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Composite model for assessment

In the appraisal and planning of transport infrastructure projects the examination should be based on all relevant impacts, which are depending on the type and size of the project addressed. Some of these impacts can be assessed monetarily and are thereby possible to include in a conventional CBA. However, no valid assessment knowledge exists for impacts such as urban development, landscape, etc. These impacts are denominated as non-monetary impacts or strategic impacts and have to be assessed by use of a MCDA.

Earlier research on composite decision support systems (DSS) within transport planning has mainly concentrated on incorporating the CBA in the MCDA. Here the European Commission's fourth framework project EUNET (EUNET/SASI, 2001), which has developed a methodology dealing with the combination of CBA and MCDA, can be mentioned. The EUNET framework applies scores to the investment criterion, e.g. the benefit cost rates (BCR), thus, it treats the rates as any other criterion in the MCDA. Exactly which criteria to include in the framework is a matter of judgment depending, among other factors, on the reliability of the data and the preferences stated by the decision-makers and/or stakeholders in the decision process. Another similar inclusive approach is proposed in (Sayers et al., 2003) for transport project appraisal in the UK. Different methodological frameworks are used varying from country to country; however, it is roughly possible to divide them into two main categories: CBA-based and MCDA-based frameworks. Among the CBA-based frameworks the Danish and German can be mentioned, while e.g. French and Dutch frameworks are based on the use of MCDA (for further information about European frameworks see e.g. (Banister and Berechman, 2000) and (EUNET/SASI 2001). Reviews of transport appraisal methodologies and their premises and results can be found in for example (Hayashi and Morisugi, 2000) and (Mackie and Preston, 1998) listing also various sources of error and bias in them.

The COSIMA DSS presented here provides a theoretical and practical methodology for adding non-monetary MCDA-criteria to the monetary CBA-impacts. Unlike previous attempts this DSS is based on the argument that the MCDA-criteria can be added to the CBA-impacts – if value functions can be computed for the MCDA-criteria using a weighting procedure describing the importance of each criterion. Hence, the COSIMA approach is based on the theoretical valid and widely used methodology of additive value functions (see e.g. (Keeney and Raiffa, 1993) or (von Winterfeldt and Edwards, 1986)).

General principles

The idea behind composite modelling assessment (COSIMA) is to extend conventional CBA into a more comprehensive type of analysis, as often demanded by decision-makers, by including "missing" decision criteria of relevance for the actual assessment task. The missing criteria often address issues that have been difficult to assess by the conventional CBA but hold a potential of improving actual decision support from the assessment if treated properly. In COSIMA the added criteria will be referred to as the MCDA part of the COSIMA analysis.

Assumptions

There may be four alternatives between which the alternative to be implemented is to be found. To find the alternative to be implemented among the four it is necessary that the phases with formulation and design are implemented in a way so that relevant considerations are reflected in the set of the four alternatives. This process has led to four alternatives and not just one, which reflect an uncertainty in the decision making which is expressed by necessitate a choice between four alternatives. An assumption is also that this choice made by one or more decision-makers can be qualified through the use of decision support.

The four alternatives are pre-tested using a cost-benefit analysis. With four results for example in terms of BCRs the election issue could be solved through the alternative with the highest BCR was chosen as it from a relative point emerges as the best of the four alternatives. At the same time it may be assumed that it also satisfies an absolute requirement with regard to socio-economic viability, namely the BCR is greater than 1 equivalent to a positive net present value.

COSIMA is based on that, at least hypothetically the alternative with highest BCR is chosen. If decision-makers feel that the CBA has provided the necessary foundation the decision process ends here. However, if decision-makers are unsure whether the necessary conditions have been present, this can be further developed through the MCDA as a supplement to the CBA. The following will be based on whether it is justified that the alternative with the highest BCR should be substituted with any of the other three alternatives. It is important to maintain that it is precisely this situation which is being treated, as this has an impact on both the process as on methodology.

The COSIMA approach

The COSIMA approach consists of a CBA part and a MCDA part and the result of the COSIMA assessment is expressed as a total value (TV) based on both parts. This model set-up emphasizes that the MCDA part should be truly additive to the CBA part. For this reason a project alternative, A_k, is better represented for the decision making by the TV(A_k) than by e.g. the net present value (NPV) derived from the CBA. The principle in COSIMA can be expressed by (Leleur et al., 2007):

$$TV(A_k) = CBA(A_k) + MCA(A_k)$$

The formulation of COSIMA introduced above thus resembles CBA but the assessment principles made use of in the MCDA part, generally based on decision-maker involvement, justifies the notation as multi-criteria analysis. It can be noted on the basis of the above that in a situation where the investment in A_k equal to the investment costs C_k is not feasible seen from CBA (i.e. CBA(A_k) ≤ C_k), then the investment can be justified by the wider COSIMA examination if TV(A_k) > C_k. This can also be expressed as TRR(A_k) > 1 where TRR expresses the total rate of return.

