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Salling, Kim Bang; Leleur, Steen

Publication date:
2006

Citation (APA):
Salling, K. B., & Leleur, S. (2006). *Modeling Decision Support and Uncertainty using @RISK: The COSIMA-ROAD Model*. Abstract from 1st European Palisade User Conference, .

Modeling Decision Support and Uncertainty using @RISK: The COSIMA-ROAD Model

Kim Bang Salling &
Steen Leleur
Centre for Traffic and Transport, CTT-DTU
Build. 115, Technical University of Denmark
DK - 2800 Lyngby
Denmark
http://www.ctt.dtu.dk/group/dmg/
kbs@ctt.dtu.dk

Abstract: This paper concerns a newly developed software model called COSIMA-ROAD for project evaluation in the Danish road sector. COSIMA-ROAD is developed as a combined effort in co-operation between the Danish Road Directorate and the Technical University of Denmark. The applied case study is developed by the Danish Road Directorate. The main purpose of this paper is primarily to describe how @RISK is used in COSIMA-ROAD. First the two main modules of COSIMA-ROAD are described as respectively a traditional cost-benefit analysis (deterministic point estimate) and a risk analysis using Monte Carlo Simulation (stochastic interval estimate). Next the actual case example is presented with the obtained results. Finally, conclusions and a perspective of the future modeling work are given.

Introduction

A few years ago the Danish Ministry of Transport released a manual for socio-economic analyses on transport issues (DMT 2003). Based on this work and the guidelines presented in this manual the Danish Road Directorate decided to develop a software program COSIMA-ROAD for use in evaluating Danish road investments. In co-operation with the Centre for Traffic and Transport (CTT) at the Technical University of Denmark (DTU) a proto-type model was finished in the spring of 2005. Current research and further development of this model is presented in this paper with emphasis on risk analysis carried out by use of @RISK (Palisade 2002).

Due to limited resources Danish infrastructure proposals are prioritized by use of socio-economic analysis. By use of COSIMA-ROAD this examination is structured to provide decision-makers with support that enables them to make more informed decisions. The main purpose is not to give strict answers but to assist by facilitating the right choice.

COSIMA-ROAD is an Excel based software model for road and infrastructure evaluation consisting of a cost-benefit analysis (CBA) part and risk analysis (RA) part. The software model consists of 9 different worksheets contributing to the CBA component also referred to as the deterministic calculation and 2 worksheets contributing to the RA component referred to as the stochastic calculation, cf. Figure 1.

