Selection and valuation of criteria in decision-making for improvements in transport systems

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Introduction

The aim of all decision-making, for companies as well as for the society as a whole, is to choose the best among a number of alternative solutions. However, what is "the best" will often depend on a judgement of the importance of different aspect of the alternatives. Variation in judgement among the decision-makers will lead to different conclusions as to which solution is the best. Variation in assessment of relevant aspects is a natural and sound ingredient in decision-making. On the other hand, lack of consistency and completeness in the set of aspects included in the decision basis will normally lead to questionable decisions. Unconsciousness in the assessment of different aspects and solutions may also result in illogical decisions. This paper will focus on these two essential points in decision processes in order to increase rationality in decision-making.

This paper addresses the following issues:

- Single-criteria decision-making
- Multi-criteria decision-making
- Cause-effect models in decision support
- Consistent sets of decision-criteria
- Valuation of criteria in a multi-criteria decision
- Political and professional duties in the decision-making process
- A procedure to obtain better decisions

Single-criteria decision-making

In some cases it is acceptable to count or calculate all the relevant aspects in a common monetary unit. This will be the case when comparing two different ways of building a bridge. Even then you have to ensure that the calculations are done in such a way that all elements are included and no element is added more than once. If the reinforcement for a bridge is calculated as a separate element, it is not to be included for each beam or pillar. If all principles for economic calculations have been followed, the total costs will be a correct basis for the decision-making.

Construction costs

Preparation	
Fundaments	
Pillars and abutements	
Bridgeway etc	
Finalization	
Sum	**S**

Earth and rock	
Falsework	
Reinforcement	
Concrete work	
Miscellaneous	
Sum	**S**

Figure 1: Construction costs may be calculated in many ways, but elements from different structures should not be mixed together

Behind such economic analyses there will, in principle, exist models containing all the significant cause-effect relationships for the system in question, for instance the rules for dimensioning of bridges. In simple situations the cause-effect relationships may form a tree-structure so that the costs at each level can be successively aggregated to a total amount, as shown in figure 1. In other situations the cause-effect relationship may be more complex, as shown in figure 2. Then the selection of decision criteria and quantification of them will be a lot more complicated.

Multi-criteria decision-making

Often it is neither acceptable nor possible to calculate in monetary units all the aspects in question, especially when health, environment, and safety are involved. Then it will be necessary to include into the decision process several aspects quantified in different units. This results in so-called multi-criteria decision-making situations.

It is evedently more challenging to secure a consistent decision basis for a multi-criteria situation than for a single-criteria situation. Unfortunately, this is often disregarded both by the decision-supporters and by the decision-makers.

Normally you need some sort of a cause-effect model to calculate or to decide the benefits or consequences for each criterion for each alternative. In simple cases there are no significant interrelationships between the criteria. An example from the traffic safety area may consist of:

- Injured persons younger than 18
- Injured persons aged between 18 and 67
- Injured persons older than 67

If reductions in the number of injuries for each age group are the only benefits from alternative improvement strategies, then you have to put weights to each group and choose the alternative with the largest weighted reduction of injuries.

Cause-effect models in decision support

We all realize that the decision basis will be wrong if there are overlaps or gaps between the age groups. This is as obvious as forgotten or double-counted elements in calculation of construction costs for a bridge. It is crucial for a rational decision that the decision basis comprises a mutually consistent set of aspects or criteria.

However, the cause-effect model for the system in question will often be quite complicated, and in fact, in many cases such a model is not established at all. Then there is every reason to examine the criteria in the decision basis before presenting them for the stakeholders and decision-makers. Without some sort of a cause-effect model it is almost impossible to establish a consistent set of decision criteria.

A simplified example of a cause-effect model from the transport sector is shown in figure 2. The red boxes at the top of this figure may be regarded as decision criteria. The arrows between the boxes represent mathematical or other relationships between the various elements necessary to determine quantities for each criterion. By using this model both for the existing and for the improved transport system, the benefits can be calculated for various improvements.