In a COSIMA analysis where A_k denominates the project alternative it has been found to be convenient to express the feasibility by the total rate of return TRR(A_k) from the investment C_k which leads to the equation below (Ibid.):

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

where:

- C_k are the total costs of alternative A_k
- $V_{CBA}(X_{ik})$, is the value in monetary units for the CBA effect i for alternative k for altogether I CBA impacts
- $V_{MCDA}(X_{jk})$ is a value-function for MCDA criterion j for alternative k for altogether J MCDA criteria
- $w(j)$ a weight that expresses the importance of criterion J
- α is a calibration factor that expresses the model set-up's trade-off between the CBA and the MCDA part

The general COSIMA principles are presented by the equations above. It can be realized that with sufficient information about the MCDA part, the equation can be specified into a CBA. This would for example be the situation if a conventional CBA is carried out and afterwards supplemented with some extra criteria which can be specified fully by impact models that lead to net effects which can be given satisfactory unit prices similar to the assessment in the CBA part. However, this will most often not be possible as the MCDA part in general is "less known" than the CBA part. The purpose of COSIMA is to handle such a situation in a comprehensive and transparent way ensured through the determination of appropriate values for α and w(j) for the J MCDA criteria and appropriate value functions $V_{MCDA}(X_{jk})$. The latter supplement the determination of V_{CBA} that, however, can be derived from a CBA manual relevant for the actual assessment case e.g. DMT (2003).

Calibration of the COSIMA DSS

Regarding the α-indicator, that expresses the balance between the CBA and MCDA parts in the model set-up, it should be noted that the CBA calculation remains unchanged in COSIMA, but that different α-values will change the MCDA's influence on the TRR. In practice it has been found convenient to express α based on a MCDA%, which reflects the relative weight of the MCDA-part compared to the CBA-part. The value of $\alpha = \alpha(\text{MCDA\%})$ is then set by determining MCDA% $= 100 \cdot \sum_j B_j / [\sum_i B_i + \sum_j B_j]$, where $B_i = \sum_{\kappa \epsilon K}(b_{ik})$ and $B_j = \sum_{\kappa \epsilon K}(b_{jk})$ represent the value elements for the individual CBA-impact i and MCDA-criterion j summed over the κ alternatives (the alternatives A_κ chosen for calibration of the model). Thus $\sum_i B_i$ and $\sum_j B_j$ are summations of the I CBA-impacts and the J MCDA-criteria, and B_i and B_j the results of the b_{ik} and b_{jk} summations of the alternatives, where some if not all are selected for the model calibration (Leleur, 2008).

The calculations in the COSIMA DSS use a parameter for the calibration named UP_j which functions as a shadow price per index value for each of the J MCDA-criteria in order to produce the b_{jk} values. These benefit values obtained are determined by $b_{jk} = VF_j(Y_{jk}) \cdot UP_j$ where the shadow price, UP_j, is a function of the α-indicator (MCDA%), the criteria weights (w_j), the sum of benefits from the CBA for the alternatives used for calibration $(\sum_i \sum_{\kappa \epsilon K}(b_{i\kappa}))$ and the sum of VF-scores for the alternatives used for calibration $(\sum_\kappa VF_j(Y_{jk}))$. In the procedure $\alpha(\text{MCDA\%})$ and w_j determine a fraction of $\sum_i \sum_{\kappa \epsilon K}(b_{i\kappa})$ that by unit scaling leads to the J unit prices that are used for calculating the $TRR(A_k)$. It should be noted that TRR-values are also calculated for alternatives not used in the calibration set. Changes in the set of alternatives A_κ behind the calibration will influence the UP_j values and thereby the TRR-values. This pool dependence is of great interest for the decision analyst who is formulating the model set-up. The alternatives should in this respect be scrutinised so that the calibration pool only consist of alternatives that are possible solutions (Leleur, 2008).

COSIMA calculation example

The COSIMA calculations can be illustrated with a simple calculation example based on Hiselius et al. (2009).

At a 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 with the observed total expenditure C1 C2, C3 and C4 leads to BCRs for the four alternatives, see Table 0.1 below.

Table 0.1: Benefit-cost data for the calculation example

Alternative	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

If there is agreement among the decision-makers - after the content of the cost-benefit analysis is reviewed - that 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, you can further involve new criteria to evaluate them by a multi-criteria analysis (MCDA) and finally perform a composite analysis after the COSIMA principles. The procedure is as follows:

1. First a number of criteria are described. In this example k1, k2, k3 and k4. This should be done so overlap with components of the cost-benefit analysis is avoided.
2. Next, the four criteria are rated and weighted. Rates 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 to this consists of a pair-wise comparison of all four alternatives under each of the four criteria k1, k2, k3 and k4. For each of these criteria is it with four alternatives needed $(4 \cdot 3) / 2 = 6$ pair-wise comparisons. More technically, by using the MCDA method REMBRANDT, where the results are translated into a value function. It gives the following results in Table 0.2:

Table 0.2: 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

3. Since the criteria usually do not get assigned equal importance by the decision-makers, the criteria are assigned the weights K1, K2, K3 and K4. This can be done directly or using the ranking criteria of importance (ROD technique) or swing weight (SW). The result, where the weights summarize to 1, is for example: (K1, K2, K3, K4) = (0.20, 0.55, 0.10, 0.15).
4. In the last part of the calculation the CBA and MCDA is linked together, which is done by decision makers provides an MCDA %. At a high MCDA % the MCDA dominates the final result, while a low MCDA % means that it will be the CBA and the detected BCR-values that dominates.