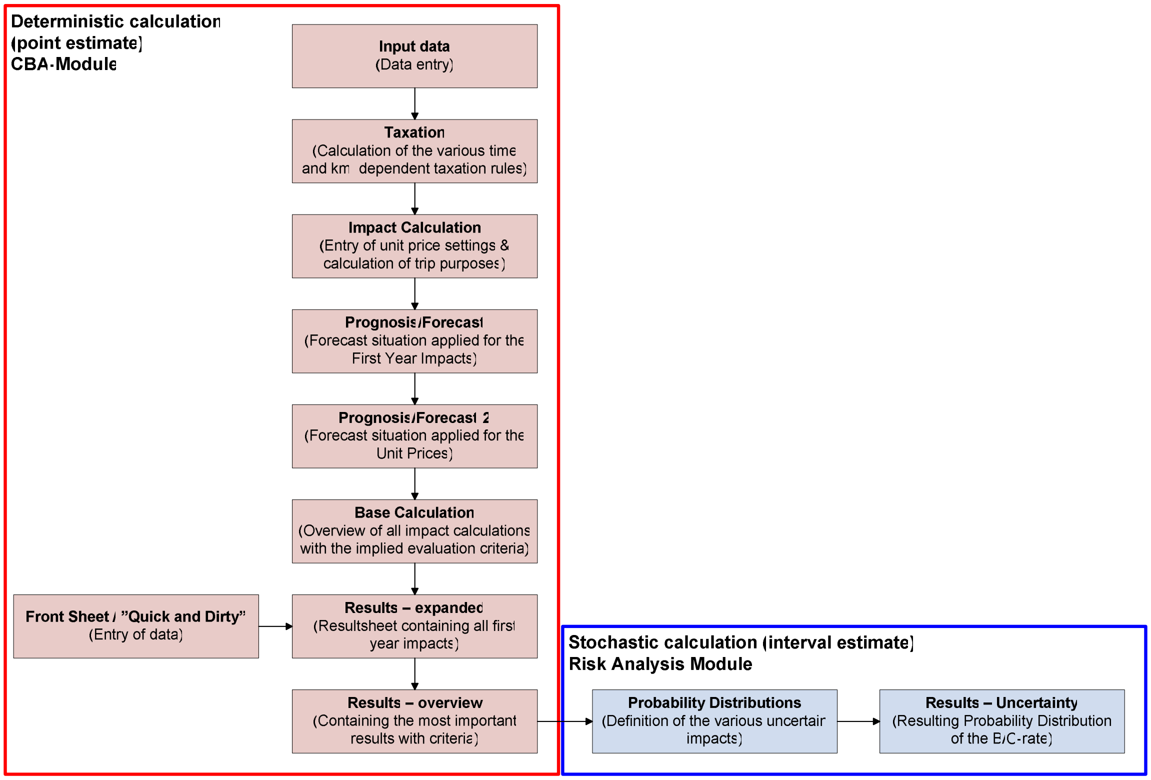

Figure 1. The module structure of COSIMA-ROAD illustrated by the various worksheets (Salling et al. 2004)

The Deterministic Calculation

The CBA module of COSIMA-ROAD consists of traditional cost-benefit analysis (CBA) split into 4 sub-categories: Passenger Cars, Lorries, Heavy Vehicles and External Effects. The three vehicle groups are further divided into impact groups for each group consisting of travel time savings, vehicle operating costs, congestion and changing traffic. It can be noted that changing traffic is assessed by making use of the so-called rule-of-a-half principle (Leleur 2000 pp. 89-91). The external effects are of different types such as accidents, pollution, barrier and perceived risk and noise. Additional entries in the input sheet are the main data concerning the case project: construction cost (investment cost), operating and maintenance costs, evaluation period and key parameters such as discount rate, growth in the economy, etc. Figure 2 is showing the input data sheet. The Danish methodology is described in (Leleur 2000 pp. 129-134).

By applying the net changes within the user impacts and the external effects as input to a socio-economic analysis, it is possible to obtain decision criteria such as the Benefit-Cost ratio (B/C-rate), Net Present Value (NPV), Internal Rate of Return (IRR) and First Year Rate of Return (FYRR). A run of COSIMA-ROAD ends up with a result sheet shown in Figure 3. The two bars on the right depict the costs and the benefits presented in the same absolute scale. By comparing the decision criteria from different runs on different projects a prioritization can be made (Ibid. pp. 99-105).

