Appendix A
COSIMA

Overview
This appendix demonstrates the COSIMA approach that is one of the hard methods in the seven hard and seven soft ("2 $\times$ 7") methodologies in the SP toolbox, see Table 5.5. The idea behind the composite model for assessment (COSIMA) is to link cost-benefit analysis (CBA) with multi-criteria analysis (MCA). Thus CBA provides an absolute, general assessment related to each alternative's core performance, whereas MCA provides a relative, context-dependent assessment related to each alternative's wider performance as set against the other alternatives under examination.

COSIMA can be adapted to very different types of selection problems, where criteria are available both in monetary and non-monetary terms. The Decision Modelling Group (DMG) at DTU Transport at the Technical University of Denmark has developed software that makes it possible to customise evaluation models for a specific study.

Appendix A is an updated version of (Leleur et al. 2007) supplemented with technical notes based on DMG (2010).

A.1 Purpose, Background and Outline

Project appraisal is the process of comparing the virtues and deficiencies of a project. The task is to determine the consequences of a project and to apply this knowledge to support decision making. It is obvious that a project is only feasible if the virtues compensate for the deficiencies and that the best project is the one with the largest net gain. The challenge is to find a method to describe and measure the effects or criteria and to find a rational and trustworthy method to compare and assess the criteria. However, not all effects can be treated in the same way. While it is possible to estimate the quantity of time savings, for instance, and assign a monetary value to this, aspects such as impacts on nature or general societal impacts cannot easily be assigned a monetary value or perhaps even be quantified.

S. Leleur, *Complex Strategic Choices*, Decision Engineering,
DOI: 10.1007/978-1-4471-2491-7, © Springer-Verlag London 2012

Many countries either use or have used CBA for transport decision making. However, this method includes only impacts that can be valued monetarily. The fundamental idea behind composite modelling assessment (COSIMA) is to extend conventional cost-benefit analysis (CBA) into a more comprehensive type of analysis—as often demanded by decision-makers (DM)—by including 'missing' decision criteria of relevance for the actual appraisal task. The missing criteria often address issues that have been difficult to assess by the conventional CBA but which hold a potential of improving the actual decision support from the appraisal if treated properly. This is the purpose of COSIMA, where the added criteria will be referred to as the multi-criteria analysis (MCA) part of the COSIMA analysis.

The COSIMA method will be described in detail below and thereafter demonstrated on two cases to show the features of the method and the possibilities it offers. The two cases concern an examination of alternatives for a by-pass road around the Danish town of Høng and for a new ring road in conjunction with a new residential area in the town of Allerød. Finally, a discussion of COSIMA compared to the CBA and MCA methods is undertaken, and the methods are compared with focus on the following three issues (Andersen and Petersen 2006):

Comprehensiveness: As previously mentioned, not all effects can be treated in the same way. This creates a challenge for the methods as they have to be able to include all important effects. The comprehensiveness issue describes how well the methods succeed in doing this.

Effectiveness: The effectiveness issue describes how easily a final choice can be made on the basis of the result of the analysis. An analysis must be able to consider all important effects but also to make the results usable for the decision-makers.

Transparency: Transparency is important with regard to transportation decision methods because the choices made by the decision-makers must be understood and accepted by the public. This does not necessarily mean that there must be complete consensus about the choices made but that a decision which is difficult to understand for the public is more likely to face opposition and thereby possibly entail expensive delays or rejection.

A.2 The COSIMA Methodology

The examination of project feasibility in transport infrastructure planning should be based on a relevant set of impacts (or effects or project consequences), which depends on the type and size of the project. For some of these impacts such as time savings, vehicle operating costs, safety, etc., valid assessment knowledge exists so that the impacts can be included in a cost-benefit analysis, while other impact types such as urban planning, driver convenience, network accessibility, etc. do not qualify in this respect. Comprehensive EU transport studies like EURET (1991–1995) and EUNET (1996–1999) have dealt with these issues (Tsamboulas et al. 1998; Leleur 2000), and more recently they have been given much attention in EU transport planning and assessment research as reported in the scientific forum project TRANSFORUM (2005–2007), see www.transforum-eu.net.

The COSIMA model aims at examining a project where a mix of CBA and non-CBA effects has been found relevant to include in the concrete appraisal study. The structure and content of COSIMA are presented below in overview (CBA impacts refer to effects, where pricing manuals and procedures exist, and MCA impacts refer to remaining non-CBA effects seen as important for the appraisal task but ‘less known’ than the CBA impacts).

The first task is to determine the relevant CBA impacts for the concrete appraisal study. Most often a standard method for the CBA is used. For Danish appraisals the CBA calculation is described in the “Manual for Socio-Economic Analysis” (Trafikministeriet 2003). Benefits and costs in the CBA are calculated before the COSIMA procedure is begun, and they do not change during the COSIMA calculations. This modelling feature will probably be considered important by people accustomed to applying CBA for decision making.

The next task is to determine the MCA impacts of relevance. Where possible these should be measured in some appropriate type of quantitative unit; for regional economic development one example could be the number of new jobs generated; for improved network accessibility another could be the gain in potential contact hours for specified trip types, for details see (Kronbak 1998). Some effects cannot, however, be measured quantitatively and must thus be described by judgement, for example using a −5, .., 0, .., +5 point scale. Another possibility—with due caution to be addressed later—is the application of the analytic hierarchy process (AHP) method, in which the alternatives under each effect are judged by the possible pairwise comparisons to assess their relative performance, thereby producing a score for each alternative (Belton and Stewart 2002, pp. 151–159).

The quantitative units and the point and AHP scores are then translated into a final rating or score to make use of in the COSIMA method. The COSIMA method follows the simple multi-attribute rating technique (SMART) or SMART exploiting ranks (SMARTER) method when assigning rating values or scores to the MCA effects. SMART assigns ratings from 0 to 100 to the effects by using value functions that describe how well the alternatives perform within each effect. The SMART method (von Winterfeldt and Edwards 1986, pp. 278–287) has been developed into the SMARTER method (Goodwin and Wright 2010, pp. 63–66) in which all the value functions applied are linear, meaning that the slope representing the actual rating-value change is constant along the curve, see Fig. A.1. If it is possible to assess an effect quantitatively, the value function gives the rating for each alternative directly from the actual quantity, but other units such as the formulated point scale values or AHP scores can also be used to assign the value function rating.

A main principle in COSIMA is that examined alternatives are assessed both absolutely and relatively. Thus CBA provides an absolute, general assessment related to each alternative’s core performance, whereas MCA provides a relative, context-dependent assessment related to each alternative’s performance as

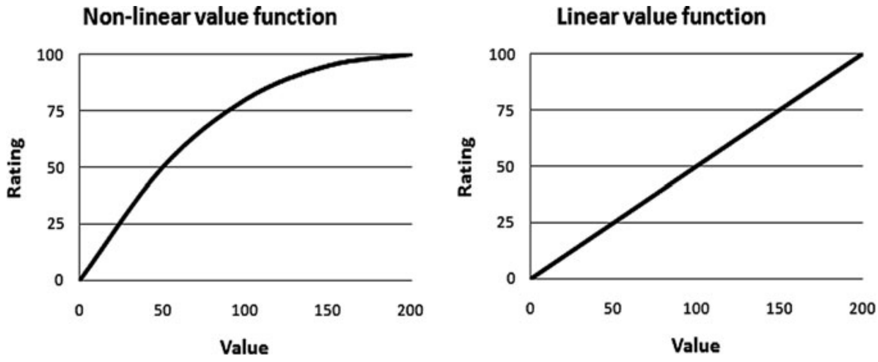


Fig. A.1 Non-linear and linear value functions. The latter are assumed in SMARTER

set against the other alternatives in the examination. For the MCA criteria a set-specific (local) scale assigns the value 0 to the worst performing alternative and the value 100 to the best performing alternative. The rest of the alternatives are then rated by relating them to these alternatives (Belton and Stewart 2002, pp. 121–122). With application of point scales and/or AHP, dependence on the actual set of alternatives is introduced. In practice this can be dealt with in a satisfactory way within the model calibration and as part of the COSIMA decision conference described later. Hereafter three stages I, II and III remain:

Stage I. With the CBA and MCA effects specified, the so-called 'anchoring' part of the COSIMA model formulation can take place, which concerns determining the importance of the MCA effects against the CBA effects, i.e. the overall MCA versus CBA trade-off, and for the MCA effects among each other, i.e. the determination of MCA criteria weights. With regard to the latter, several MCA techniques can be made use of: direct weights, pairwise comparisons, swing weights, etc. (Ibid., pp. 134–143, pp. 157–159). To ease the assignment of criteria weights for the MCA effects that can represent the actual DM preferences, the rank order centroid (ROC) or the more recent rank order distribution (ROD) weighting technique are also applicable. The determination of rank order weights is based on the assumption that weights assigned by the decision-makers—by simply ranking the actual MCA criteria—can be derived by using specified probability density functions (Roberts and Goodwin 2002; Goodwin and Wright 2010, pp. 63–66). The choice of relevant MCA effects and the assignment of weights to these effects will usually be determined during a number of decision conference sessions, where both DM and decision analysts take part, see the description later.

Stage II. After the MCA effects and their assigned weights have been agreed upon, COSIMA can be run. As previously mentioned, COSIMA includes the MCA effects or criteria along with those usually treated in a CBA, thereby calculating a total value (TV) in monetary units for alternative A_k obtained by spending the investment cost C_k:

$$TV(A_k) = CBA(A_k) + MCA(A_k) \tag{A.1}$$

The formulation of COSIMA introduced by (A.1) resembles CBA, but the assessment principles used in the MCA part, generally based on the involvement of DM, are not used in CBA and justify the denomination of COSIMA as an MCA (ECMT 1981, pp. 16, 23). It can be noted on the basis of (A.1) that in a situation where the investment in A_k (equal to the investment cost C_k) is not feasible seen from a CBA point of view, i.e. $CBA(A_k) < C_k$, the investment may be justified by the wider COSIMA examination if $TV(A_k) > C_k$. If examined as a total rate of return (TRR), the latter can be expressed as $TRR(A_k) > 1$, see (A.2) for a COSIMA examination comprising I CBA effects and J MCA criteria.

$$TRR(A_k) = \frac{TV(A_k)}{C_k} = \frac{1}{C_k} \cdot \left(\sum_{i=1}^{I} V_{CBA}(X_{ik}) + \alpha \cdot \left[\sum_{j=1}^{J} w(j) \cdot V_{MCA}\left(X_{jk}\right) \right] \right) \tag{A.2}$$

with:

$V_{CBA}(X_{ik})$: Value in monetary units for CBA effect i for alternative k for altogether I CBA effects. During model calibration it is kept fixed as b_{ik}.

$V_{MCA}(X_{jk})$: Value function rating for MCA criterion j for alternative k for altogether J MCA criteria. During model calibration it is transformed into a monetary value b_{jk}.

α: Calibration factor that expresses the specific model's trade-off between the CBA and the MCA part. It should be observed that the CBA calculation remains unchanged, but that different values of α will change the influence of the MCA on the TRR value. The value of $\alpha = \alpha(MCA\%)$ is set by specifying $MCA\% = 100 \cdot \Sigma_j(B_j)/[(\Sigma_i(B_i) + \Sigma_j(B_j)]$, where A_κ denominates a subset of the $k = 1..K$ alternatives A_k (with this subset selected for calibration, see the Technical Notes accompanying Appendix A below) and $B_i = \Sigma_{\kappa \in K}(b_{i\kappa})$ and $B_j = \Sigma_{\kappa \in K}(b_{j\kappa})$ enter as the value elements for the individual effects i and criteria j summed over the κ alternatives; thus $\Sigma_i(B_i)$ and $\Sigma_j(B_j)$ concern 'row' summations over the I CBA effects and the J MCA criteria and B_i and B_j the results of b_{ik} and b_{jk} 'column' summations over the alternatives, where some if not all are selected for the model calibration.

$w(j)$: Weight that expresses the influence of criterion j.

The general COSIMA principles are presented by (A.1) and (A.2). It can be seen that with sufficient information about the MCA part, (A.2) can be specified into a CBA-like calculation. This will be the situation when, for example, a conventional CBA is carried out, and it is afterwards (1) supplemented with some extra criteria which can be specified fully by impact models that (2) can determine net effects which (3) can be given satisfactory unit prices similar to the assessment in the CBA part. Most often, however, this will not be possible, because usually the MCA part will be 'less known' than the CBA part. In fact the purpose of COSIMA is to handle such a situation. In modelling terms, this can be done by the determination of appropriate values for α and $w(j)$ for the J MCA criteria and by the determination of appropriate value function ratings $V_{MCA}(X_{jk})$.

