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A COST-EFFICIENCY STUDY OF VARIOUS MEASURES FOR REDUCING ROAD TRAFFIC NOISE ANNOYANCE IN NORWAY

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ABSTRACT
Cost efficiency analyses based on the assumption that the cost of one Person Highly Annoyed (PHA) is 1.250 EUR, show that: **i)** Measures related to tyres, speed reductions (from 50 to 30 km/h), reduced traffic volume and low-noise road surfaces probably are profitable to the society even if they all are fully implemented. **ii)** Measures related to engines, speed reductions (from 80 to 70 km/h) and noise shielding probably are profitable if they are partly implemented. **iii)** "Environmental roads", building new roads in general, and redemption of highly noise exposed houses probably are not profitable. Combinations of different measures are probably needed to reach the targets. There are large uncertainties as to effect of each measure, annoyance reduction and implementation. A strategic tool is proposed for handling such uncertainties.

1 - NOISE ANNOYANCE AND NATIONAL NOISE REDUCTION TARGETS

The Parliamentary White paper no 8 (1999-2000) on national noise reduction targets aims to reduce noise annoyance by 25% within 10 years. To reach such an ambitious target it is necessary to critically evaluate noise reduction and abatement efforts with regards to how effective different measures are with respect to reaching the given target and their cost. Table 1 gives an overview of the noise annoyance for different noise sources in Norway.

Noise Source	Number of persons exposed for different noise levels $L_{ekv,24h}$ (dBA)						MRI
	50-55	55-60	60-65	65-70	70<	Total	
Road		410.000	386.000	204.000	57.000	1.059.000	411.000
Air		32.000	13.000	5.000	1.000	67.000	25.000
Rail	18.000	22.000	24.000	15.000	4.000	83.000	24.000
Industry	74.000	36.000	16.000	8.000	4.000	138.000	74.000
Total	92.000	502.000	439.000	232.000	66.000	1.331.000	534.000

Table 1: Number of persons exposed for equivalent noise levels in 1999 in Norway and the mean response index (MRI); source: Norwegian Pollution Control Authorities (2000).

2 - COST EFFICIENCY ANALYSES OF THE MOST ACTUAL MEASURES

The most actual measures related to road traffic and their potential for reducing persons highly annoyed (PHA) are shown in Table 2. The cost of the noise reduction measure and its cost efficiency are shown in the same table. The principles of cost efficiency of noise reduction and noise abatement measures is selected as a criterion for systematising and sorting different types of noise reduction measures, because this principle ensures a systematic and unbiased treatment of the different effects included in the analyses and an optimal use of scarce public funds and thereby also obtaining the maximum level of noise reduction possible within the allocated funds. Cost-benefit analyses is also advocated by WHO [1] as an approach for decision making.

Measures	Potential for reductions. Number of PHA	Measure cost. Net present value. Mill. NOK.	Cost efficiency. Mill. NOK per PHA
1a. Better engines. Low ambition level.	53.000*	6.299	0,119
1b. Better engines. High ambition level.	70.000*	10.032	0,143
2a. Better tyres. Low ambition level.	45.000*	2.135	0,047
2b. Better tyres. High ambition level.	84.000*	5.039	0,060
3. Reduced speed limits. From 80 to 70 km/h.	6.300	1.627	0,258**
4. Reduced speed limits. From 50 to 30 km/h.	8.400	872 (time loss not included)	0,104
5. Reduced traffic. 8% in major cities.	850	-21.225	-24,971
6. Reduced traffic. 18% in whole country.	15.100	665	0,044
7. Noise shielding.	8.950	3.080	0,344
8. Low-noise surfaces A	5.000	0	0,000
9. Low noise surfaces B	18.500	2.100	0,114
10. "Environment roads"	1.200	1.125	0,938
11. New road building	1210/1750	3.631/4.169***	3,001/2,382
12. Redemption of houses	90	110	1,222

Table 2: Different measures and their potential reduction in number of people highly annoyed (PHA), their cost and their cost efficiency (* number of PHA is based on noise reduction estimates from Berge (1999), however, the realistic effect of these general measures is uncertain; ** probably large local differences of the effect of this measure, the same comment may apply to other measures also; *** only investment costs, these should be reduced by other benefit values like reduced travel time and accidents before they are comparable with the other measures).