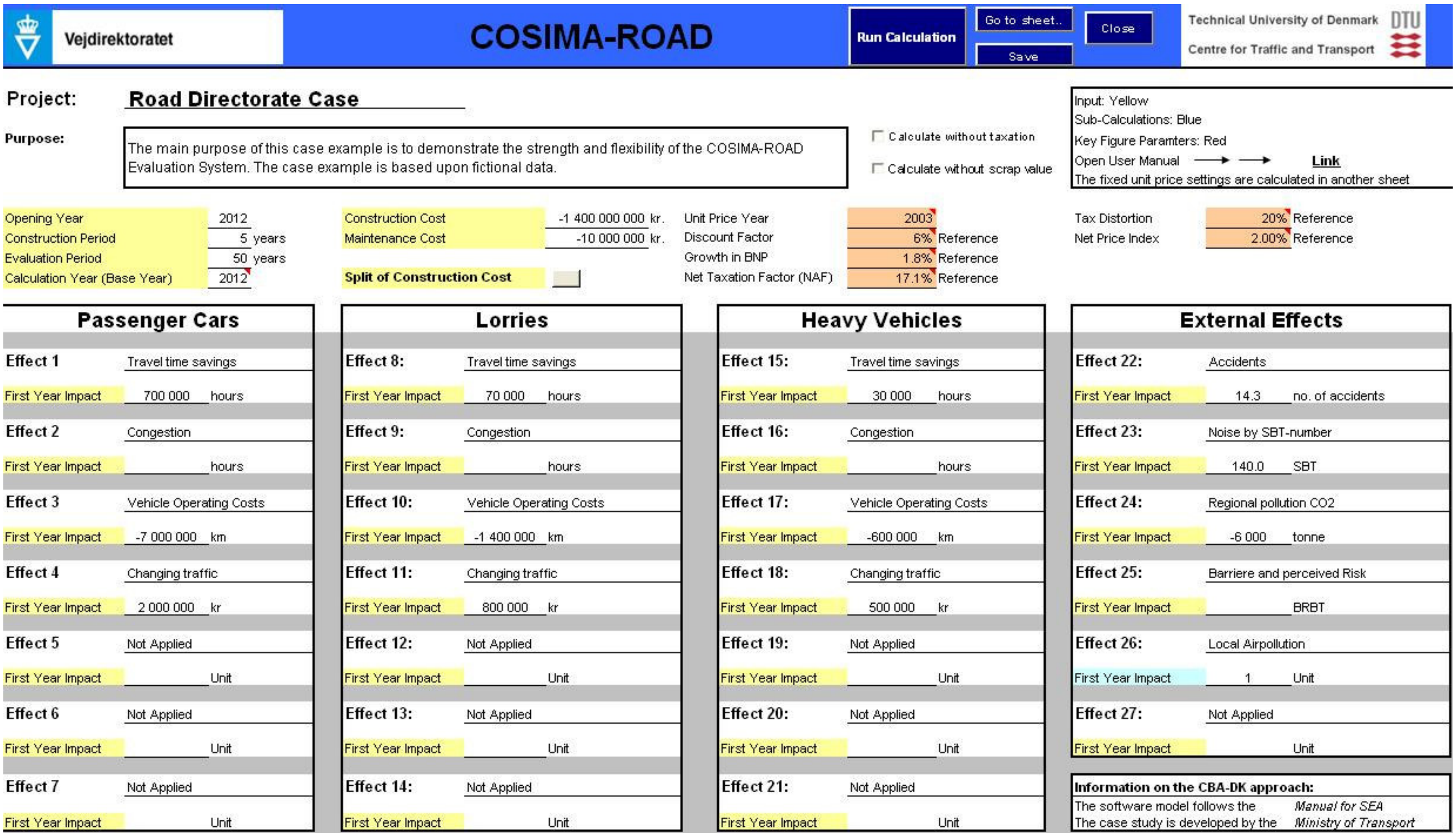

Figure 2. Screen dump of the Input data sheet

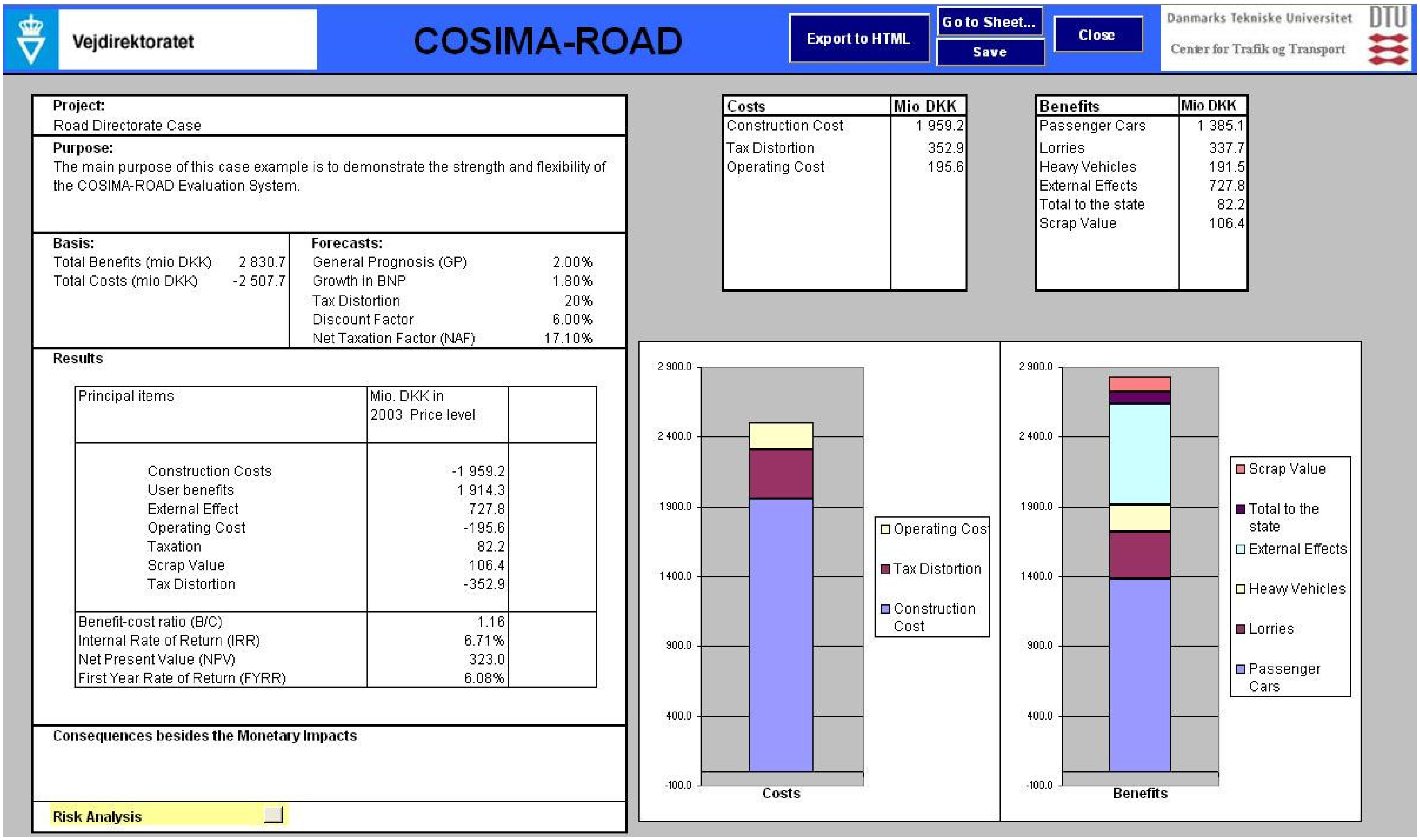

Figure 3. Screen dump of the results overview sheet containing the most important results from this case

After such deterministic runs it is possible to make risk analyses with B/C-rate intervals as the output. This provides a broader basis for assessing the individual projects.

The Stochastic Calculation

To make a CBA, as performed in the COSIMA framework, it is necessary to obtain information from various traffic and impact models. The various types of models combined with varying degrees of effort and resource input for impact modeling result in different degrees of uncertainties. In this respect it is necessary to use different probability distributions in accordance with the variability/uncertainty that characterizes the parameters set focus upon in the risk analysis. The Danish Manual from the Ministry of Transport determines unit prices which in COSIMA-ROAD remain fixed (time unit price, vehicle operating costs a.o.). In the view of this work these parameters are assumed as certain. The COSIMA model examines selected parameters that are considered the most important for RA such as: construction costs, number of hours saved per year for traveling time, maintenance unit costs and safety unit price (Salling 2006). The first two are matters of variability and the latter two of uncertainty (Vose 2002 p. 18). Variability and uncertainty reflect ontological and epistemic issues, see Figure 4 from (Walker et al. 2003 p. 13).