The latter supplement the determination of $V_{CBA}(X_{ik})$ that can be derived from a CBA manual relevant for the actual assessment case.

Stage III. At this stage COSIMA is run for all the project alternatives. Then the model inputs and the related assessment questions are addressed on the basis of the results obtained and the assumptions behind them, and a new exchange with the decision-makers (DM) is carried out with two principal possibilities available now. The study may simply end here if the DM are confident about the model outcome, or the DM may want to go back into the process and re-address some of the previous model settings to shed light on some issues that have caught their attention.

One important characteristic of the COSIMA approach is that the model is more or less customised to the specific appraisal case. It should be observed, however, that the assessment result produced is given as total rate of return (TRR) values stemming from an 'objective' CBA part and a more 'subjective' MCA part, where the CBA part represents a result in its own right, i.e. without the MCA add-on which actually 'only' provides the DM with some extra discriminatory information. The CBA-like way applied in COSIMA to present both the CBA and MCA assessment information may appeal to decision-makers who want the possibility of refined analysis using all the available information but kept in a simple and straightforward way. To illustrate this, the decision-makers may wish to use only the benefit-cost rate (B/C) part of the TRR value from a base case scenario without any further analysis—this would in fact be a conventional analysis—or they may like to inspect some or all the TRR values and their composition as produced in a number of "what-if" scenarios.

Figure A.2 shows the locations of the two case examples presented in this appendix. The first case concerns the assessment of seven by-pass alternatives for relieving the town of Høng in a rural area in western Zealand of through traffic. The second case deals with four alternatives for a new ring road around the town of Allerød situated in an urban area north of Copenhagen in northern Zealand.

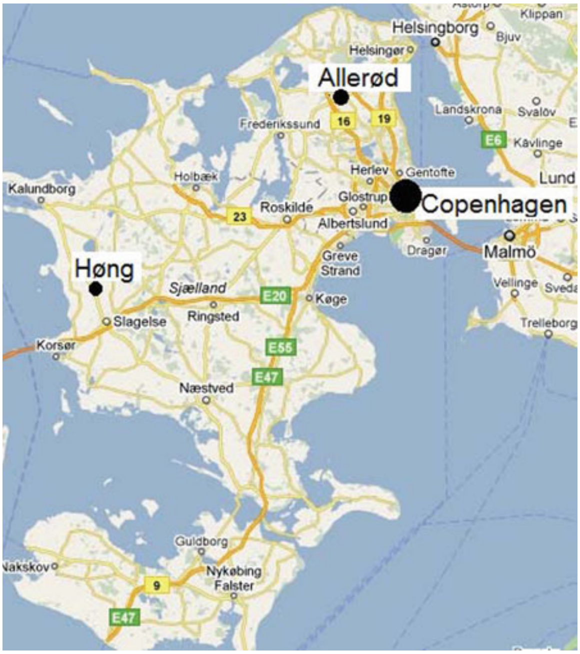
Both case examples are representative of a typical appraisal task in infrastructure investment planning: a mix of hard (CBA) and soft (MCA) issues that are relevant for the decision-makers to take into consideration when selecting the most attractive alternative.

A.2.1 Case Example 1: COSIMA with a Point Scale

The purpose of the following example is to illustrate the practical content of COSIMA when applying point scales for the MCA part. The case examines seven alternatives: a short alternative 1 west of Høng and alternatives 2 and 3 as less narrow by-pass solutions; a short alternative 4 east of Høng and alternatives 5 and 6 as less narrow ones; a final alternative 7 is a combination of alternatives 4 and 5.

It has been found relevant to add altogether three MCA impacts. This means that the alternatives are examined on the basis of the seven Danish standard CBA criteria (travelling time, vehicle operating costs, accidents, maintenance costs,

Fig. A.2 The two case towns in Zealand, Denmark (from Google Maps)



noise, air pollution and severance and perceived risk) and the following three MCA criteria: network accessibility, urban planning and landscape.

By use of the methodology from the Danish Road Directorate, first-year benefits (FYB) have been calculated for the seven alternatives (Leleur 2000). This information has been put together with point scores for the three MCA criteria, where the point scores are determined by thorough examination of the alternatives based on a rating protocol. Hereby the project-effect matrix in Table A.1 has been formulated (Steffensen and Testmann 2000).

At this stage the next step is anchoring the MCA criteria. The three MCA effects are assigned a value describing their performance on a scale from −5 to +5, where +5 is best.

The scores are then translated into ratings between 0 and 100, see Table A.2, using a linear, local value function (Belton and Stewart 2002, pp. 121–122).

The MCA impacts must then be assigned weights to be used in the COSIMA analysis. As the ROD weights are used, the effects need only be ranked by the DM with the weights themselves being predetermined according to the ROD weight principles (Roberts and Goodwin 2002). Any ranking could have been used, but it is assumed that the decision-makers have agreed on the ranking in Table A.3 and hereby indirectly on the shown weights.

The ratings and weights of the MCA effects are entered into the COSIMA software along with the normal CBA input for each alternative. It should be noted that traffic forecasts are also included and that the COSIMA results are based on discounting the values for a 30-year service-period back to the opening year.

Table A.1 The three MCA impacts together with the investment cost and first-year benefits (FYB) from the CBA methodology

Alternatives	Cost in m DKK	FYB in k DKK	Network accessibility	Urban planning	Landscape
Alternative 1	16.7	1,310	+2	+1	−2
Alternative 2	15.3	790	+1	+1	+4
Alternative 3	16.9	350	−1	+3	+2
Alternative 4	18.0	2,900	+4	−2	+2
Alternative 5	17.2	2,460	+3	+2	+3
Alternative 6	20.8	1,790	−3	+4	0
Alternative 7	19.9	2,330	+3	+1	+3

Table A.2 The three MCA impacts rated using the point scale method

Alternatives	Cost in m DKK	FYB in k DKK	Network accessibility	Urban planning	Landscape
Alternative 1	16.7	1,310	71	50	0
Alternative 2	15.3	790	57	50	100
Alternative 3	16.9	350	29	83	67
Alternative 4	18.0	2,900	100	0	67
Alternative 5	17.2	2,460	86	67	83
Alternative 6	20.8	1,790	0	100	33
Alternative 7	19.9	2,330	86	50	83

Table A.3 ROD weights w(*j*) for the MCA effects

Effect ranking	w(*j*)
1. Network accessibility	0.52
2. Urban planning	0.33
3. Landscape	0.15

Afterwards α is determined so the CBA and MCA parts of the analysis are traded off in a way found suitable by the decision-makers. In this case an MCA% $=$ 50 split is used. The programme then calibrates the model so that the MCA fraction of the total benefits equals the split specified by the user. The case example 1 results are shown in Table A.4.

Figure A.3 indicates how the total rate of return (TRR) values consist of both the CBA and MCA impact contributions for all the alternatives.

It is clearly seen that alternative 5 scores higher than the other alternatives due to a reasonably good performance with regard to the B/C-rate and the MCA criteria. The MCA criteria are assessed by trade-off implied unit prices, set against the costs of the individual alternative and added to the CBA part; in principle only the latter is a monetary return of the investment (the costs of the alternative) and the MCA 'rate' solely a value expression of further information to make it possible to discriminate between the alternatives.

Table A.4 TRR values with MCA% = 50

Alternatives	B/C	Network accessibility	Urban planning	Landscape	TRR values
Alternative 1	1.66	1.35	0.58	0.00	3.59
Alternative 2	1.09	1.18	0.64	0.60	3.51
Alternative 3	0.44	0.53	0.96	0.36	2.29
Alternative 4	3.40	1.75	0.00	0.34	5.49
Alternative 5	3.03	1.57	0.76	0.45	5.81
Alternative 6	1.82	0.00	0.94	0.15	2.91
Alternative 7	2.47	1.36	0.49	0.39	4.71

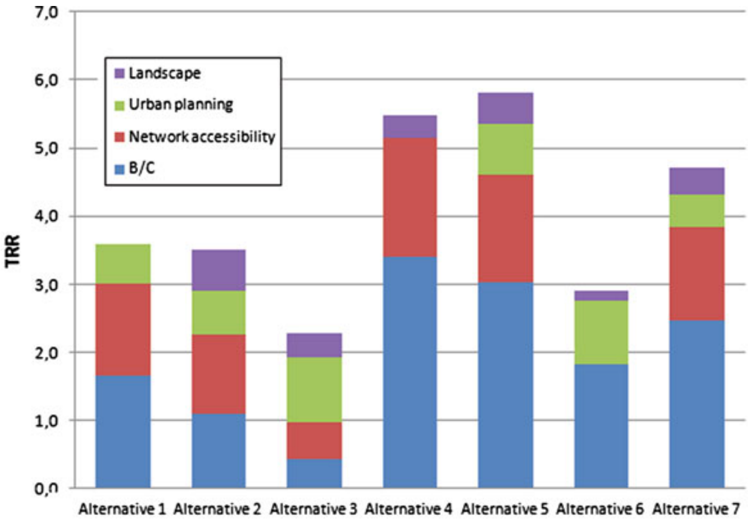


Fig. A.3 TRR values with MCA% = 50

An interesting COSIMA feature is that it is possible to analyse how the results change as the relative weight (MCA%) assigned to the MCA part changes, which reveals whether more than one alternative should be considered. In Fig. A.4 the results of such an analysis are indicated.

Very high percentages assigned to the MCA are not included in the graph as the TRR values rise to very high numbers, thus making the changes in the rest of the graph difficult to follow. However, it can be argued that if such a high importance is given to the MCA, it might be better to use another appraisal method such as the pure MCA.

Figure A.4 clearly shows that two alternatives can be considered as the most attractive ones. Alternative 4 is best when a low weight trade-off is assigned to the MCA, but if the MCA is weighted higher than 30%, alternative 5 obtains the highest TRR value. The graph thus does not depict a single answer as to which alternative is best, but it provides the decision-makers with an overview of which

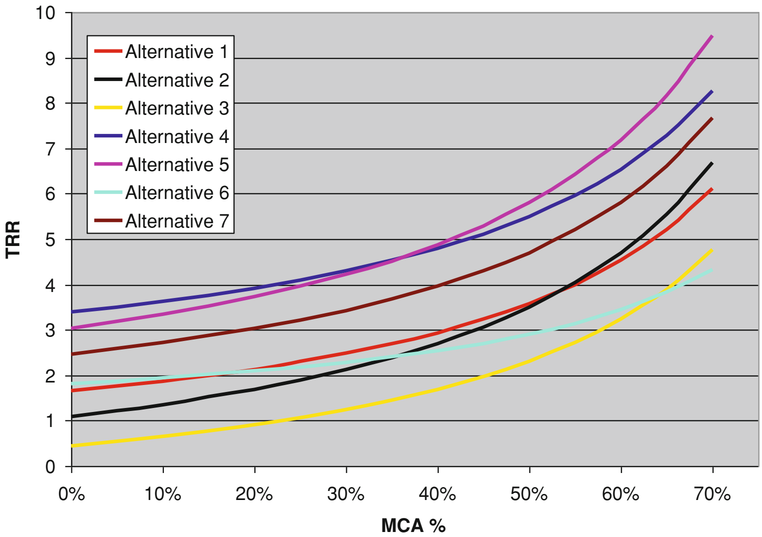


Fig. A.4 TRR values as a function of the MCA%

alternatives to consider, and it can also help sort out the lowest scoring alternatives in the entire range.

A.2.2 Case Example 2: COSIMA with AHP Impacts

The second case deals with a new ring road around the Danish town of Allerød, which is situated north of Copenhagen, see Fig. A.2. The purpose of this example is to illustrate the use of the AHP method for determining the MCA ratings (Belton and Stewart 2002, pp. 151–159). The new ring road is constructed in conjunction with a new residential area, and the case examines four alternatives: a short alternative 1 east of the new residential area, a long alternative 4 west of the area, which entails the crossing of a railroad, and furthermore two 'in-between' alternatives 2 and 3 located west and east of the new residential area respectively.