   The decision-makers are asked what effect the MCDA should have and may answer 50%. Since this is a relative percentage, it means that the CBA % is 50 as well and MCDA and CBA must therefore count the same in the overall analysis. Based on the choice of A2 with the highest BCR the MCDA now should "count the same". Benefit value B2 was found to 160 which mean that the MCDA part of A2 should sum to 160. Now p1 can be determined in the following manner, as p2, p3 and p4 is expressed by p1 and the available criteria weights:

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

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

   Hereby the set of prices is determined:

   $$p_1 = 0.43$$

   $$p_2 = \frac{0.55}{0.20} \cdot 0.43 = 1.19$$
   $$p_3 = \frac{0.10}{0.20} \cdot 0.43 = 0.22$$
   $$p_4 = \frac{0.15}{0.20} \cdot 0.43 = 0.32$$

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

   $$TRR(A1) = \frac{110 + (25 \cdot 0.43 + 0 \cdot 1.19 + 0 \cdot 0.22 + 100 \cdot 0.32)}{70} = 2.18$$

   $$TRR(A2) = 4.00$$
   $$TRR(A3) = 2.25$$
   $$TRR(A4) = 4.09$$

   From this it is seen that A4 is the most attractive alternative. In Table 0.3 the results are shown together:

Table 0.3: The results of the calculation example

	A1	A2	A3	A4	Method	Unit
Costs	70	80	120	65	CBA + NM	Mkr
Benefits	110	160	165	120	CBA + NM	Mkr
BCR	1.57	2.00	1.38	1.85	CBA + NM	
k1	11	43	0	19	MCDA	Evaluation Mkr
k2	0	89	71	119	MCDA	Evaluation Mkr
k3	0	6	22	8	MCDA	Evaluation Mkr
k4	32	22	11	0	MCDA	Evaluation Mkr
Total MCDA	43	160	104	146	MCDA	Evaluation Mkr
Total value	153	320	269	266	CBA + NM + MCDA	Mkr + Evaluation Mkr = attractiveness Mkr
Total rate	2.18	4.00	2.25	4.09		

The result of the above example is based on the use of CBA carried out by use of a national manual (NM) and MCDA. CBA + NM produce a monetary result, which is validated from a socio-economic thinking and common use. MCDA produces a result which is based on preferences indicated in the decision and the result is in principle only valid from this point of view.

By comparing the MCDA results with CBA results “evaluation Mkr” are calibrated, as seen in Table 0.3 and as explained in the above example. The total value for an examined alternative is found by adding Mkr (found by CBA) by 'evaluation Mkr' (found by MCDA). Mixing of Mkr and the imaginary ‘evaluation Mkr’ are then expressed by the unit 'attractiveness Mkr', which not only are socio-economically based as it now also includes ‘evaluation Mkr’ based on specific MCDA preferences. The final result of the analysis is presented by the total rate, where the result in ‘attractiveness Mkr’ is weighed against the costs for the alternative concerned, see Table 0.3. In the table you can see for each MCDA criterion, which values (in ‘evaluation Mkr’) the method assigns each alternative. It is noted that because of the approach of the method the worst alternative is always given the value 0.

By the COSIMA calculations it is possible to base the decision of the choice of alternative on the socioeconomic BCR contribution attributed to an additional, wider social evaluated value. This combined result expresses the overall attractiveness of a given alternative. As mentioned, the CBA result is valid from a socio-economic evaluation, while MCDA in principle only is valid from the decision conference proceedings, etc.

The values in Table 0.3 are developed on the basis of the phrase "influence of the MCDA must be 50%". How can this be interpreted further? The basis for choosing between 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 MCDA must be arranged so that the MCDA criteria indirect priced also contributes with 160, which has just been completed in the calculation example. As a result of fixed alternative-scores and criteria weights the unique total rates are determined for all four alternatives, and A4 stands as the most attractive alternative. From a calibration point of view is the principle, however, that CBA and MCDA, based on A2 both counts by 50%.

Pros and cons of COSIMA

The COSIMA model is straightforward in its design and application as it simply “adds to” (and does not hide or change) CBA information. Through its incorporation of relevant MCDA criteria COSIMA may be seen as an MCDA extension of the traditional CBA and may therefore by administrative units be perceived as less of a “black box” than other types of current MCDA decision aid tools.

However, COSIMA depends on an interpretation of the unit prices of the MCDA criteria. What does it mean that given MCDA impacts must contribute with a certain percentage of the total amount of benefits associated with the reference project(s) – which indirect trade-offs lie behind such percentages? The method assumes that the users can express their preferences by the percentage measures as described above.