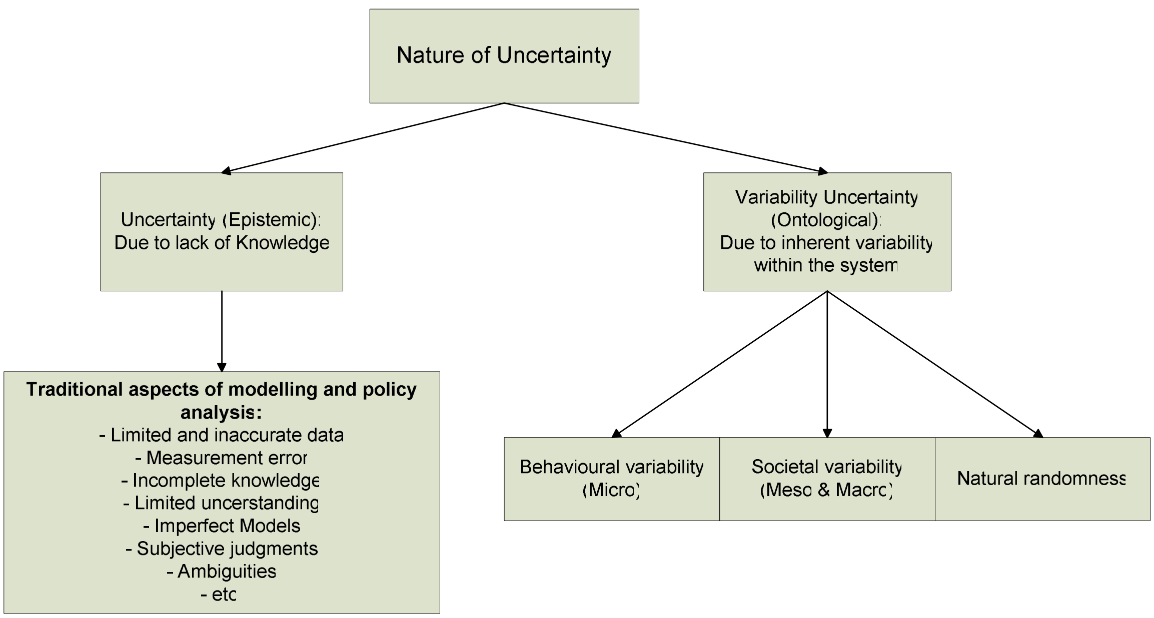

Figure 4. The nature of Uncertainty: Inherent variability or lack of knowledge (Walker et al. 2003)

An ongoing Ph.D. study (Salling 2006) seeks to describe the types of probability distributions suitable for use in the COSIMA framework. They follow a level of knowledge typology diagram moving from a relatively "high level" of knowledge to a relatively "low level". The current four types of distributions used within COSIMA from high to low level is: Erlang (Gamma), Normal, Triangular and Uniform distribution. Figure 5 shows how the various distributions are related to the level of knowledge applied on the variable or parameter.