The CBA was conducted following the Danish manual for appraisal (Trafikministeriet 2003), and afterwards this analysis was extended with the following three MCA criteria:

Accessibility (assessment of accessibility to the new residential area)
Local land use (future plans for local land use)
Regional network (improvement of the regional road network)

The ratings of the impacts are conducted by first scoring the alternatives under each MCA criterion by using the AHP method. These scores are then transformed into a linear value function applying generally a local scale between 0 and 100,

Table A.5 Ratings assigned to the three MCA effects by using the AHP method

Alternatives	Cost in m DKK	Accessibility	Local land use	Regional network
Alternative 1	19.2	0	0	0
Alternative 2	54.9	46	100	23
Alternative 3	48.6	19	7	3
Alternative 4	194.9	100	100	100

Table A.6 ROD weights w(*j*) for the MCA effects

Effect ranking	w(*j*)
1. Accessibility	0.52
2. Local land use	0.33
3. Regional network	0.15

Table A.7 TRR values with MCA% = 50

Alternatives	B/C	Regional network	Accessibility	Local land use	TRR
Alternative 1	2.03	0.00	0.00	0.00	2.03
Alternative 2	1.05	0.10	0.66	0.89	2.70
Alternative 3	1.52	0.01	0.31	0.07	1.91
Alternative 4	0.50	0.13	0.43	0.27	1.33

see Table A.5. Note that alternative 1 is rated as the lowest for all the MCA effects, while alternative 4 is rated best. It can be noticed that the AHP assessment depends on the actual alternatives; this may be more pronounced than it could be observed in the previous case example 1 applying the formulated point scale. Although such dependencies can be seen as less attractive from a theoretical viewpoint, this method aspect is due to the more subjective nature of MCA, see the earlier discussion of the CBA and MCA part of COSIMA. The various theoretical and practical issues relating to the application of AHP are treated thoroughly by (Belton and Stewart 2002).

The MCA effects are ranked according to importance and weighted using the ROD weights as seen in Table A.6. As in case example 1, any ranking could have been used.

The CBA is based on the “Manual for Socio-Economic Analysis” (Trafikministeriet 2003). The TRR values for COSIMA with 50% weight on the MCA are seen in Table A.7.

Table A.7 and Fig. A.5 indicate how the total TRR values are made up by the CBA and MCA effects.

Alternative 1 only has a contribution from the CBA effects, but it still scores higher than alternatives 3 and 4. Due to a large contribution from the MCA effects, alternative 2 has a better TRR than the other alternatives.

Figure A.6 shows that alternatives 1 and 2 are possible contenders to finally being selected as the most attractive choice. For a low percentage

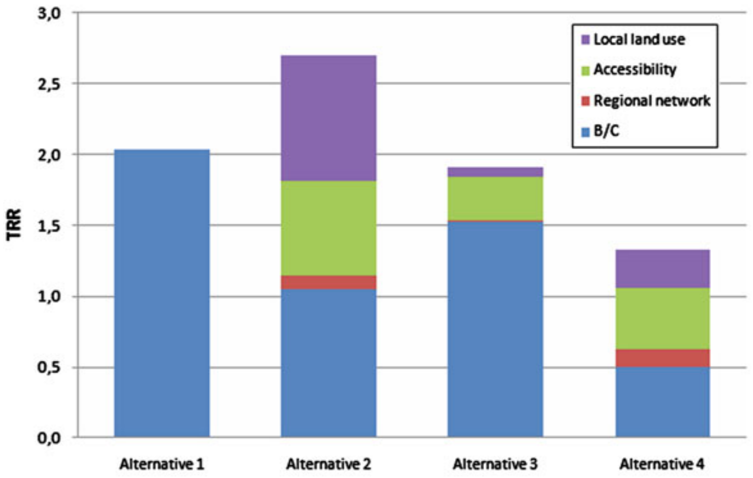


Fig. A.5 TRR values with MCA% = 50

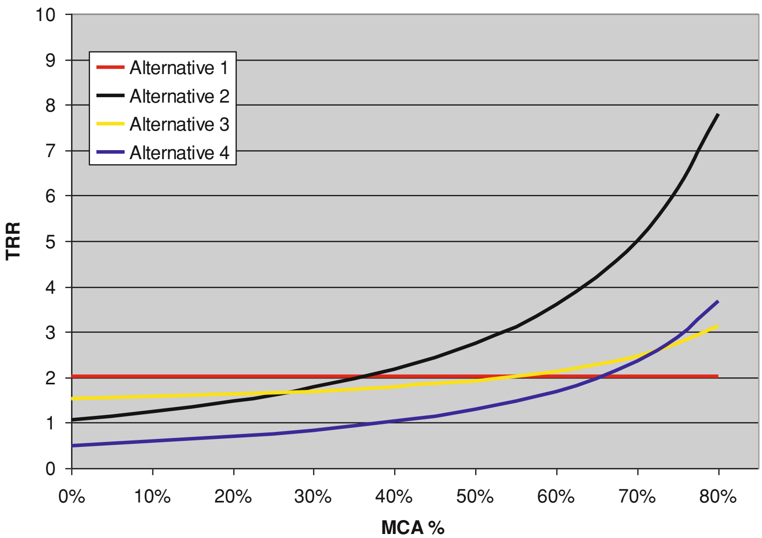


Fig. A.6 TRR values as a function of the MCA%

assigned to the MCA, alternative 1 scores highest, while alternative 2 is the most attractive alternative for a relatively high percentage assigned to the MCA. Alternative 4 is the least attractive one for all trade-off percentages except for the MCA% equal to 70 or 80.

The results are presented to the decision-makers, who are then able to make an informed decision based on both the usual CBA and the COSIMA approach with varying percentages assigned to the trade-off between CBA and MCA.

The MCA% values that ought to be applied in the concrete appraisal task depend on the decision-makers and their interpretation of which amount and type of factors or criteria they want to influence their decision. Practical experience so far points to MCA% values in the range of 10–50. Furthermore, it seems that high MCA% values are most likely to be adopted when appraising larger and more complex transport infrastructure projects.

A.3 COSIMA Decision Conference

As demonstrated by the results of the cases, the COSIMA 'language' is rather CBA-like although COSIMA seeks to go beyond CBA in making appraisal studies more comprehensive. Thus maintaining the CBA language, which means among other things expressing results as rates of return, etc., is seen as an important feature of COSIMA if this approach to wider appraisal is to be accepted by CBA users such as civil servants, business analysts and others.

With the focus so far on methodology and assessment principles, the description below concerns the process of interacting with the DM, see (Goodwin and Wright 2010, pp. 317–319). This will be referred to as the decision conference component of COSIMA. It will be described how decision-makers can be involved in designing the specific COSIMA model, which by intervention of the analysts is to be set up to address their specific appraisal task. The description of the COSIMA decision conference takes as its point of departure a set of alternatives that has already been examined by an accepted CBA that may be available, for example by use of a national manual (NM) or a methodology backed by an international institution such as a lending bank, etc. Thus as a first study result benefit-cost rates (BCRs) have been obtained, and the decision-makers (DM) can be asked the first question (Q1) by the analysts/conference facilitators (CF) as follows:

Q1: Through CBA we have found that alternative k is the most attractive one. Do you agree with this?

The situation may now be—and that would often be the case with more standardised appraisal tasks—that DM agree and feel comfortable with selecting alternative k for implementation. This indicates that the task has been treated satisfactorily and there is no need to make the appraisal analysis more comprehensive.

On the other hand—and that would often be the case with non-standardised, more complex problems—DM do not agree with the alternative selected by use of CBA solely. There is 'more' to the problem than that. In brief DM feel uncomfortable as 'something is missing' in the appraisal. In this situation CF can proceed with the question below.

Q2: Can you explain and put words on what you see is missing in the appraisal? More specifically, can you formulate some criteria that express this?

DM will then, supported by a dialogue with CF, produce a list of 'extra' criteria. A brainstorming session can help establish a first listing, which can be scrutinised in various ways so criteria of minor importance can be left out.

Technically, the CF will as part of this scrutinisation address issues of clarity, overlapping, orthogonality, etc. Hereafter assisted by the analysts using either quantitative measurement, point scores or AHP, scores on the new criteria—the MCA criteria—will be determined and expressed as value functions and then presented by CF to DM with the next question below.

Q3: Do you think—when you take a closer look at the alternatives and the new criteria—that the different alternatives have been rated in a satisfactory way?

This, of course, may lead to some adjustments but the expected end result at this stage is that the rating of the alternatives is accepted. Then follows a question about the importance of the new criteria when compared relatively.

Q4: Is it possible for you to formulate and agree upon a ranking of the MCA criteria?

Depending on the problem type and the different interests represented by DM, it will be possible to produce one or more relevant rankings of the criteria. COSIMA rankings—instead of direct weighting—are used to reveal and express DM preferences at this stage. With more than one ranking formulated by DM, each of these can be used in the continued process as an expression of some particular strategy representing, for example, a specific viewpoint or coalition of interests. In the following it has been assumed that it has been possible to agree upon one ranking, which leads CF to the next question.

Q5: How do you think the CBA part (the monetary issues) and the MCA part (the non-monetary issues) should influence the appraisal?—By use of percentages adding to 100% could you express the relative influence of the CBA part versus the MCA part?

As with Q4 different answers may be obtained. This stage of the process can be supported simply by testing the suggested different percentages. Furthermore, the specific percentage at which one alternative gives way to another as the best one is information of high interest for DM. This situation may also be used to examine how stable or robust the original top alternative based on CBA solely is when competing with the other alternatives based on a broader set of criteria.

The idea of the COSIMA decision conference is to obtain the necessary DM inputs to the COSIMA methodology in a straightforward, non-technical way. At all stages it is possible to return to and answer a previous question again in case the DM would like to do so. It is important that the process is supported by a software system that makes it possible to incorporate the implications of changes in input more or less instantly on a large screen in the conference room. The COSIMA software used in this respect is described below.

A.3.1 COSIMA Software

The COSIMA software is developed in Excel with an emphasis on flexibility and adaptability. The flexibility makes it possible to switch, for example, between different rating and weighting techniques, and the adaptability makes it possible to provide a customised decision model (CDM) for the task at hand. An application example that was finished in the middle of 2007 is a COSIMA version (TGB) for the planning of new airfields in Greenland (DTU 2007). In addition to the basic features treated in this appendix, COSIMA-TGB contains features for the handling of the complex data input from flow modelling and from accessibility modelling, which is one of the MCA criteria (Kronbak 1998). Furthermore, the model is set up to treat various taxation issues and growth scenarios, and it is also endowed with features for quantitative risk analysis (QRA) based on Monte Carlo simulation (MCS) (Vose 2002; Leleur et al. 2004a, b; Salling 2008).

One basic issue to be addressed when setting up a new COSIMA model application concerns its calibration. In the programme it is possible to select the alternatives that are to be used for the calibration of the unit prices. Usually, all alternatives that are thought to be serious contenders as a final choice are used for the calibration. Alternatively, the project alternative with the highest B/C-rate can be used for the calibration. The two calibration methods can give slightly varying results, but which of the two methods to apply may depend on whether the project with the highest B/C-rate is seen as being challenged by all others or, for example, a minor or major group is seen as more or less equal candidates.

When calibrating, the user must make sure that all MCA effects are taken into account. Therefore, if the alternative with the highest B/C-rate does not have a rating above 0 in all effects, this alternative alone cannot be used for the calibration and more alternatives must be used. In the case examples 1 and 2, described to demonstrate the COSIMA approach, it is not possible to calibrate from the alternative with the highest B/C-rate, as these alternatives do not have contributions from some or all MCA effects. Therefore, all alternatives are used for the calibration as all alternatives are thought to be possible contenders for a final choice. When relating to the appraisal of large transport infrastructure investments, COSIMA can also be calibrated to accommodate computable general equilibrium (CGE) analysis, see (Leleur and Holvad 2004) for an analysis of the Øresund Fixed Link.

A.4 Comparison of COSIMA to Other Approaches

The different approaches to transport decision making have different strengths and weaknesses, and in this section, the COSIMA approach will be compared with the regular CBA and the multi-criteria approach. The three methods will be compared with emphasis on the three previously mentioned issues: comprehensiveness, effectiveness and transparency (Andersen and Petersen 2006).

Regarding *comprehensiveness*, the MCA and COSIMA approaches have clear advantages compared to the CBA. The pure CBA can only include effects that can be assigned a monetary value, meaning that some effects cannot be included at all. These effects must therefore be treated separately as is the case with regard to the method presently used in Denmark. However, this can present a problem as it is often difficult for the decision-makers to combine the information from the CBA and the other effects.