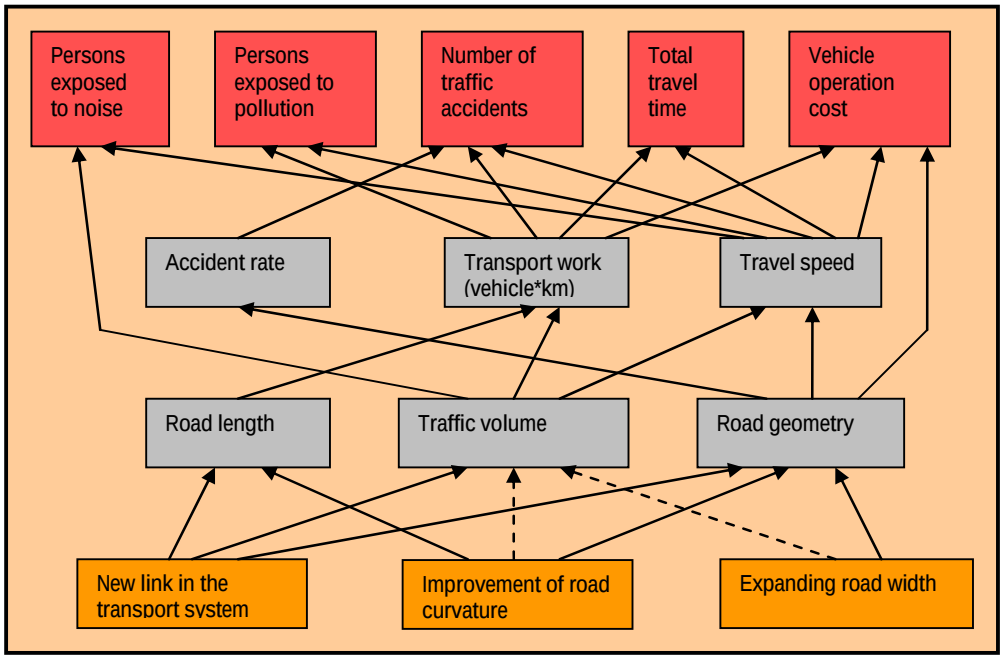

Figure 2: Simplified example of relationships in a cause-effect model for road improvements

Some people may consider accident rate, travel speed, or road geometry as relevant decision criteria instead of, or in addition to, the criteria in the red boxes. Or they may consider health impacts to be added to the red box criteria and presented to the decision-makers. How should planners or decision-supporters deal with such questions?

The decision-makers have to judge the relative importance of the decision criteria to come to their conclusion. Which considerations would be rational for them in this connection? They are expected to have a superior goal for the society, and therefore an opinion on the contribution of each criterion to this goal. This represents an upper part of the cause-effect model as shown in figure 3.