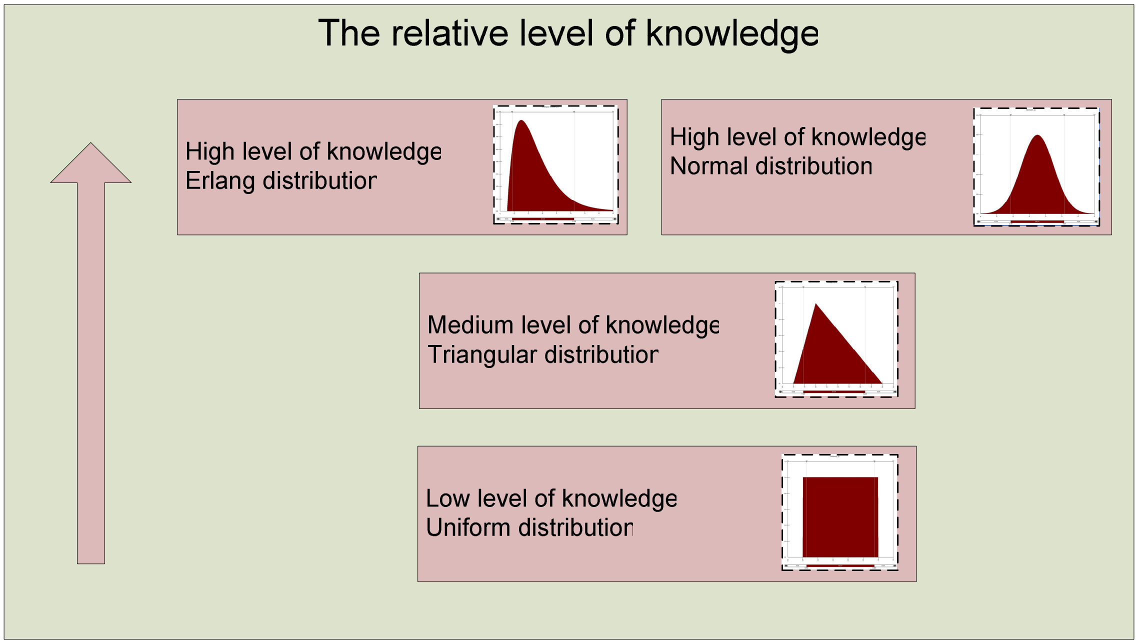

Figure 5. Overview of probability distributions applied in COSIMA-ROAD

<u>Construction Costs</u>

The cost of investing in a project ex-ante is often predicted lower than the actual cost e.g. due to technical problems, delays, etc. A Danish mathematician has developed this experience into a principle based upon successive calculation (Lichtenberg 2000). The strength of applying Lichtenberg's principle is that the decision-maker only has to consider a minimum, most likely (ML) and maximum value. Then by use of a so-called triple estimation approach the mean and standard deviation are calculated by the two following formulas (Lichtenberg 2000 p. 125):

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

Due to the properties of the Erlang distribution a scale (k) and shape (θ) parameter is needed. It has been found that a scale parameter of k = 5 matches the distribution of the uncertainty involved in determining the construction cost (Salling 2006). From the triple estimation is the mean (μ) calculated by (1). The relationship to the shape parameter is found by the equation: $\theta = \frac{\mu}{k}$. The applicability of the Erlang distribution is related to the variation of the scale parameter, see Figure 6. For k = 1 the distribution is similar to an Exponential distribution, whereas with increasing k the distribution will begin to resemble a Normal distribution.