The MCA as generic method can include all possible effects as it is not necessary to be able to assign monetary values to the MCA effects. Therefore, DM wanting one method to include all effects could be tempted to use the pure MCA approach. However, the composite method COSIMA can also include all effects, but as described they will be split into effects that can and cannot in principle be assigned a monetary value. Furthermore, when using the COSIMA method, the result is a total rate of return which shows how the benefits are made up of the CBA part and the different MCA effects. This means that the COSIMA method provides the DM with CBA based information about socio-economic viability, which cannot be provided in the MCA. Furthermore, MCA is a comparative tool only and therefore it does not tell the decision-makers if the benefits of the project at hand exceed the costs. COSIMA thus combines some merits, as it gives information about socio-economic viability while at the same time being able to include all effects like the MCA.

It is not correct to refer to the MCA approach—although it is only done generically—as being one method as many methods are available (Tsamboulas et al. 1998; Belton and Stewart 2002). In this context the MCA method therefore refers only to some common traits across a number of individual MCA methods. However, to ease comparison issues, one could see the SMART approach developed by von Winterfeldt and Edwards (1986) as an exemplar MCA methodology that is perceived as a recommendable standard approach (Goodwin and Wright 2010, pp. 31–56). Very briefly one could see the COSIMA approach and the SMART approach as appraisal methodologies that follow opposite strategies: where SMART translates what in this context has been described as the CBA impacts into MCA-like value functions, COSIMA translates the MCA impacts and their associated value functions into a CBA-like comprehensive type of analysis, see Eqs. A.1 and A.2. Below CBA, MCA and COSIMA will be compared further as concerns efficiency and transparency.

Efficiency describes how easily a final decision can be made on the basis of the results of the analysis. The CBA itself gives a very clear answer as to which alternative is the most attractive as it presents a single point estimate for each alternative. However, as not all effects can be included in this analysis, it is necessary to take these into account separately, and the decision will easily become more complex.

Similarly, the MCA and COSIMA approaches per se give a final, single appraisal result for each alternative based on considering all the effects. Therefore, the final decision on the basis of these two methods is very straightforward, although it is necessary to scrutinise the applied MCA scores for the different alternatives and the appropriate CBA/MCA split. With regard to COSIMA it should be noted that the MCA part is context-dependent by setting focus on the relative performance of an alternative as compared to the worst of alternatives under a specific criterion. Therefore the set of alternatives needs to be made up by alternatives where each of these under a specific viewpoint represents a sound candidate for being selected for implementation. At the same time it must be required that each criterion in the criteria set should help to discriminate in an adequate way between the alternatives. If this is not the case (in AHP leading to very similar scores across the alternatives) this should lead to the exclusion of that criterion or to the inclusion of an alternative that changes this situation but at the same time is seen as a sound alternative worthwhile to consider.

Transparency is important in transport decision making to prevent, for example, public opposition to the decisions taken. The traditional CBA has a high degree of transparency as the analysis in theory can be redone by anyone. The assigned unit prices are predetermined ensuring that the project will be appraised in the same way no matter who carries out the analysis.

Both the MCA and COSIMA assume the presence of the DM during the calculation process, and the decision-makers are required to make choices regarding which effects to include and how to rate and rank them. This entails the need for thorough discussions among the decision-makers and in order to ensure transparency of the choices taken the reasons behind them must be presented. It is considered an advantage that the decision-makers are not asked to determine specific weights directly and that a COSIMA decision conference can be run in a more or less non-technical way.

The procedures in the MCA method can be very straightforward and easy to follow for the decision-makers. The COSIMA method may appear to be slightly more demanding to the decision-makers, for which reason its principles should be explained, for example, by use of a demo-case at the beginning of the first decision conference meeting before the described DM/CF question–answer session begins. However, the results of the COSIMA method, the TRR values, could be easier to understand than MCA results as the CBA method is presumed to be well known to the DM.

The involvement of decision-makers in the entire process demands transparency but is a great advantage as it makes it possible to adjust the analysis to local conditions and the specific requirements of the decision-makers. What is weighted highest in a transportation project can differ from project to project and between decision-makers. Therefore, DM in one planning context and location, for example, might assess a problem differently from decision-makers in another context. Both the MCA and COSIMA approaches allow the users to influence the setting of weights of the effects according to their wishes, for example by determining suitable rankings.

Summing up the COSIMA method combines the comprehensiveness of the MCA with the information given in the CBA about socio-economic viability. Furthermore, the method allows the decision-makers to include the MCA effects of their choice and rank and weight them according to their perceptions of importance.

A.5 Conclusions and Perspectives

This appendix has presented and exemplified an appraisal approach, COSIMA, to assist decision-makers in exploring and appraising transport infrastructure investments in a systematic way. Although straightforward in its design and application by simply ‘adding to’ (and not hiding/changing) CBA information, COSIMA contains features that make it useful to address complex assessment problems by incorporating relevant MCA criteria and applying different ROD-based scenarios.

COSIMA seeks to address the overall feasibility/attractiveness issues of an appraisal study comprising a number of alternatives by exploring whether some other issues/impacts complementing the formulated CBA can possibly make a particular alternative change from, for example, not feasible to overall attractive compared to the other alternatives?—Thus COSIMA has been formulated to deal with the often occurring problem that the CBA says ‘too little’ about the particular problem, for which reason the decision-makers may want further, yet systematic examinations that can extend the already available CBA information. It can be concluded that COSIMA can be useful in this respect. Furthermore, administrative units may consider the COSIMA approach as less of a ‘black-box’ than other types of current MCA.

COSIMA has been developed as a multi-purpose or customised decision model (CDM), from which particular versions of COSIMA software can be set up, with one elaborate example being COSIMA-TGB addressing airfield alternatives in Greenland, see (DTU 2007). Compared with the early versions of COSIMA, the COSIMA-TGB software contains some new possibilities for examination by handling a range of both different future scenarios and of different sets of user preferences. A specific set of user preferences affects which MCA impacts should be included and also their ranking leading to ROD criteria weights and the specific CBA versus MCA trade-off behind the final assessment results (Jensen et al. 2007).

Finally, it can be noted that although developed for transport planning, the features and functioning of COSIMA provide it with a general problem-solving scope. Therefore as a decision analysis tool it can also be applied for planning and assessment in other areas, see (Barfod et al. 2011), which concerns a COSIMA-based customised decision model (CDM) developed to assist decision making about strategic office relocation for an international IT company in the Øresund Region. This case is treated in Chap. 7.

Technical Notes About SMART, AHP and Calibration of COSIMA

These notes describe the principles of the SMART and AHP methods used in COSIMA for the MCA. After this presentation the notes describe how the CBA and MCA parts are combined. This is addressed by the way the trade-off parameter MCA% can be calibrated dependent on alternatives. Finally a simple numerical example shows how the calculations are carried out. The notes are based on (DMG 2010).

The Multi-Criteria Method SMART

The SMART technique is based on a linear additive model. This means that an overall value of a given alternative is calculated as the total sum of the performance rating/score (value) of each criterion (attribute) multiplied with the weight of that criterion. The main stages in the analysis are based on (Olson 1996, pp. 35–36; Goodwin and Wright 2010, pp. 33–34):

Stage 1: Identify the decision-makers
Stage 2: Identify the issue of the evaluation
Stage 3: Identify the alternatives
Stage 4: Identify the criteria
Stage 5: Determine the alternative-ratings under each criterion
Stage 6: Rank the criteria in order of importance
Stage 7: Determine the weight of each of the criteria
Stage 8: Calculate the overall values and make a provisional decision
Stage 9: Perform sensitivity analysis

In Stage 7 the least important criterion from Stage 6 is assigned the value 10. The second-least important criterion is given a value that indicates its value relatively to the least important criterion and so on until all the criteria are assigned values. These are then normalised into weights summing up to 1.

In SMART, the ratings of the alternatives in Stage 5 are assigned directly by using appropriate, natural scales of the criteria. For instance, when assessing the criterion "cost" for the choice between different road layouts, a natural scale would be a range between the most expensive and the cheapest road layout. In order to keep the weighting of the criteria and the rating of the alternatives as separate as possible, the different scales of the criteria need to be converted into a common internal scale. In SMART, this is done mathematically by the decision-makers by means of a value function. The simplest and most widely used value function is a scale going from 0 to 100.

SMART Exploiting Ranks

The assessment of value functions and swing weights in SMART can sometimes be a difficult task, and decision-makers may not always feel confident about it. Because of this, Edwards and Barron have suggested a simplified form of SMART named SMARTER (Roberts and Goodwin 2002). Using the SMARTER technique the decision-makers place the criteria into an importance order, for example "Criterion 1 is more important than Criterion 2, which is more important than Criterion 3, which is more important Criterion 4" and so on leading to $C1 \geq C2 \geq C3 \geq C4\ldots$. Afterwards SMARTER assigns weights by using the rank order distribution (ROD) method.

ROD is based on a weight approximation that assumes that valid weights can be elicited by the ranking of criteria; this is very convenient in a decision conference as ranking is more easily negotiated than are direct weights.

The approximated ROD weights for $n = 2$ to 10 have been found mathematically. For further information about the underlying calculations, see (Roberts and Goodwin 2002). Weight sets are indicated below for a number of criteria between two and eight with rank order of criteria from left to right. Note that Roberts and Goodwin originally indicate the weights with four decimals, which may, however, indicate a kind of precision that is not realistic. They also indicate weights for nine and ten criteria but as can be seen from the values below more than eight criteria will mean that practically no discriminatory power is given to the criteria ranked as numbers nine and ten. This information is relevant for the participants in a decision conference when engaged in reducing an initially long list of criteria, see the case examples in Sect. 8.1.

Two criteria	(0.69; 0.31)
Three criteria	(0.52; 0.33; 0.15)
Four criteria	(0.42; 0.30; 0.19; 0.09)
Five criteria	(0.34; 0.27; 0.20; 0.13; 0.06)
Six criteria	(0.30; 0.24; 0.19; 0.14; 0.09; 0.04)
Seven criteria	(0.26; 0.22; 0.18; 0.14; 0.10; 0.07; 0.03)
Eight criteria	(0.23; 0.20; 0.17; 0.14; 0.11; 0.08; 0.05; 0.02)

The Multi-Criteria Method AHP

The analytic hierarchy process (AHP) method was developed by Saaty in the 1970s and is based on utilising pairwise comparisons as a way of assessing a set of alternatives (Hwang and Yoon 1995; Saaty 2001). The method is applicable for a hierarchical structure set out as a decision tree with several levels. In most cases, however, three levels are applied, namely the alternatives level and the criteria level and the goal level, with the latter expressing the overall purpose to be achieved. The idea is then to compare all alternatives under each criterion and afterwards all the criteria under the goal, with the latter expressing the overall rationale of implementing one of the alternatives.

The scale applied is shown below:

Equal importance	(1)
In-between grading	(2)
Moderate importance	(3)
In-between grading	(4)
Strong importance	(5)
In-between grading	(6)

Very strong importance	(7)
In-between grading	(8)
Extreme importance	(9)

With two alternatives (or criteria) A and B compared, the DM are asked to indicate the preference intensity. If, for example, A is preferred to B with "strong importance" grade 5 is chosen (if B is preferred to A with the same intensity the reciprocal value 1/5 is indicated). In this way a positive comparison matrix a_{ij} is set out with the reciprocal property that $a_{ij} = 1/a_{ji}$ and the diagonal-elements equal to 1. Furthermore preference transitivity leads to $a_{ij} = a_{ik}/a_{jk}$.

In the original approach by Saaty the Perron–Frobenius theory is used to determine the preference weights (relative performance indicators) for the alternatives with respect to each criterion and on the next level for the criteria with respect to the goal. Saaty found that the problem of determining these preference weights can be formulated as an eigenvector problem (Hwang and Yoon 1995). By multiplicating 'upwards' in the hierarchy the overall relative performance of each alternative with respect to the goal can then be determined.

Due to its intuitive appeal and the development of software such as Expert Choice, AHP gained widespread use (Expert Choice Inc. 2004). This success is no doubt due to the fact that decisions produced in an AHP session have generally appeared to be in accordance with the preference-views expressed by the DM participating in the AHP process (Vaidya and Kumar 2006).

It should be noted, however, that criticism has been expressed concentrating on the following three issues (Olson et al. 1995; Lootsma 1999):

The 1–9 ratio scale applied to quantify the preference judgments
The application of the Perron–Frobenius eigenvector method
The arithmetic mean aggregation rule

It can be noted that these criticisms have been dealt with by introducing a multiplicative version of AHP called the REMBRANDT method, which is based on (1) applying a difference-based scale judging the preference intensity for the individual pairwise comparisons, (2) replacing the eigenvector method by geometric mean aggregation (thereby—in case of adding a new alternative—rank reversal of presently examined alternatives can be avoided) and (3) by replacing the weighted arithmetic mean aggregation of scores with aggregation by the product of relative scores lifted into the power of the criteria weights (Ibid.).