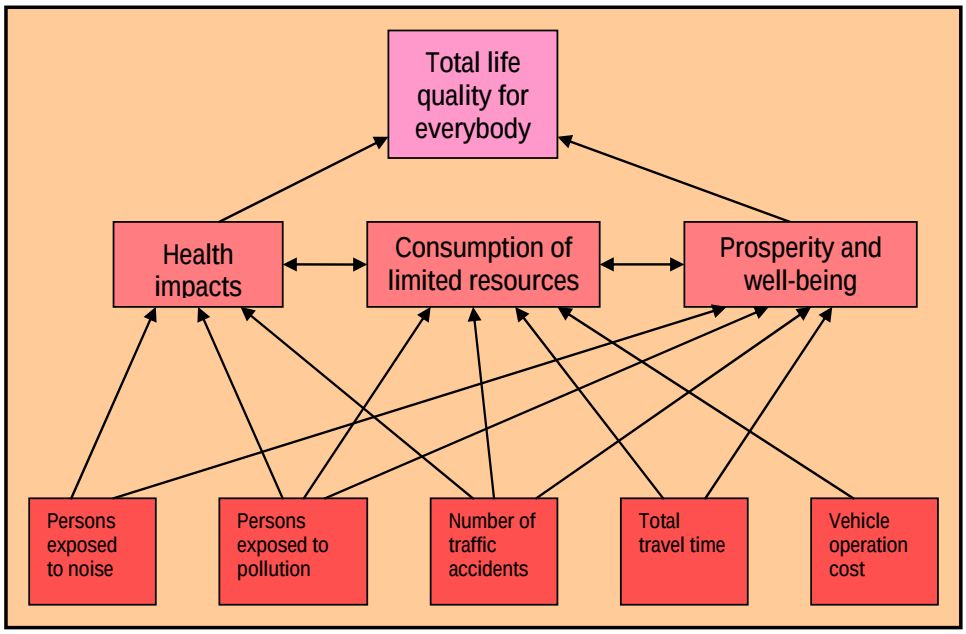

Figure 3: Idealised representation of the upper part of a cause-effect model

The upper part of the cause-effect model is significantly more dependent on personal opinions than the lower part shown in figure 2. The purple box on top raises the question wheather life quality for animals should be included, and even if there is a life after death. These are examples of aspects which politicians are supposed to take into account when making their conclusions.

Noise as well as pollution and traffic accidents form, according to figure 2, are the basis for determination of health impacts. If health impacts from noise, pollution and accidents are added to the red box decision criteria, then the decision-makers in essence double count these health aspects.

Consistent sets of decision-criteria

So, the red box criteria in figure 2 and figure 3 may be an appropriate set of decision-criteria for situations covered by this cause-effect model. There will certainly also exist other sets of decision-criteria which will satisfy the consistency requirements.

Figure 4 shows two consistent sets of criteria for two different situations. Both the rectangle and the circle are supposed to represent total benefits for specific values of each criterion shown as coloured areas in the rectangle.

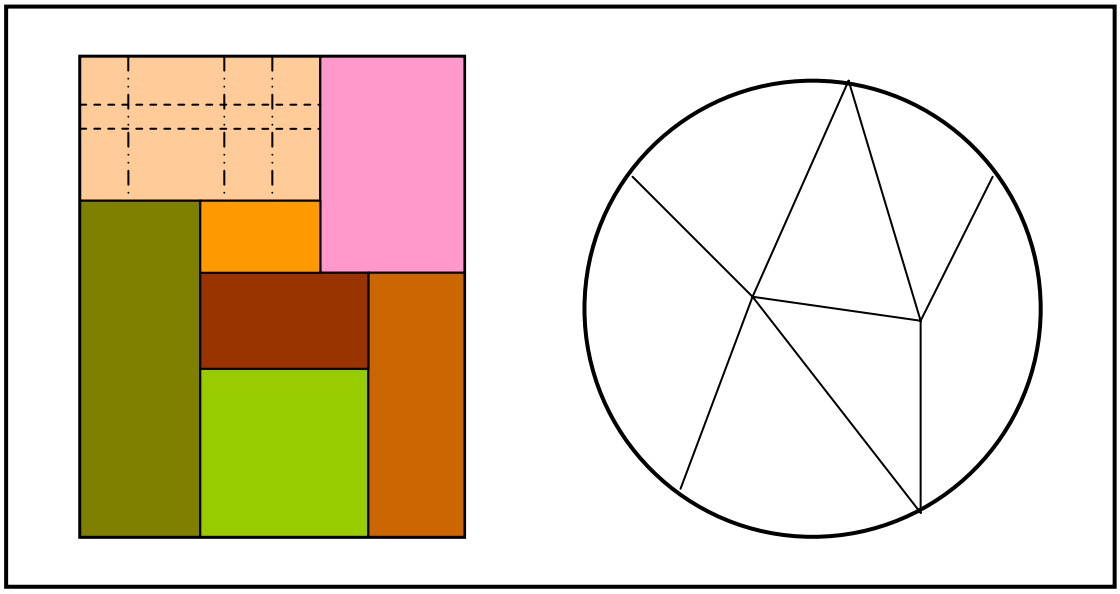

Figure 4: Illustration of two formally correct sets of decision criteria, all the area is covered and there is no overlap between any of the criteria