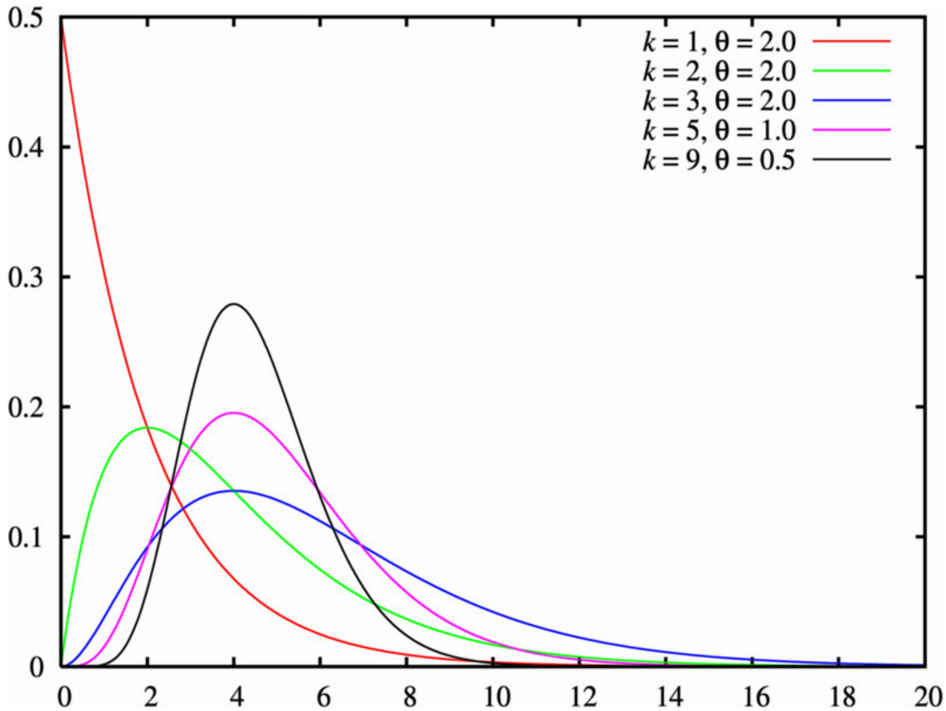

Figure 6. Illustration of an Erlang distribution with various shape and scale parameters (Salling 2006)

<u>Travel Time Savings</u>

The travel time savings have been found to follow a Normal distribution where the mean is based upon the first year effect entry determined as the net change in hours spent on traveling in the influence area of the road project. Standard deviations relating to traffic models applied in Denmark have been found to be around 10-20% (Knudsen 2006). By testing a traffic model in several scenarios it has been proven that the standard error within this model is around 11% for the transport mode and 16% for the traffic loads. Further investigations show that a standard deviation in the area of 10% for smaller projects and 20% for large projects are not unlikely (Ibid.).

<u>Maintenance Costs</u>

The maintenance costs (MC) are developed based on empirical accounting formulas considering different cost factors (Leleur 2000 p. 158). It has been found suitable to use a Triangular distribution (Salling 2006). Specifically, the uncertainty assigned to this parameter using the Triangular distribution is defined by 10% possibility of achieving a lower MC and 50% possibility of achieving a higher value at the tales. It should be noted that this effect is a disbenefit towards society.

<u>Accident Unit Price</u>

The accident benefits are determined by their value to society stemming from multiplying the expected number of accidents saved with a societal unit price. The Uniform distribution shows the assumed uncertainty included in the price-setting where information on a high and low range is estimated (Ibid.). In the actual case run a rather conservative estimate with ± 10% to the standard unit price has been applied.

The Risk Analysis and its Results

The actual Monte Carlo Simulation shown in Figure 7 is based upon the previous parameters and distributions. The purpose of the COSIMA-ROAD RA result sheet is to give the decision-makers a mean to widen their assessment of the possible B/C-rate (Hertz & Thomas 1984). Specifically, Figure 7 shows three COSIMA reports based on @RISK: Histogram showing the most frequent B/C-rate, a descending accumulated graph that shows the "certainty" of achieving a certain B/C-ratio or better and finally a correlation tornado graph that illustrates the impact (correlation) of each variable or parameter to the overall B/C-ratio (Salling 2006).

The presentation will contain an in-depth examination of the COSIMA-ROAD software program together with a demo run of the model.