It has been concluded that both the ratio-based AHP and the difference-based REMBRANDT methods are useful, practical multi-criteria decision making tools (Barfod and Leleur 2011). The REMBRANDT method is explained as part of the Technical Notes accompanying Appendix B below.

A thorough treatment of AHP for strategic decision making is given in (Saaty 2001; Bhushan and Rai 2004). As mentioned in Chap. 8 the latter reference has served as a general background reference for the approach to strategic decision making set out with the systemic planning (SP) approach.

Calibration of COSIMA with a Numerical Example

Calibration Principles

It should be observed that in the software system the COSIMA calculations use a calibration parameter UP_j that functions as a kind of unit or shadow price per index value for each of the *J* MCA criteria to produce the b_{jk} values. These 'benefit' values are determined by $b_{jk} = V_{MCA}(X_{jk}) \cdot UP_j$ with $UP_j[\alpha(MCA\%), w(j), \Sigma_i \Sigma_{\kappa \in K}(b_{i\kappa}), \Sigma_\kappa V_{MCA}(X_{j\kappa})]$, see Eqs. A.1 and A.2, and with κ indicating the alternatives A_κ that have been included in the set of alternatives serving as a base for the model calibration.

In the procedure $\alpha(MCA\%)$ and $w(j)$ determine a fraction of $\Sigma_i \Sigma_{\kappa \in K}(b_{i\kappa})$ that by unit scaling, see below, leads to the *J* unit prices that are applied then to calculate $TRR(A_k)$. Note that $TRR(A_k)$ values are calculated also for the alternatives not included in the calibration set. Changes in the set of alternatives A_κ behind the calibration will influence the UP_j values and thereby the total rate of return (TRR) values. This pool dependence, of course, will be of interest for the decision analysts working to formulate the model set up. The alternatives in this respect ought to be scrutinised as either 'serious contenders' or maybe as 'wildcards'. The latter type of alternatives ought not to be included in the calibration pool. The analysts are supposed to inform the decision-makers about the principally open calibration questions that could be of interest.

In the COSIMA software both the ratio-based original eigenvector method and the more recent difference-based geometric (REMBRANDT) pairwise comparison method have been implemented. In overview the following options are available for intra-criterion rating: AHP, REMBRANDT, direct rating based on either judgement or measurement, while the following options are available for inter-criteria weighting: ROD weight technique or swing weights. There is a procedure to ascertain the discriminatory power of each MCA criterion included in the examination. The swing weight (SW) method is based on setting and comparing the 'swing' in one criterion with the swing of another criterion (ratio of relative importance with criteria typically chosen in order of importance). SW is seen as more precise but also more demanding than the ROD weight technique, which determines more general importance weights. The latter aim at allocating or distributing means, whereas SW weights are based on trade-off considerations. With ROD weights the scaling of the unit price UP_j is based on the individual *j*-sums $\Sigma_\kappa V_{MCA}(X_{j\kappa})$, while, with swing weights applied for setting the criteria weights, the individual *j*-sums are replaced by an average of the summed ratings over the *J* criteria being equal to $1/J(\Sigma_j \Sigma_\kappa V_{MCA}(X_{j\kappa})$.

Table A.8 Benefit-cost data for the calculation example

Alternatives	A1	A2	A3	A4
B1..B4	110	160	165	120
C1..C4	70	80	120	65
BCR	1.57	2.00	1.38	1.85

Numerical Example

The COSIMA calculations can be illustrated with a simple calculation example based on (Hiselius et al. 2010).

In the present alternative survey four alternatives A1, A2, A3 and A4 are available. Using a national cost-benefit manual and its fixed unit price values the total benefits are calculated: B1, B2, B3 and B4, which by dividing them with the observed total expenditure C1 C2, C3 and C4 leads to benefit-cost rates (BCR) for the four alternatives, see Table A.8.

If the DM agree—after the content of the CBA is reviewed—that the decision making is complete, a decision to choose A2 can be taken, since this alternative has the highest BCR value = 2.

If the CBA is insufficient, new criteria can be added to evaluate them by a MCA and finally perform a composite analysis according to the COSIMA principles. The procedure is as follows: first a number of criteria are described, which in this example leads to the criteria k1, k2, k3 and k4 that are determined in such a way that an overlap with the components of the CBA is avoided.

Next, the four criteria are rated and weighted. The rating means that each alternative for each criterion is assigned a value (score), which lies between 0 and 100. The value 0 is given to the alternative that is performing worst under the given criterion and 100 to the alternative which is performing the best. The two remaining alternatives will have values between 0 and 100. The approach is based on pairwise comparison of all four alternatives under each of the four criteria k1, k2, k3 and k4. For each of these criteria with four alternatives examined altogether $(4 \times 3)/2 = 6$ pairwise comparisons are needed. Based on the MCA method REMBRANDT (see Appendix B) the following scores are obtained from a transformation of the REMBRANDT results into a value function, see Table A.9.

Since the criteria are usually not assigned equal importance by the decision-makers, the criteria are assigned the weights K1, K2, K3 and K4. This can be done directly or by using the ranking criteria method ROD. The result, where the weights are set directly and summarise to 1, is for this example: (K1, K2, K3, K4) = (0.20; 0.55; 0.10; 0.15).

In the last part of the calculation the CBA and MCA are linked together, which is done by decision-makers providing the MCA%. At a high MCA% the MCA will dominate the final result, while a low MCA% means that it will be the CBA and the BCR values that dominate.

Table A.9 Value function scores for the calculation example

Criteria/Alternative	A1	A2	A3	A4
k1	25	100	0	45
k2	0	75	60	100
k3	0	26	100	35
k4	100	68	35	0

The decision-makers are asked about the MCA% and they decide, for example, to set this CBA/MCA trade-off parameter to 50%. Thus MCA and CBA count the same in the overall analysis. Based on the choice of A2 with the highest BCR as calibration basis, the MCA part should now 'count the same'. Benefit value B2 was found to be 160 which means that the MCA part of A2 should also sum up to 160. Adding up the MCA-components of A2 using the scores in Table A.9 p_1 can be determined in the following manner, with p_2, p_3 and p_4 expressed by p_1 and the criteria weights:

$$100 \cdot p_1 + 75 \cdot p_2 + 26 \cdot p_3 + 68 \cdot p_4 = 160 =>$$

$$100 \cdot \frac{0.20}{0.20} \cdot p_1 + 75 \cdot \frac{0.55}{0.20} \cdot p_1 + 26 \cdot \frac{0.10}{0.20} \cdot p_1 + 68 \cdot \frac{0.15}{0.20} \cdot p_1 = 160$$

Hereby the set of prices is determined:

$$\begin{aligned} p_1 &= 0.43 \\ p_2 &= \frac{0.55}{0.20} \cdot 0.43 = 1.19 \\ p_3 &= \frac{0.10}{0.20} \cdot 0.43 = 0.22 \\ p_4 &= \frac{0.15}{0.20} \cdot 0.43 = 0.32 \end{aligned}$$

With this set of prices the following values of the total rate (total rate of return TRR) are given, which expresses the overall attractiveness of an alternative from CBA and MCA:

$$\begin{aligned} \mathrm{TRR}(\mathrm{A}_1) &= \frac{110 + (25 \cdot 0.43 + 0 \cdot 1.19 + 0 \cdot 0.22 + 100 \cdot 0.32)}{70} = 2.18 \\ \mathrm{TRR}(\mathrm{A}_2) &= 4.00 \\ \mathrm{TRR}(\mathrm{A}_3) &= 2.25 \\ \mathrm{TRR}(\mathrm{A}_4) &= 4.09 \end{aligned}$$

From this it is seen that A4 is the most attractive alternative. In Table A.10 the results are shown in overview. The example is based on the use of cost-benefit analysis (CBA) carried out by use of a national manual (NM) and a multi-criteria analysis (MCA). CBA + NM produce a monetary result, which is validated from socio-economic thinking and common use. MCA produces a result which is based on preferences indicated in the decision process and the result is in principle only valid from this point of view.

Table A.10 The results of the calculation example

COSIMA example	A1	A2	A3	A4	Method	Unit
Costs	70	80	120	65	CBA + NM	m DKK
Benefits	110	160	165	120	CBA + NM	m DKK
BCR	1.57	2.00	1.38	1.85	CBA + NM	
k1	11	43	0	19	MCA	eval m DKK
k2	0	89	71	119	MCA	eval m DKK
k3	0	6	22	8	MCA	eval m DKK
k4	32	22	11	0	MCA	eval m DKK
Total MCA	43	160	104	146	MCA	eval m DKK
Total value	153	320	269	266	CBA + NM + MCA	m DKK and eval m DKK
Total rate	2.19	4.00	2.24	4.09	–	–

With the CBA benefits expressed in million DKK (m DKK) the MCA results (MCA 'benefits') will also be expressed in million DKK, here to be expressed as 'evaluation DKK' (eval m DKK) to indicate their way of determination. With the TRR based on both types of benefits (m DKK and eval m DKK) the TRR benefits are therefore a mix of m DKK and eval m DKK. The total rate for an examined alternative is found by adding the benefits from CBA and MCA and dividing them by the costs in m DKK. Table A.10 presents the results of the numerical example.

The final result is determined by having A2 as the basis for the calibration and the MCA% set to 50.

By means of the COSIMA calculations it is possible to base the decision of the choice of alternative on the socio-economic BCR core contribution in combination with its MCA-based wider performance. This combined result expresses the overall attractiveness of a given alternative. As mentioned, the CBA result is valid in the light of being provided by a socio-economic evaluation, while the MCA result in principle only is valid on the basis of the conducted decision conference and the actual deliberations that have taken place. A better background can be obtained if a log book is worked out with user inputs and background comments. This allows a second-opinion to be set out by inspecting these.

As stated, the values in Table A.10 are developed on the basis of the phrase "influence of the MCA must be 50%". How can this be interpreted further? The basis for choosing among A1, A2, A3 and A4 is a CBA, which shows that the A2 due to the highest BCR (= 2.00) is the best choice. This BCR value for A2 is given by C2 = 80 and B2 = 160. A balance between CBA and MCA must be arranged so that the MCA criteria indirectly priced also contribute with 160, which has just been illustrated in the calculation example. Keeping the scores of the alternatives and the criteria weights unchanged this determines unique total rates (TRRs) for all four alternatives, and A4 stands as the most attractive alternative. In brief the COSIMA analysis replaces A2 by A4 as the most attractive choice.

Appendix B
SIMDEC

Overview
This appendix demonstrates the SIMDEC approach that is one of the hard methods in the seven hard and seven soft ("2 × 7") methodologies in the SP toolbox, see Table 5.5. The idea behind risk simulation and multi-criteria analysis in combination for decision making (SIMDEC) is to incorporate risk analysis (RA) by using Monte Carlo simulation (MCS) as one specific criterion within a multi-criteria analysis (MCA). Absolute assessment of each examined alternative's core performance is provided by RA as a probability-based interval result, whereas MCA provides a relative, context-dependent assessment related to each alternative's wider performance as set against the other alternatives under examination.

SIMDEC can be adapted to very different types of selection problems, where criteria are available both in monetary and non-monetary terms. The Decision Modelling Group (DMG) at DTU Transport at the Technical University of Denmark has developed software that makes it possible to customise evaluation models for a specific study.

Appendix B is an updated version of (Leleur et al. 2010) supplemented with technical notes based on DMG (2010).

B.1 Purpose, Background and Outline

Providing suitable decision support for strategic transport decision making is a topic of growing concern. For large infrastructure investments, to exemplify with one important transport topic area, comprehensive assessments are needed (Banister and Berechman 2000). Typically such investments have many-sided consequences which all ought to be taken into consideration to seek out the best alternative from a set of candidates that have come forward from the preparatory planning and design phases.

The traditional cost-benefit analysis (CBA) as prescribed in various national and international appraisal manuals is insufficient for comprehensive assessments

S. Leleur, *Complex Strategic Choices*, Decision Engineering,
DOI: 10.1007/978-1-4471-2491-7, © Springer-Verlag London 2012

as often important decision factors such as environment, regional development, etc. are not possible to cover by CBA (Leleur 2000). Furthermore, uncertainties play a major role in connection with large-scale projects, where factors such as construction costs and demand prognoses are uncertain for a number of reasons but clearly of very high importance for the long-term feasibility of the investment. Many cases have been documented where uncertainty of these factors have led to investments that later on turned out to be less than satisfactory (Priemus et al. 2008).