Besides, there often exist a great variety of sets of decision-criteria which will not fulfil the consistency requirements, as illustrated in figure 5. The decision-supporters are expected to be aware of this and to avoid inconsistent sets of criteria in the decision basis. Thus a main duty for decision-supporters is to select a set of criteria which gives the stakeholders and decision-makers a good basis for personal judgements and conclusions. However, this duty does not always get the attention it should. In fact, the planners or decision-supporters often ask the decision-makers to tell them which set of criteria should be used.

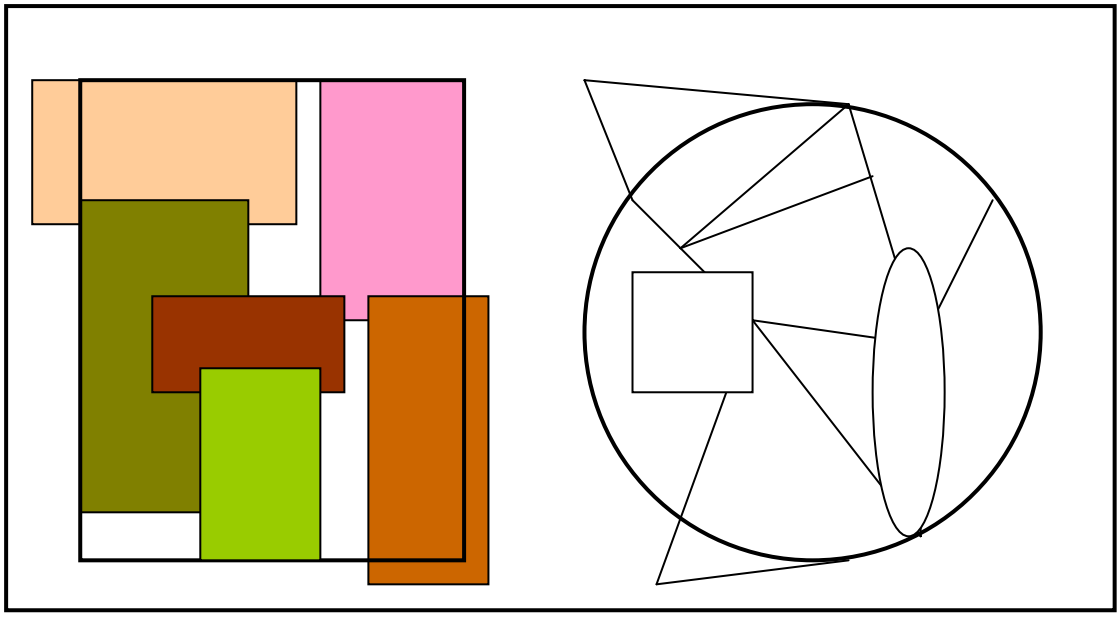

Figure 5: Illustration of two formally incorrect sets of decision criteria, since the whole area is not covered and there are overlaps between many of the criteria

Valuation of criteria in a multi-criteria decision

Provided that the decision basis comprises a consistent set of decision-criteria, it will be possible to attach weights or economic values to each of the criteria. Then a multi-criteria decision situation turns out to be a single-criteria decision. Various sets of values may result in different conclusions. Within specific ranges of weights or values, the conclusion will be the same. The robustness of specific conclusions can be checked by varying the weights or values in a systematic way. This is illustrated by a small example with 3 different criteria: A, B, and C. At first only two alternative solutions are considered: ALT 1 and ALT 2. Quantities for each of the criteria and solutions are shown in table 1.