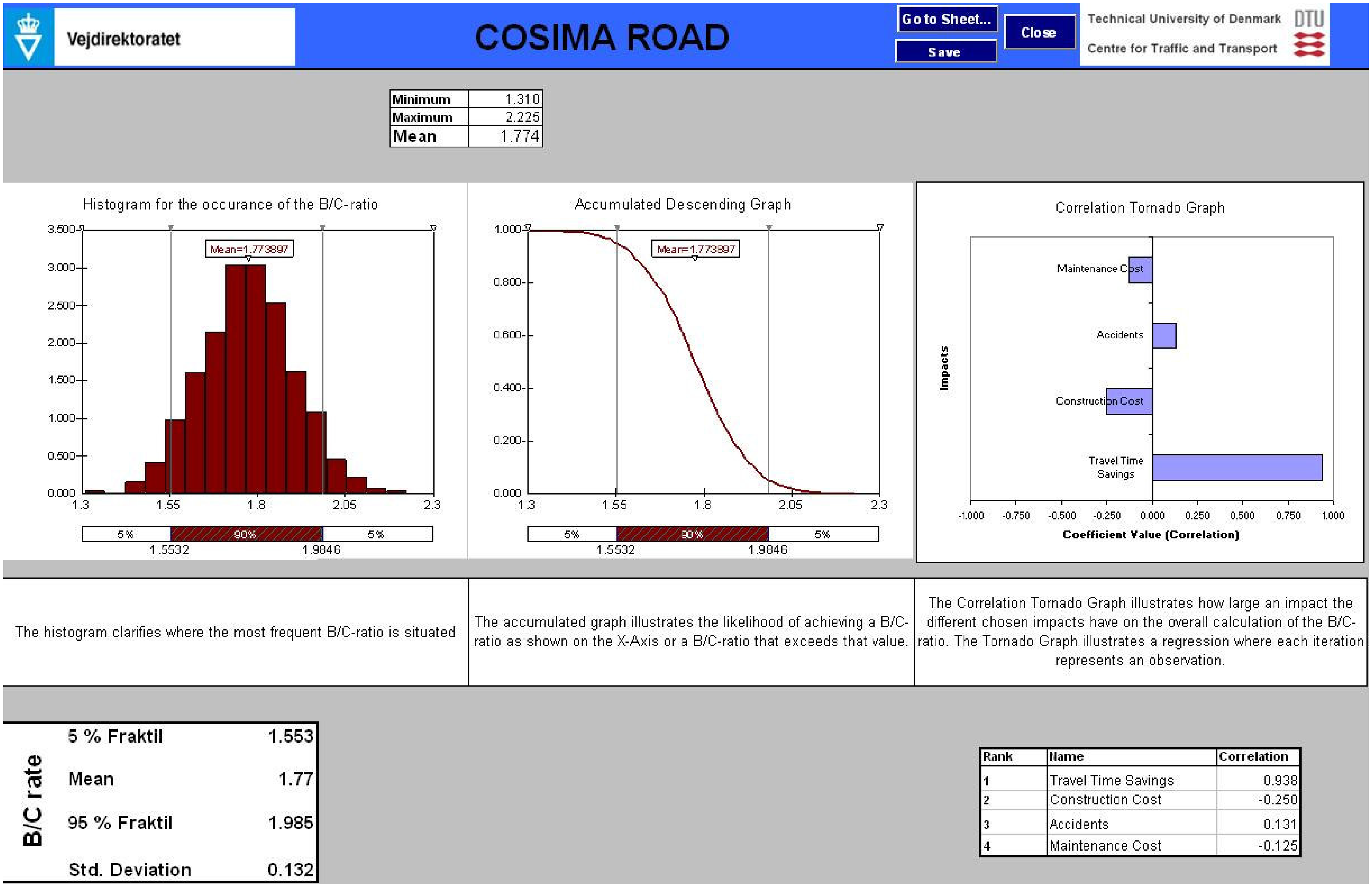

Figure 7. Screen dump of the resulting sheet from a Monte Carlo Simulation in COSIMA-ROAD

Conclusion and Perspective

With COSIMA-ROAD it is possible to carry out a Danish project appraisal study according to the principles determined in the manual developed by the Danish Ministry of Transport (DMT 2003). The software model has been designed as a combined approach in determining the feasibility of a road infrastructure project by use of both a deterministic and a stochastic approach based on @RISK. Thus a deterministic point estimate and a stochastic interval measure make it possible to assist the decision-makers by an accumulated graph whereby risk aversion can be taken into consideration.

The decision support model will be further developed in future studies. Thus it can be mentioned that a new COSIMA model is applied in a large transport study on Greenland with focus upon appraisal of airfields. In this study the work with applying @RISK for Danish transport project appraisal will be continued in a more comprehensive study.

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