This case concerns a new approach to strategic transport decision making, SIMDEC, based on using risk simulation and multi-criteria analysis in combination for decision support. First the SIMDEC modelling framework and the theories behind are described, and afterwards SIMDEC is illustrated by an example concerning examination of four alternatives between Helsingør (Elsinore)-Helsingborg. These alternatives need to be assessed to facilitate decision making about a second northern fixed link between Denmark and Sweden to supplement the already established fixed link in the southern part of Øresund between Copenhagen and Malmö. Finally, after a discussion of results, a conclusion is given together with a perspective on the further application of SIMDEC.

B.2 The SIMDEC Modelling Framework

As mentioned in the introduction, SIMDEC is based on applying risk analysis (RA) in combination with multi-criteria analysis. With the focus of the RA on the feasibility of each of the alternatives, this concerns feasibility risk assessment (FRA) where the focus is on the risk that the investment could turn out not to be socio-economically feasible. SIMDEC proceeds by first examining FRA for the alternatives one by one, and afterwards the FRA results are used as input as one of the criteria within a set of decision criteria to a multi-criteria analysis (MCA) that aims at ranking the alternatives. The two major components of the SIMDEC modelling framework are described below.

B.2.1 Feasibility Risk Assessment

The FRA is carried out by using Monte Carlo simulation (Vose 2002; Salling 2008) on the results stemming from a conventional cost-benefit analysis, which is assumed to be prescribed by and conducted in accordance with a manual that can generally be accepted in the study context. For a large transport infrastructure investment the impacts to be covered will consist of: construction and maintenance costs, time savings, operation costs, accident savings, noise emissions, local air pollution and climate effects based on change in CO_2 emissions. With the exception of construction costs and time savings these effects can be determined in a relatively precise manner on the basis of current transport engineering modelling knowledge represented first and foremost by traffic and impact models (Leleur 2000; Trafikministeriet 2003).

Recently a methodology to handle construction costs and time savings that relate to demand prognoses has been set out with the reference scenario forecasting (RSF) technique presented in (Salling and Leleur 2009; 2010). RSF concerns Monte Carlo simulation and is based on prospect theory developed by Kahneman and Tversky in 1979 (Daniel Kahneman received the Nobel Prize in Economics in 2002 for his work in collaboration with Amos Tversky (1937–1996)). The prospect theory gave rise to reference class forecasting (RCF), which was used by Flyvbjerg and others to set out various “uplift” principles (Priemus et al. 2008). This again laid the foundation for a scenario-based simulation procedure that made it possible to formulate and introduce reference scenarion forecasting (RSF) (Salling and Leleur 2009, 2010). This appendix about SIMDEC concentrates on applying RSF to provide input to MCA as this methodology (based on scenarios related to the actual study) for each of the examined alternatives can produce what has been termed a certainty graph (CG). This graph is made up of the probability estimates of achieving at least the benefit-cost rate (BCR) indicated as argument; thus $CG(x) = Prob(BCR \geq x)$. Examples are given in the following section about case illustration.

B.2.2 Multi-Criteria Analysis

The MCA is carried out by using the REMBRANDT technique (Olson et al. 1995; Olson 1996) based on pairwise comparisons for rating of the alternatives and determination of the criteria weights. The REMBRANDT technique is recognised as a both valid and practical framework (Lootsma 1999; Barfod et al. 2011; Barfod and Leleur 2011).

In SIMDEC a set of relevant decision criteria for the decision problem at hand is laid down. Generally such a set will consist of both monetary and non-monetary criteria. As already indicated the monetary criteria are taken into account by using a CBA, which again is used as an input to conducting a feasibility risk assessment (FRA) of each of the alternatives. Specifically a certainty graph, $CG(x)$, is produced for each of the alternatives. For each alternative this graph represents its FRA-performance (based on the monetary criteria and the conducted MCS). This FRA-performance is added as a criterion to the formulated non-economic criteria that typically represent strategic issues and impacts relating to the decision problem. Thereby the total criteria set is established for the examination of the decision problem. This set should be scrutinised to reduce possible overlapping with regard to criteria definitions, while at the same time it should be ensured that no valuable information for the decision making has been left out.

The multi-criteria analysis proceeds by making pairwise comparisons (either by the decision-makers (DM) themselves or facilitated by analysts interpreting information revealed by the decision-makers about their preferences). In the rating, alternatives are successively compared two by two demanding a preference statement of the following type: very strong preference for.., strong preference for.., definite preference for.., weak preference for.., and indifference.. (Olson et al. 1995). A numerical REMBRANDT scale value associated with each statement is fed into the model and afterwards the same procedure is conducted for the other criteria to determine all the ratings and for the set of criteria to determine weights. Weights can also be obtained as ROD weights, see Appendix A. Based on ratings and criteria weights REMBRANDT finally produces a total score for each alternative, which makes it possible to rank the alternatives in accordance with their attractiveness.

One of the new features of SIMDEC is the mixing of monetary and non-monetary decision criteria with the first type of concern represented by the calculated FRA-performance. In SIMDEC the FRA-performance ratings of the alternatives are based on a set of pairwise comparisons of the previously determined certainty graphs with each of these representing one of the alternatives that candidate for a decision about being selected and implemented. The final information presented to the decision-makers to base their decision on consists of the overall ranking based on the wider criteria set, where also the non-monetary aspects have been rated based on pairwise comparisons. Below it is illustrated how SIMDEC manages to reduce very complex decision-related information to a set of criteria with rated alternatives that are used to produce a final ranking of the examined alternatives and thereby to indicate which alternative ought to be preferred.

B.3 Case Illustration

The case illustration concerns an examination of four alternatives for a new fixed link between Helsingør (Elsinore) and Helsingborg, see Fig. B.1.

The case clearly concerns a complex planning problem where both core and wider performance of the candidate alternatives need to influence the choice of alternative. Due to lack of rail capacity on the southern fixed link between Copenhagen and Malmö (opened in 2000) there is a need to provide more cross-sound capacity for railway transport. A special concern will be to relieve the current fixed link for goods traffic. At the same time a new northern link will be an important piece of the north–south EU transport corridor Sweden-Denmark-Germany for which reason also person traffic need to be considered. At the same time a new fixed link will influence the Øresund Region transport, among other things by finalising a regional Danish-Swedish public transport circle line connecting the major urban centres.

Altogether four alternatives were assessed in the SIMDEC examination (Larsen and Skougaard 2010). As can be seen from the results all four alternatives are relevant and sound candidates as each of these have qualities that are successively demonstrated in the examination.

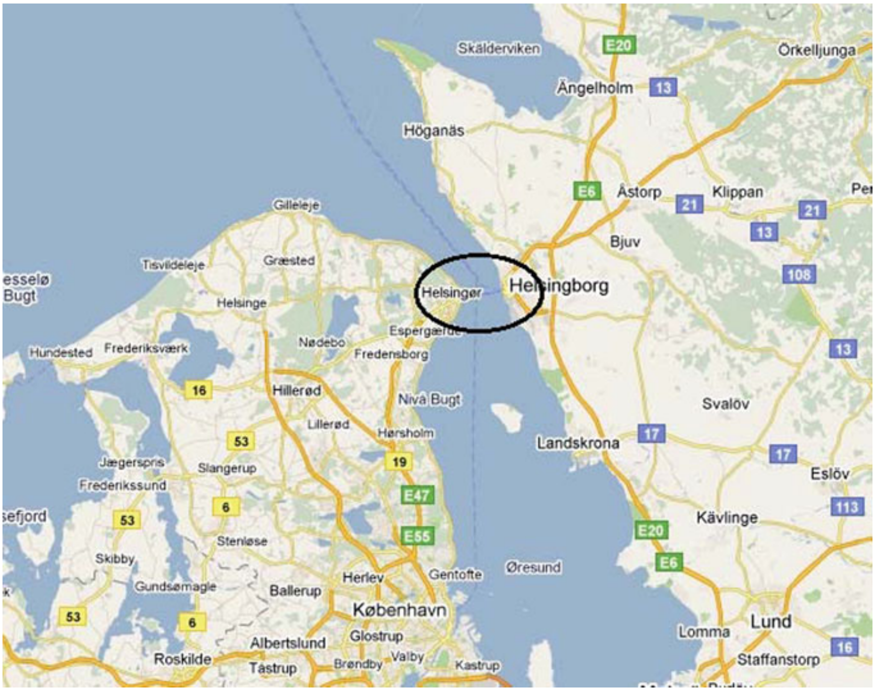


Fig. B.1 HH-fixed link location at Helsingør (Elsinore)-Helsingborg (from Google Maps)

Table B.1 The four alternatives incl. cost in bn DKK for the HH-fixed link

HH-fixed link (alternatives)	Description (type of construction)	Total cost (bn DKK)
Alternative A1	Tunnel for rail (2 tracks) passenger traffic only	7.7
Alternative A2	Tunnel for rail (1 track) goods traffic only	5.5
Alternative A3	Bridge for road and rail (2 × 2 lanes & 2 tracks)	11.5
Alternative A4	Bridge for road (2 × 2 lanes)	6.0

The four alternatives are listed in Table B.1 with indication of type of construction and total cost (1 US$ equals around 5 DKK) (Ibid.)

In general the ‘pure’ person transport alternatives seem to perform best in a conventional CBA whereas alternatives with rail improvement gain in the wider SIMDEC analysis. Due to the fixed link’s high influence on nearby towns, the impact on the ecology conditions in the sound (tunnels better than bridge solutions with regard to flow of water), on regional development (trade, work and education-related benefits) and the improvement in network (locally, nationally and in an EU-perspective) the wider set of decision criteria shown below has been adopted.

Criterion 1: Robustness of feasibility (FRA-performance)
Criterion 2: Impact on towns

Table B.2 The four alternatives with conventional cost-benefit rates

Cost-benefit rates for the four alternatives related to scenarios			
The four alternatives for the link	Economic growth expressed by three scenarios		
	High	Middle	Low
A1: Tunnel, rail passenger service	1.34	1.15	1.01
A2: Tunnel, rail goods transport	0.43	0.39	0.34
A3: Bridge, road & rail	2.40	2.17	1.94
A4: Bridge, road	3.01	2.63	2.41

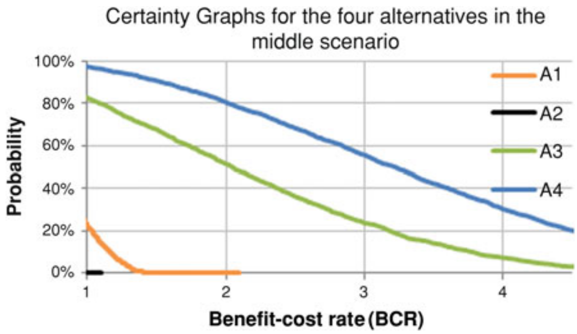


Fig. B.2 Certainty graphs for the four alternatives in the middle scenario

Criterion 3: Impact on ecology in sound
Criterion 4: Impact on regional economics
Criterion 5: Impact on transport network and accessibility

Based on the Danish national manual for socio-economic assessment (Trafikministeriet 2003) the benefit-cost rate (BCR) values shown in Table B.2 have been determined applying transport modelling for road and rail traffic set in a context of three economic development scenarios spanning high, middle (continuation of established trend) and low economic growth (Larsen and Skougaard 2010).

Afterwards this conventional socio-economic calculation reference scenario forecasting (RSF) is applied to produce three sets of certainty graphs (CGs) consisting of CG(A1), CG(A2), CG(A3) and CG(A4), with one set for each of the three scenarios mentioned above, see Fig. B.2 for the four CGs in the middle scenario.

The RSF-calculations behind the CGs are based on cost-benefit analysis and Monte Carlo simulation using estimated RSF distributions (Erlang and Beta Pert distributions for construction costs and time savings respectively with the latter influenced by the actual scenario), see (Salling and Leleur 2009; 2010).