Table 1: Decision criteria for two alternatives

Criteria	Benefits ALT 1	Benefits ALT 2	Weights	Results ALT 1	Results ALT 2
A	400	100	1	400	100
B	300	400	2	600	800
C	300	500	1,5	450	750
Total weighted results				1450	1650

ALT 2 have higher score than ALT 1 for this set of weights. For another set of weights the conclusion may be the opposite. By varying the weights a dividing line will appear between the two alternatives as shown in figure 6. The vertical axis represents the quotient between weight B and A, the horizontal axis represents the quotient between weight C and A. On the left hand side of the dividing line ALT 1 should be chosen, on the right hand side ALT 2 should be chosen.

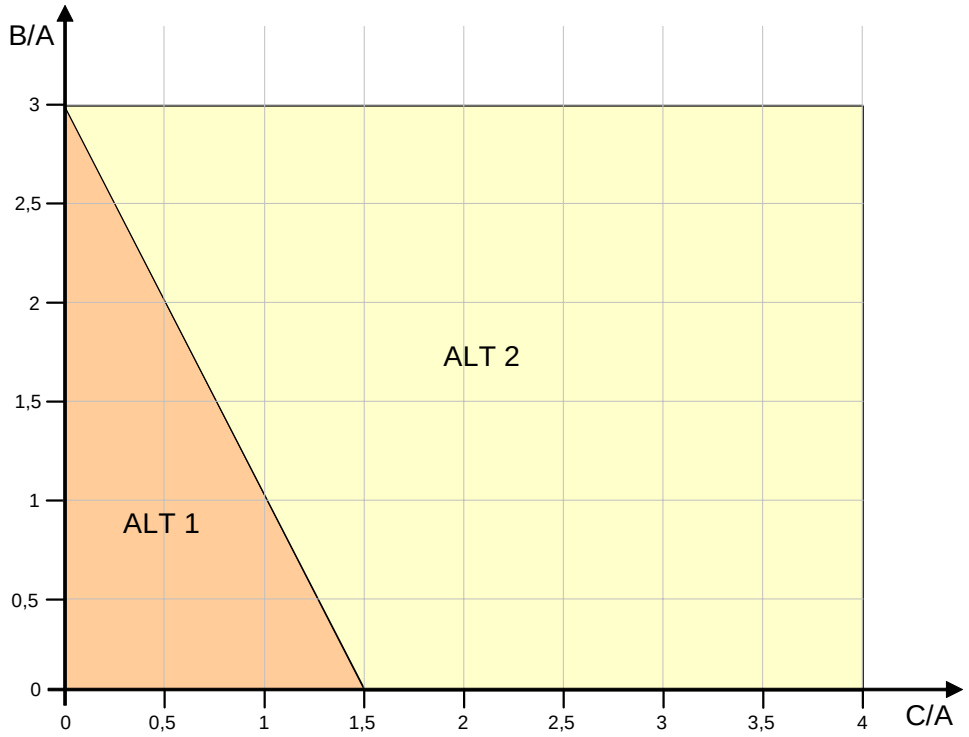

Figure 6: Conclusions as a function of weights or values for two alternatives

If negative weights are considered to be meaningful, the negative part of the diagram in figure 3 has to be included.

In the next step an extra ALT 3 is brought into the discussion as shown in table 2. With the same weights as above, ALT 2 will still have the highest score.

Table 2: Decision criteria for three alternatives

Criteria	Benefits ALT 1	Benefits ALT 2	Benefits ALT 3	Weights	Results ALT 1	Results ALT 2	Results ALT 3
A	400	100	200	1	400	100	200
B	300	400	100	2	600	800	200
C	300	500	700	1,5	150	750	1050
Total weighted results					1150	1650	1450

It might have been so that some of the alternatives would never be relevant, especially as long as negative weights are irrelevant. With the data used in this example, this is not the case. The map of rational decisions for this situation is then shown in figure 7. Each alternative has its specific area in the diagram for which weights they should be preferred.

