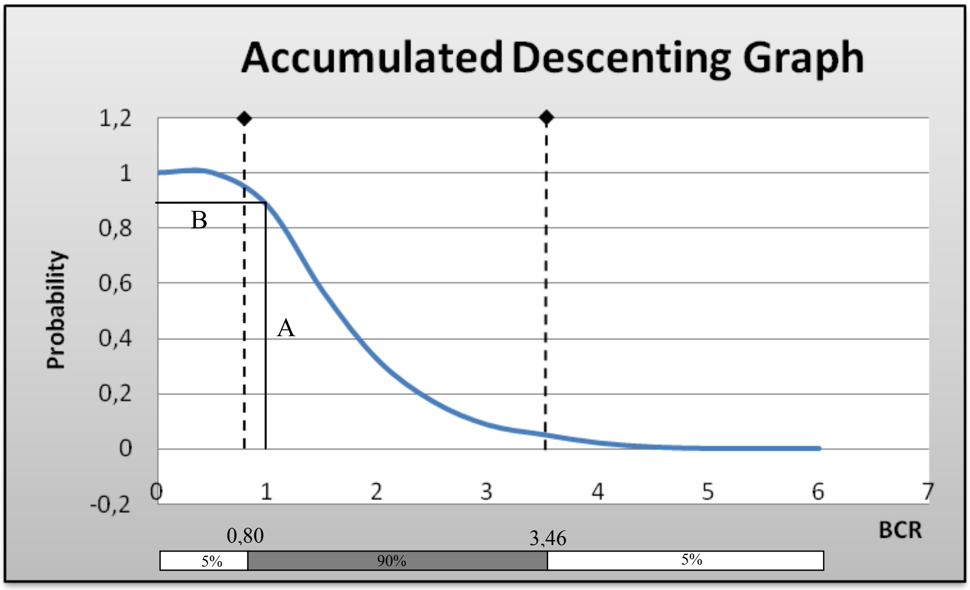

Figure 7. Resulting accumulated graph illustrating the variation of the BCR (Mudova, 2009)

Evidently, the results shown in Figure 7 illustrate a boundary threshold for decision-makers corresponding to their risk aversion towards the project. Comparing this result with the deterministic calculation reveals a much more robust framework model, where the project allows societal feasible results in 84% of the runs with an actual BCR of 3.46 as an upper boundary (95% confidence). A practical use of the model result could be as follows: There is a 84% probability of having a BCR greater than or equal to 1.00, which is by decision-makers in this case considered to be sufficient for an implementation decision.

The final Table 5 presents a summary of the findings from a model run in the CBA-DK model. Three deterministically based results, CBA original, CBA with Optimism Bias uplift of 23% and CBA with Optimism Bias uplift of 55% are produced. It is noticeable, that the last calculation with a high level of acceptable Optimism Bias actually produces an infeasible result towards society. The introduction of a stochastic calculation resulting in an interval result supports the latter where 16% of the iterations in the Monte Carlo simulation is infeasible seen from a societal point of view.

Scenario	BCR	BCR > 1 [%]
Deterministic	1.68	100
Deterministic (Optimism Bias uplifts 23%)	1.24	100
Deterministic (Optimism Bias uplifts 55%)	0.83	100
Stochastic	0.80 – 3.46	84

Table 5. Summary of the four various results embedded within a fixed model run of the CBA-DK (Mudova, 2009)

The feasibility risk to be adopted in the actual case is, of course, up to the decision-makers to debate but the features to deal with uncertainty in the CBA-DK model may help support their considerations. Some of these will be to get acquainted with the various assumptions behind the scenarios, probability distributions, and the way the latter have been assessed/estimated and related to the different scenarios. The resulting graph illustrated in Figure 7 shows the variation of the BCR with interval results spanning from 0.80 to 3.46. Note that for the accumulated descending graph with the probability on the y-axis and the rate of return on the x-axis more reliable data will lead to steeper curves.

Conclusion and Perspective

The CBA-DK model makes it possible to conduct a comprehensive assessment examination of transport infrastructure projects. In practical studies, it has been seen as an advantage that conventional cost-benefit analysis can be supplemented with a risk analysis examination. However, even though Monte Carlo simulation is a well-established technique in the field of risk analysis, it still lacks a generally approved way of implementation in the transport infrastructure area. A particular interest is the variety of various probability distributions and their strengths and weaknesses.

The feasibility risk assessment adopted in the CBA-DK software model has demonstrated that a combination of conventional cost-benefit analysis and quantitative risk analysis examination can increase the decision-makers' possibility of making informed decisions. The underlying modelling technique of Monte Carlo simulation provides comprehensive interval results of the given project alternatives replacing single value results. Thus, this modelling tool moves one step further than the proposed Optimism Bias method for the British Department for Transport. The CBA-DK model should be seen as a 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 e.g. by the various probability distributions

Helping decision-makers to address exact risks by identifying uncertain parameters and variables can be modelled into illustrations of accumulated descending graphs. It has to be taken into consideration that the conclusions have to be very strict when choosing one out of several similar alternatives. The CBA-DK model can be a useful method to consider the uncertainties in the appraisal of infrastructure projects, but it has to be kept in mind that the model is based on assumptions and predicted forecasts.

The decision support model will be further developed in the current master thesis project. The next stage within the investigation involves the application of multi-criteria analysis elaborating upon non-monetary impacts. Five various multi-criteria criterions are selected as relevant in evaluating fixed links projects, namely economy, environment, integration, accessibility, landscape and urban development.

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