Each CG can be interpreted as follows: for $x = 1$ the probability or certainty of BCR $\geq$ 1 (with 1 indicating the ordinary socio-economic cut-off value with regard to feasibility) can be seen from the y-axis value. For the alternatives in the middle scenario in Fig. B.2 their certainty values (CVs) are: CV(A1) = 22%, CV(A2) = 0%, CV(A3) = 83% and CV(A4) = 97%. In the scenario runs, the

Table B.3 The four alternatives also expressed by certainty values

Cost-benefit rates and certainty values for the four alternatives related to the scenarios			
The four alternatives for the link	Economic growth expressed by three scenarios		
	High	Middle	Low
A1: Tunnel, rail passenger service	1.34; 37%	1.15; 22%	1.01; 11%
A2: Tunnel, rail goods transport	0.43; 0%	0.39; 0%	0.34; 0%
A3: Bridge, road & rail	2.40; 86%	2.17; 83%	1,94; 78%
A4: Bridge, road	3.01; 100%	2,63; 97%	2.41; 96%

Table B.4 REMBRANDT rating of criterion 1: robustness of feasibility

Pairwise comparison of alternatives under criterion 1: robustness of feasibility				
Scale value (*j*, *k*)	A1	A2	A3	A4
A1	0	Strong (+6)	Definite (−4)	Strong (−6)
A2	Strong (−6)	0	Strong(−6)	Very strong(−8)
A3	Definite (+4)	Strong (+6)	0	Weak (−2)
A4	Strong (+6)	Very strong (+8)	Weak (2)	0

Note relating to *j* compared to *k*: indifference 0, weak +2, definite +4, strong +6 and very strong +8. Observe that a reversal of *j* to *k* is indicated by −. Elements in the diagonal are all necessarily 0.

expected economic growth associated with the actual scenario will affect the obtained certainty values, see Table B.3.

Where the conventional cost-benefit rate gives a deterministic point estimate of the feasibility, the RSF-based certainty values give a probability-based interval estimate of how the two most important uncertainty factors could affect such a point estimate. Specifically, construction costs and time savings are simulated using historical reference class knowledge made operational by using the Erlang and Beta Pert distributions respectively with the latter embedded in a scenario context (Ibid.). In the simulation the uncertainty due to the estimation of construction costs is considered generally, i.e. across the scenarios and not related to a specific scenario.

In SIMDEC the certainty graphs and certainty values are used as the basis of the final REMBRANDT procedure with regard to criterion 1 about robustness of feasibility. The four alternatives are compared two by two resulting in altogether $(4 \times 3)/2 = 6$ pairwise comparisons as shown in Table B.4.

For the remaining four criteria, information has been gathered to serve as sufficient background for the criteria rating, which leads to additional 4×6 comparisons. As an example the pairwise comparisons for criterion 5 about impact on transport network and accessibility are indicated in Table B.5.

The rating values for all five criteria are shown in Table B.6 together with the criteria weights, which have been determined by the ROD technique. In case pairwise comparison had also been applied for the five criteria, this would have demanded another $(5 \times 4)/2 = 10$ comparisons.

Table B.5 REMBRANDT rating of criterion 5: impact on transport network and accessibility

Pairwise comparison of alternatives under criterion 5: network and accessibility

Scale value (*j*, *k*)	A1	A2	A3	A4
A1	0	Strong (+6)	Definite(−4)	Weak(−2)
A2	Strong (−6)	0	Very strong (−8)	Strong (−6)
A3	Definite (+4)	Very strong (+8)	0	Definite (+4)
A4	Weak (+2)	Strong (+6)	Definite (−4)	0

Table B.6 Rates and weights for the five criteria

Rates and weights determined by using altogether 30 pairwise comparisons and importance ranking of the five criteria

Five criteria/four alternatives	A1 rates	A2 rates	A3 rates	A4 rates	Weights
Robustness of feasibility	0.03	0.00	0.19	0.78	0.35
Impact on towns	0.20	0.79	0.00	0.01	0.13
Impact on ecology	0.47	0.47	0.03	0.03	0.06
Impact on regional economics	0.05	0.00	0.76	0.19	0.19
Impact on network and accessibility	0.05	0.00	0.84	0.11	0.27

Table B.7 The four alternatives with total scores and rank order indicated

HH-fixed link (alternatives)	Description (type of construction)	Cost (bn DKK)	Score	Rank
A1	Tunnel for rail (2 tracks) passenger traffic only	7.7	0.09	4
A2	Tunnel for rail (1 track) goods traffic only	5.5	0.13	3
A3	Bridge for road and rail (2 × 2 lanes & 2 tracks)	11.5	0.44	1
A4	Bridge for road (2 × 2 lanes)	6.0	0.34	2

As concerns the theoretical set up of REMBRANDT it should be noted that the processing of scale values for the determination of ratings and criteria weights differs with regard to the so-called progression factors, see (Olson et al. 1995; Barfod and Leleur 2011). This, however, does not influence the easy and straightforward application of this multi-criteria methodology. The DMG at the Technical University of Denmark has developed SIMDEC software that can be applied for instantaneous use in the context of a decision conference (DMG 2010).

It should be observed that a documentation report, also referred to as a log book, is worked out as part of doing the pairwise comparisons. Afterwards the considerations behind each comparison can be studied/inspected to judge the overall validity of the model outcome. In case of disagreement and debate among the decision-makers this also makes it possible to make adjustments as a basis for model reruns.

Based on the values in Table B.6 the total score for each alternative is determined using all five criteria by Σ(weight × rate) leading to the prioritising of the four alternatives shown in Table B.7.

B.4 Discussion

Conventional decision support for deciding upon the four HH-alternatives would consist of a calculation of benefit-cost rates (BCRs) supplemented by various information not accounted for in the BCRs. SIMDEC offers an approach where simulation and MCA are applied to deal with the complex decision problem. The BCR information contained in Table B.2 indicates that three (A1, A3 and A4) out of the four alternatives are socio-economically sound with BCR values also in the low growth scenario being around or above 1. Conducting reference scenario forecasting (RSF), however, indicates, by inspecting the produced certainty graphs (CGs) and certainty values (CVs) that really only two alternatives (A3 and A4) are sound when including RA in the assessment (CV $\geq$ 75–80%). By accounting for estimation bias in the cost estimates and prognosis bias in the forecasting of traffic and exploring this by simulation embedded in scenarios, the alternative A1 is shown to have a feasibility that cannot be considered robust.

With alternatives A3 and A4 remaining as candidates for implementation, these are explored in a wider context where strategic, non-monetary issues are introduced together with the criterion about robustness of feasibility based on the described risk analysis. With CGs and CVs of the alternatives as input to this criterion a REMBRANDT multi-criteria analysis is carried out which comprises also the criteria about the impacts on towns, on ecology, on regional economics and on transport network and accessibility. The result is that even with the highest criterion weight on robustness of feasibility the order of importance with regard to A4 and A3 is now reversed as alternative 3 now becomes the most attractive alternative.

For the lower ranking alternatives A1 and A2 it should be observed that A2 is now better than A1. The wider assessment based on the multi-criteria analysis has thus revealed and indicated some qualities contained in A2, which were not captured by the BCR values.

B.5 Conclusions and Perspective

The SIMDEC approach is seen as promising since relatively complex decision problems of a strategic nature can be based on both explicit risk precaution and influence from a set of wider, non-monetary issues. As the approach with its successive building up of assessment information is easy to grasp it can be applied in decision sessions where a high involvement of decision-makers is possible. SIMDEC software has been worked out that can facilitate such decision conferences. Hereby the SIMDEC methodology becomes embedded in a process that includes also criteria formulation by use of soft operations research methods such as, for example, brainstorming and futures workshops; based on the software the participants can ask various “what-if”-questions to test the robustness of the priority-ordering of the alternatives. One important issue that can be treated is how different stakeholder strategies—defined by the chosen set of decision criteria and the stated value inputs to the pairwise comparisons—will affect the result (Leleur 2008; Jeppesen 2010).

The SIMDEC approach has so far been tested on transport planning problems but the perspective is to explore its potential also for complex decision problems outside the transport sector. It is expected that alternatives for construction projects in general can be examined by SIMDEC in a way that satisfies both theoretical validity and practical userfriendliness.

Technical Notes About REMBRANDT, Monte Carlo Simulation and Certainty Graphs

These notes first describe the principles of the REMBRANDT method used in SIMDEC for the multi-criteria analysis. REMBRANDT has been shown to have some advantages compared to AHP. After this presentation the notes describe how risk analysis (RA) by the use of Monte Carlo simulation can produce the certainty graphs made use of in SIMDEC as one of the criteria that enter the REMBRANDT examination of alternatives. The notes are based on (DMG 2010).

The Multi-Criteria Method REMBRANDT

There are various methods for the assessment of alternatives based on pairwise comparisons. The most known and used method is the AHP method developed by Saaty over the past 30 years. Saaty's method has been criticised because of weaknesses in the theoretical basis, see (Belton and Stewart 2002). An improved theoretical model has been formulated by Lootsma in the beginning of the 1990s with the REMBRANDT method (Ratio Estimation in Magnitudes or deci-Bells to Rate Alternatives which are Non-DominaTed), see (Olson et al. 1995; Lootsma 1999).

The REMBRANDT system is intended to remedy three contended flaws in AHP. First, direct rating is now on a geometric scale (using logarithmic transformation) instead of on a ratio scale. Second, the scores and weights are now calculated by the geometric mean. Third, aggregation of scores by the arithmetic mean is replaced by the product of the individual scores weighted by the power of the normalised weights obtained from analysis of hierarchical elements above the alternatives. The AHP and REMBRANDT methods are based on the preference scales in Table B.8.

In connection with the specific pairwise comparison, the user should only concentrate on the verbal scale, while the two numerical scales only are of technical interest as input into the mathematical model.

Table B.8 AHP and REMBRANDT scales

Preference intensity	Explanation	AHP	REMBRANDT
Indifference	Neither of the two alternatives is preferable over the other	1	0
Weak	One of the alternatives is preferred slightly over the other	3	2
Definite	One of the alternatives is preferred definitely over the other	5	4
Strong	One of the alternatives is preferred strongly over the other	7	6
Very strong	One alternative is preferred very strongly over the other	9	8
Compromise	Values for graduation between two of the preferences above	2, 4, 6, 8	1, 3, 5, 7

There are as mentioned three main criticisms of the AHP method which the REMBRANDT method tries to correct. The first is related to the scale in AHP where 1 represents two objects being equal in value, 3 means that the first object is slightly better than the second object, 5 indicates clear preference in this respect, 7 a strong preference and 9 a very strong preference. Based on a number of examples and reflections, Lootsma (1999) has adjusted the numerical scale for REMBRANDT, so it is more convenient for subsequent calculations.

The second point that REMBRANDT tries to improve is the calculation of scores. AHP uses a method which has the disadvantage that if a new alternative is added later in the process, it may reverse the existing ranking of alternatives (known as "rank reversal of alternatives"). REMBRANDT uses logarithmic regression or geometric mean, whereby the potential problem of rank reversal is overcome. For a more detailed technical analysis refer to Olson et al. (1995).

The third and last point which the REMBRANDT method tries to improve compared with AHP is the way the individual scores are aggregated. The AHP uses a method based on calculation of eigenvectors leading to scores and arithmetic mean aggregation by summation of the scores multiplied by the criteria weights, while REMBRANDT calculates the value of an alternative by using the geometric mean scores and multiplying these scores after they have been uplifted with the criteria weights.

To illustrate the principles of REMBRANDT a small calculation example is described below (Ibid.).

There is a decision problem involving three alternatives (A, B and C) and four criteria (W, X, Y and Z). The criteria weights are already set to:

$$(0.493;\ 0.246;\ 0.174;\ 0.087)$$

Scores for each alternative under each criterion is calculated using the following transformation: $e^{\ln(2)\ \delta(jk)}$. It is noted that when REMBRANDT is used to determine criteria weights the transformation $e^{\ln(\sqrt{2})\ \delta(jk)}$ is used (Lootsma 1999;

Barfod and Leleur 2011). The pairwise comparisons of the three alternatives under each of the four criteria are shown below:

Pairwise comparison: Transformation: Geometric mean:

Criterion W:

	A	B	C
A	0	4	6
B	-4	0	4
C	-6	-4	0

	A	B	C
A	1	16	64
B	0.0625	1	16
C	0.015625	0.0625	1

10.08
1
0.0992

Criterion X:

	A	B	C
A	0	-2	1
B	2	0	4
C	-1	-4	0

	A	B	C
A	1	0.25	2
B	4	1	16
C	0.5	0.0625	1

0.7937
4.0
0.3150

Criterion Y:

	A	B	C
A	0	0	-4
B	0	0	-3
C	4	3	0

	A	B	C
A	1	1	0.0625
B	1	1	0.125
C	16	8	1

0.3969
0.5
5.0397

Criterion Z:

	A	B	C
A	0	1	-1
B	-1	0	-2
C	1	2	0

	A	B	C
A	1	2	0.5
B	0.5	1	0.25
C	2	4	1

1
0.5
2

Afterwards the total score for each alternative A, B and C is found by using the determined values above and the criteria weights of the four criteria W, X, Y and Z as indicated below; the obtained total scores are as a matter of convention (like in AHP) transformed into a normalised set of numbers.