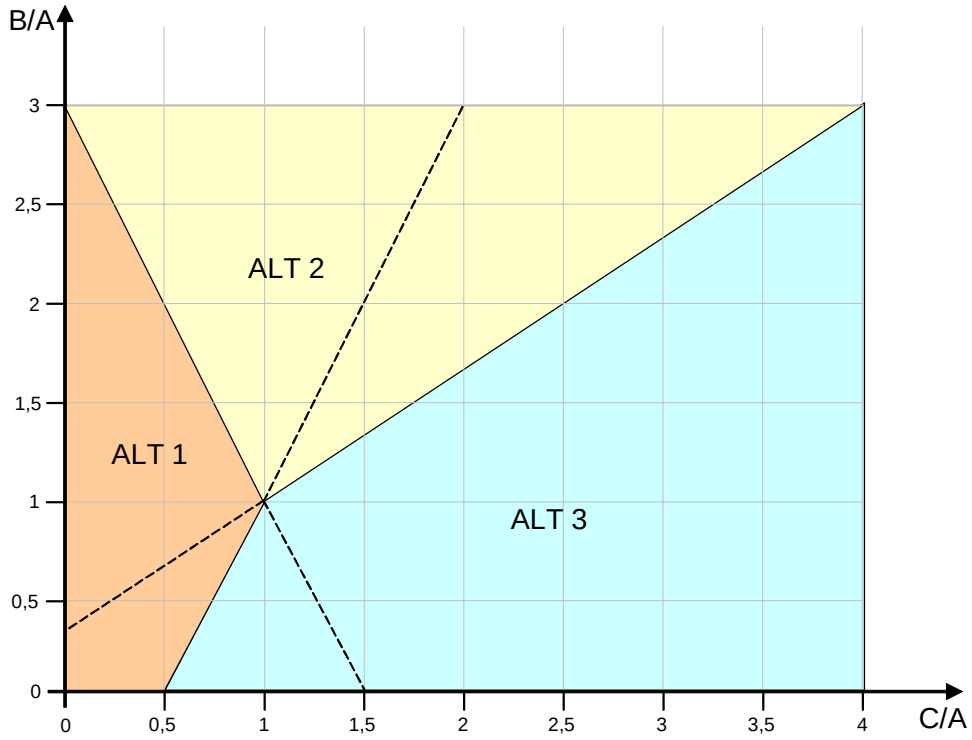

Figure 7: Conclusions as a function of weights or values for three alternatives

One might wonder if an extra alternative now automatically would have excluded another. This is normally not the case. This is demonstrated by adding an ALT 4 into table 3 and figure 8 below. In this case ALT 4 will capture parts of the conclusion areas from all the former alternatives. Still there is a conclusive area attached to each of the alternatives. The "right" decision depends on which weight each decision-maker will put to each of the decision criteria.

Table 3: Decision criteria for four alternatives

Criteria	Benefits ALT 1	Benefits ALT 2	Benefits ALT 3	Benefits ALT 4	Weights	Results ALT 1	Results ALT 2	Results ALT 3	Results ALT 4
A	400	100	200	300	1	400	100	200	300
B	300	400	100	200	2	600	800	200	400
C	300	500	700	600	1,5	150	750	1050	900
Total weighted results						1150	1650	1450	1600

In some cases an extra alternative may capture parts of, or the whole, area from one or some of the original alternatives. This is well demonstrated through the examples in this paper.

However, sometimes an additional alternative may turn out to capture no area at all, since there are better alternatives available regardless of the set of weights put to the decision criteria. It is an important task for the planners or decision supporters to provide the decision-makers with such information.