In a cost benefit analysis of a noise reduction measure, the different effects are made comparable by assigning the different effects a monetary value. A cost benefit analysis thus requires that the unit costs of different effects be specified. For example that the value of one noise annoyed person less has a value of xx NOK, or that the reduction of travel time by one-hour can be assigned the value of yy NOK.

A measure having a beneficial effect with respect to one environmental problem can also have other environmental effects and will often also affect other factors like traffic safety issues and time usage. Indeed one will often be in the position that the effects on noise is only a small part of the total effects of such measures. Such multiple effects can however be handled within a cost benefit approach to prioritising noise reduction measures. The approach has thus an important advantage in that it will promote measures that from an isolated noise perspective will not be considered. It also takes into account the side-effects of some noise abatement measures that may either work in synergy or in opposition to their noise reduction effects.

Valuation studies where one values different types of environmental qualities and allow people to choose between different combinations, can give important information of the relative valuation of different environmental goods (qualities). Such studies aid the specification of unit costs and how to handle combined effects in cost benefit analyses [2].

Table 2 shows that cost efficiency (i.e. cost per reduced PHA) of the different measures vary. Based on an assumption that the cost of one PHA is 10.000 NOK, the analyses show that i) measures related to tyres, speed reductions (from 50 to 30 km/h), reduced traffic volume and low-noise road surfaces probably are profitable to the society even if they all are fully implemented, ii) measures related to

engines, speed reductions (from 80 to 70 km/h) and noise shielding probably are profitable if they are partly implemented, and iii) measures like "environmental roads", new road building in general and redemption of highly noise exposed houses probably are not profitable.
Combinations of different measures are probably needed to achieve the noise reduction goals. However, there are large uncertainties both with respect to the effect of each measure and the effect of combined measures. This dependence between measures can be implemented in cost benefit analyses by an assumption of decreasing effect in reducing the number of PHA when two or more measures are implemented in the same area.

3 - UNCERTAINTIES OF SINGLE AND COMBINED EFFECT MEASURES

Strategic decisions in order to attain specified environmental targets are probably associated with more uncertainty than for instance goals to reduce the number of fatalities and person injuries in traffic. There are varying degrees of uncertainty associated with each of the many levels of knowledge on different types of noise reduction measures and different types of assessments.
If we focus on a measure to reduce noise emissions we have uncertainty associated with all of the following points:

- Which effect a measure has on actual noise emissions and when the measure can be implemented (some measures will require a period of testing and implementing)
- What effect the measure has over time (technical measures can have a reduced effect over time)
- What is the effect of the noise reduction on people's annoyance and health (uncertainty as to exposure-effect relationships) – see also [3]
- What other effects the measure may have and
- How to deal with complex decision processes when having to weigh different types of effects

For handling such types of uncertainty a knowledge and research based inventory of environmental measures based on a cost efficiency/cost-benefit approach can be an important tool.

4 - TORNADO – INVENTORY OF NOISE REDUCTION MEASURES AND STRATEGIC DECISION TOOL

In this chapter a tool (on the planning stage) for ranking noise reduction measures is described. The tool, which is given the name TORNADO, combine an inventory of noise reduction measures descriptions with a prioritising scheme based on cost-benefit and uncertainty analyses. Figure 1 shows the structure of TORNADO.
In figure 1 the inventory part of the tool is described from noise measures via noise changes and other changes and valuation of the effects to a cost-benefit analyses for each measure.
The prioritising part of the tool is in figure 1 described from cost-benefit analyses via ranking and strategic choices to realisation of the measures. In addition the prioritising will take into consideration uncertainty of effects, uncertainty as to when measures become available, uncertainties in valuation in the non-market good included and a cost optimal dosage of different measures.
Using the template used for describing traffic safety measures in the Handbook of traffic safety [4] a systematic inventory of noise reduction measures will be established. Figure 1 shows the structure of the inventory part of the tool for ranking noise reduction measures. The measures will be described as they become available and will be continuously updated with respect to the following main points:

- Environmental problem and purpose of the measure.
- Description of the measure (link to descriptions in the Environmental Handbook [5]).
- Noise reduction effect and the impact with respect to the reduction of the proportion of people highly annoyed (PHA) or mean response index (MRI).
- Effects with respect to other environmental problems (link to descriptions in the Environmental Handbook).
- Effects with respect to traffic safety (link to descriptions in the Handbook of traffic safety).
- Effects with respect to mobility and accessibility.