A:	$10.08^{0.493}$	$* \ 0.7937^{0.246}$	$* \ 0.3969^{0.174}$	$* \ 1^{0.087}$	=	2.513	0.624
B:	$1^{0.493}$	$* \ 4^{0.246}$	$* \ 0.5^{0.174}$	$* \ 0.5^{0.087}$	=	1.174	0.292
C:	$0.0992^{0.493}$	$* \ 0.315^{0.246}$	$* \ 5.0397^{0.174}$	$* \ 2^{0.087}$	=	0.339	0.084

It should be noted that in the SIMDEC example criteria weights were determined by the ROD technique.

Monte Carlo Simulation and Certainty Graphs

Monte Carlo simulation (MCS) is a commonly used technique for risk analysis (RA) as concerns project appraisal. The purpose of RA is to calculate the combined impact of various uncertainties in model variables to determine an overall uncertainty influence (Vose 2002). In this context, a risk or uncertainty assessment is prepared by inserting different continuous or discrete probability distributions. In SIMDEC the Erlang distribution has been used for the construction costs and the Beta Pert distribution for the traffic demand forecasts on the new transport infrastructure alternative (Salling 2008). Other application cases would make it relevant to examine other types of probability distributions to be applied for the model variables expected to dominate the overall uncertainty. In SIMDEC the model software @RISK has been applied, which can be linked to the Excel-based SIMDEC calculations (Palisade 2007; DMG 2010).

The principle behind MCS is, based on the applied probability distribution functions, to make (simulate) a large number of individual model results or 'events', typically around 2,000 runs or more. In case of simulating the benefit-cost rate (BCR) the individual model results are pieced together to represent the overall simulation result. The following explains the process of an MCS within the frame of SIMDEC as four main steps:

1. Determine the uncertain variables
2. Add an appropriate probability distribution to selected variables
3. Simulate a set of benefit-cost rates (BCR) by making a number of runs
4. Plot and interpret the probability distribution of the benefit-cost rates (BCR) values

The use of MCS for transport evaluation is described in (Salling 2008) with a special focus on feasibility risk assessment (FRA) concerned with the examination of the certainty that a given transport investment project is feasible from a socio-economic viewpoint. This can be illustrated as follows.

The CBA result is typically presented by one or more of the following index values: the net present value (NPV), the internal rate of return (IRR), the benefit-cost rate (BCR) or a combination of these. Setting focus on the BCR value the MCS is used to determine the robustness of feasibility when a CBA-based point estimate is transformed into an interval result provided by a certainty graph for the investment showing non-feasible and feasible outcomes by use of probability estimates of the BCR values. Specifically, this graph is made up of the probability estimates of achieving at least the BCR indicated as argument; thus $CG(x) = Prob(BCR \geq x)$. An example is shown in Fig. B.3 indicating a 90% confidence interval between BCR-rate values 0.80 and 2.44 and a certainty value (CV) equal to 83%, which means that the BCR-rate value has a 83% probability of being equal to or higher than the cut-off value equal to 1.

In recent research of feasibility of transport investment projects it has been verified that especially construction costs and traffic demand forecasts are important (Priemus et al. 2008; Salling and Leleur 2009; 2010).

In an ongoing research project "Uncertainty in Transport Project Evaluation", UNITE (2009–2012), funded by the Danish Strategic Research Council a decision support system (DSS) has been developed containing both a deterministic CBA module, a deterministic MCA module (AHP and REMBRANDT) and a stochastic MCS module. Thereby the DSS software can support both the COSIMA

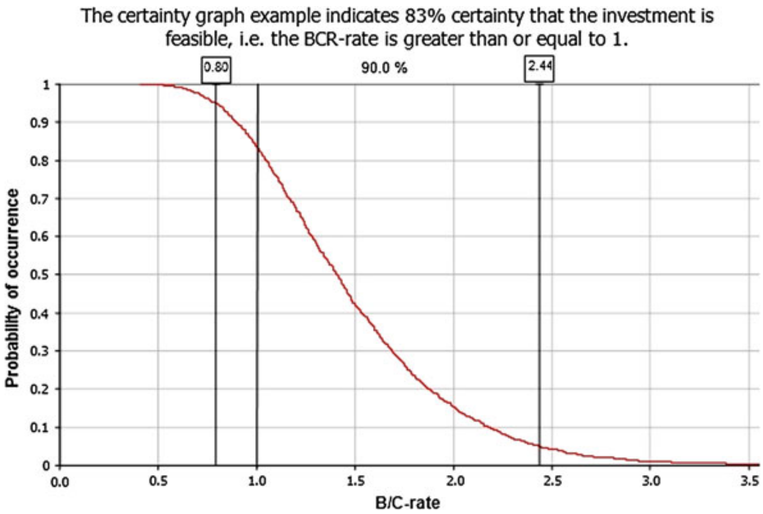


Fig. B.3 The concept of certainty graph

methodology described in Appendix A and the SIMDEC methodology described in this Appendix B.

The DSS software has as part of the research project EcoMobility (2010–2012), funded by the EU Regional Development Fund Interreg IV-A, been used to implement the EcoMobility assessment model. This model applies the SIMDEC approach to make it possible to include an impact studied and labelled "greening of goods logistics" as a decision factor. The model has been tested in a recent decision conference (October 2011), and it was verified that the certainty graphs can easily be understood and interpreted by the participants to judge the influence of socio-economic robustness being one of the important criteria in the SIMDEC analysis.

References for Appendices A and B

Andersen M, Petersen NB (2006) Bedømmelse af omfartsveje i Allerød. M.Sc. thesis, Centre for Traffic and Transport (CTT), Technical University of Denmark (DTU)

Banister D, Berechman J (2000) Transport investment and economic development. UCL Press, London

Barfod MB, Leleur S (2011) Scaling transformations in the REMBRANDT technique: a sensitivity examination of the progression factors. Paper presented at the 21st international conference on multiple criteria decision making, Finland

Barfod MB, Vestergaard AV, Leleur S (2011) Examination of decision support systems for composite CBA and MCA assessments of transport infrastructure projects. In: Shi Y, Wang S, Kou G, Wallenius J (eds) New state of MCDM in the 21st century. Lecture notes in economics and mathematical systems, vol 648. Springer, pp 167–176

Belton V, Stewart TJ (2002) Multiple criteria decison analysis—an integrated approach. Kluwer Academic Publishers, Dordrecht

Bhushan N, Rai K (2004) Strategic decision making: applying the analytic hierarchy process, springer series in decision engineering

DMG (2010) Decision modelling group compendium decision support: theory and practice, DMG, DTU Transport. Technical University of Denmark, Denmark

DTU (2007) Dokumentationsmodel for TGB Vurderingsmodel (Trafikplan for Grønland: Beslutningsredskab), Center for Trafik og Transport (CTT). Danmarks Tekniske Universitet

ECMT—European Conference of Ministers of Transport, Group of Experts (1981) Exchange of information criteria applied to transport infrastructure projects, ECMT Publication

Expert Choice Inc (2004) Expert Choice, Arlington

Goodwin P, Wright G (2010) Decision analysis for management judgement, 4th edn. Wiley, New York

Hiselius LW, Barfod MB, Leleur S, Jeppesen SL, Jensen AV, Hjalte K (2010) Helhetsorienterad utvärdering av kollektivtrafikåtgärder, Bulletin 246, Institutionen för Teknik och Samhälle, LTH, Lunds Universitet

Hwang CL, Yoon K (1995) Multi attribute decision making—an introduction, Sage University Series No. 07-104, Sage Publications, London

Jensen AV, Barfod MB, Leleur S (2007) Strategic planning and decision analysis: presentation of the COSIMA software system. Paper presented at the INFORMS 2007 Congress, Puerto Rico, July 2007

Jeppesen, SL (2010) Sustainable transport planning. Ph.D. dissertation, Department of Transport, Technical University of Denmark

Kronbak J (1998) Trafikplanlægning og GIS-baserede konsekvensberegninger. Ph.D. Dissertation, Institut for Planlægning. Danmarks Tekniske Universitet

Larsen LA, Skougaard BZ (2010) Vurdering af alternativer for en fast forbindelse Helsingør-Helsingborg. M.Sc. thesis, DTU Transport, Danmarks Tekniske Universitet

Leleur S (2000) Road infrastructure planning—a decision-oriented approach, 2nd edn. Polyteknisk Forlag, Lyngby

Leleur S (2008) At navigere mod fremtiden: Systemisk planlægning som ide og metode. Polyteknisk Forlag, Lyngby

Leleur S, Holvad T (2004) New appraisal methodology for large European transport investments. In: Proceedings of the European transport conference 2004. Association for European Transport (AET), Strasbourg

Leleur S, Jensen AV, Salling KB (2004a) COSIMA—software manual, Version June 2004, Centre for Traffic and Transport (CTT). Technical University of Denmark

Leleur S, Jensen AV, Salling KB (2004b) Modelling decision support and uncertainty for large transport infrastructure projects: the CLG-DSS model of the Øresund fixed link. In: Antunes CH, Dias LC (eds) Proceedings of the 15th mini-EURO conference in managing uncertainty in decision support models—MUDSM 2004, INESC-Coimbra, Coimbra, 2004

Leleur S, Petersen NB, Barfod MB (2007) The COSIMA approach to transport decision making: combining cost-benefit and multi-criteria analysis for comprehensive project appraisal. In: Kim K-S (ed) Proceedings of the Korean Development Institute and World Bank conference, Seoul, May 2007. Improving public investment management for large-scale government projects: focusing on the feasibility studies. KDI, pp 100–122

Leleur S, Larsen AL, Skougaard BZ (2010) Strategic transport decision making: the SIMDEC approach based on risk simulation and multi-criteria analysis. In: EUROSIS Proceedings of the Asian simulation technology conference ASTEC' 2010 conference, Shanghai, March 2010

Lootsma FA (1999) Multi-criteria decision analysis via ratio and difference judgement. Kluwer Academic, Dordrecht

Olson DL (1996) Decision aids for selection problems, springer series in operations research

Olson DL, Fliedner G, Currie K (1995) Theory and methodology: comparison of the REMBRANDT system with analytic hierarchy process. Eur J Oper Res 82:522–539 (Elsevier)

Palisade (2007) @RISK version 5.0—Advanced risk analysis for spreadsheets. Palisade Corporation, New York

Priemus H, Flyvbjerg B, van Wee B (2008) Decision making on mega-projects: cost-benefit analysis, planning and innovation. Edward Elgar Publishing, Cheltenham

Roberts RJ, Goodwin P (2002) Weight approximations in multi-attribute decision models. J Multi-Criteria Decis Anal 11:291–303 (Wiley)

Saaty TL (2001) Decision making for leaders: the analytic hierarchy process for decisions in a complex world. RWS Publications, Pittsburgh

Salling KB (2008) Assessment of transport projects: risk analysis and decision support. Ph.D. Dissertation, Department of Transport, Technical University of Denmark

Salling KB, Leleur S (2009) Modelling of transport project uncertainties: risk assessment and scenario analysis. In: Proceedings of the modelling and applied simulation'09 conference, Puerto de la Cruz, Tenerife, Sept 2009

Salling KB, Leleur S (2010) Reference scenario forecasting: a new approach to transport project assessment. Paper presented at the 12th world conference on transport research in Lisbon, July 2010

Steffensen M, Testmann L (2000) Vurdering af omfartsveje belyst gennem alternative projekter for Høng. M.Sc. thesis, Institut for Planlægning, Danmarks Tekniske Universitet

Trafikministeriet (2003) Manual for samfundsøkonomisk analyse, Copenhagen, juni 2003

Tsamboulas D, Beuthe M, Grant-Muller S, Leleur S, Nellthorp J, Panou K, Pearman A, Rehfeld C (1998) Innovations in decision analysis, deliverable D10, EUNET research project, EU 4th Framework Programme

Vaidya SO, Kumar S (2006) Analytic hierarchy process: an overview of applications. Eur J Oper Res 169:1–29 (Elsevier)

Vose D (2002) Risk analysis: a quantitative guide, 2nd edn. Wiley, New York

von Winterfeldt D, Edwards W (1986) Decision analysis and behavioural research. Cambridge University Press, Cambridge

Index

S. Leleur, *Complex Strategic Choices*, Decision Engineering,
DOI: 10.1007/978-1-4471-2491-7, © Springer-Verlag London 2012

S

T

U

V

W