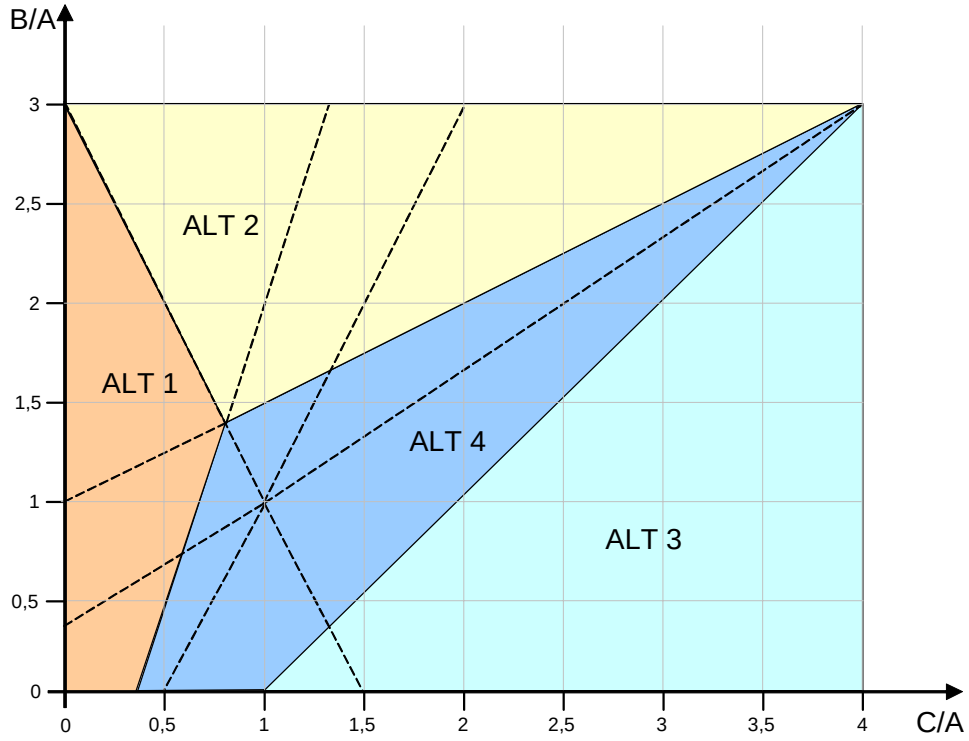

Figure 8: Conclusions as a function of weights or values for four alternatives

Situations with more than three decision criteria are difficult to illustrate graphically, but the principles are the same as for the limited cases presented above.

Political and professional duties in the decision-making process

There is considerable confusion as to who should be responsible for various tasks in the decision-making processes. There will always be discussions and different opinions on this question. Nevertheless, some main principles should be regarded:

- It is a professional's duty to provide a consistent set of decision criteria
- It is a professional duty to point out rational conclusions with various sets of weights to the decision criteria
- It is a politician's duty to consider appropriate weights to the criteria and decide upon a solution according to these weights

If one follow these principles it will increase the rationality in decision-making. Besides, there will always be a need for communication and discussions between planners, decision-supporters, decision-makers and stakeholders in order to achieve good decisions.

A procedure for better decisions

Based on the ideas presented in this paper, a procedure can be suggested to enhance decision-making. This procedure contains the following steps:

- Establish a conceptual cause-effect model for the decision situations in question
- Select a decision criteria for a suitable package of related decision situations
- Develop methods for quantification of each decision criteria
- Produce a decision map according to various sets of weights to the decision criteria
- Communicate a decision map to politicians, administrators, stakeholders, etc.
- Learn from each of the decision processes in order to improve the process next time

There is a need for more focus on the responsibility for various participants in a decision-making process. My statement is that professionals so far have not been willing to challenge decision-makers and stakeholders as to the facts and non-facts in decision processes.

Professionals have a duty to prevent politicians and other decision-makers from breaking the laws of nature. Politicians and other decision-makers have the duty to ensure that they are not manipulated by interest groups or questionable professionals.

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