- The cost of the measure.
- Cost benefit evaluation.
- Implementation responsibilities and processes.

In the beginning a systematic inventory of the different noise measures only containing rudimentary knowledge about the different types of uncertainty will be build. In the long run, the knowledge base will be updated on the basis of international and national research results. Over time it is expected that the English version of the information in the Environmental handbook and the Handbook of traffic safety measures will be closely knit together with the Environmental research and knowledge based inventory in TORNADO by means of a system of cross-referencing. Such cross references will on one hand avoid the duplication of efforts and difficulties in updating the different parts of the knowledge systems, while providing the interested practitioner or researcher a comprehensive introduction to the relevant measures. This will ensure that a more holistic approach will be adapted when completing the implementation of specific measures irrespective whether they are motivated primarily for safety or environmental reasons.

5 - STRATEGIC DECISION MAKING WITHIN TORNADO

The systematic inventory of noise reduction measures will allow strategic decisions with respect to which measures that are the most cost efficient on the basis of the unit costs of the different cost-components that are taken into account.
The prioritisation part of TORNADO differs however from traditional cost benefit analyses in that one explicitly tries to take into account the substantial uncertainties associated with especially new and unproven noise reduction measures. These uncertainties are associated with i) the noise reduction potential of the given measure ii) the costs associated with the measure, iii) the valuation of other environmental goods traffic safety and mobility that form part of the cost benefit analyses, and iv) uncertainty that are associated with the implementation of the measures.
These types of uncertainty can by assessed by the application of meta-analysis, Monte Carlo simulations, sensitivity analyses or expert panels. Such a systematic charting of the uncertainties provide an improved basis for decisions concerning:

- How changes in the premises and unit costs affect the resulting benefit cost ratios.
- Whether it is possible to attain the given goals with respect to the noise reductions that must be achieved with the given measure and within the time slot available.
- The implementation sequencing of measures given that the more effective measures will only be available in the latter part

The concept of optimal societal efforts serve as ranking criterion with respect to how noise measures should be prioritised. By this criterion the priority and use of noise reduction measures are undertaken as far as they serve to minimise the societal costs of road traffic.

6 - NUMBER OF HIGHLY ANNOYED OR MEAN RESPONSE INDEX?

Current procedures for calculating the benefit of noise reductions base such monetary estimates on the number of people who are highly annoyed (PHA). A reduction of one PHA is assigned a unit benefit. An alternative is the use of the mean degree of annoyance weighted with the number of people affected, by using the mean response models for noise annoyance developed by Miedema [6]. Use of such a mean response index (MRI) is proposed in the Parliamentary White Paper with a corresponding unit benefit. The change from one type of annoyance indicator to another has important implications for noise control policy. An important benefit is that one takes into account lesser degrees of annoyance associated with primarily lower and intermediate noise levels. This means it will be easier for general noise reduction measures to prove socio-economically profitable and be implemented. Noise reduction efforts will also be profitable in areas with many people, even though noise levels are intermediate.
There are however also aspects that suggest using caution in going from one noise exposure measure to another for prioritising societal noise combatting efforts. As the changes in exposure effect curves for lower annoyance categories are steeper at lower noise levels, it is likely that more of the noise reduction efforts will be channelled to lower noise levels. This has an important societal distribution effect as funds now allocated to the black spots will be redistributed. People highly annoyed are also the people who complain of being annoyed "most of", or "all the time" instead of "some of the time". Adopting a mean response model for prioritasion of the type of noise reduction measures to implement and the locations

where they are most profitable, may fail to take fully into account health effects of chronic stress, relative to more intermediate stress situations.

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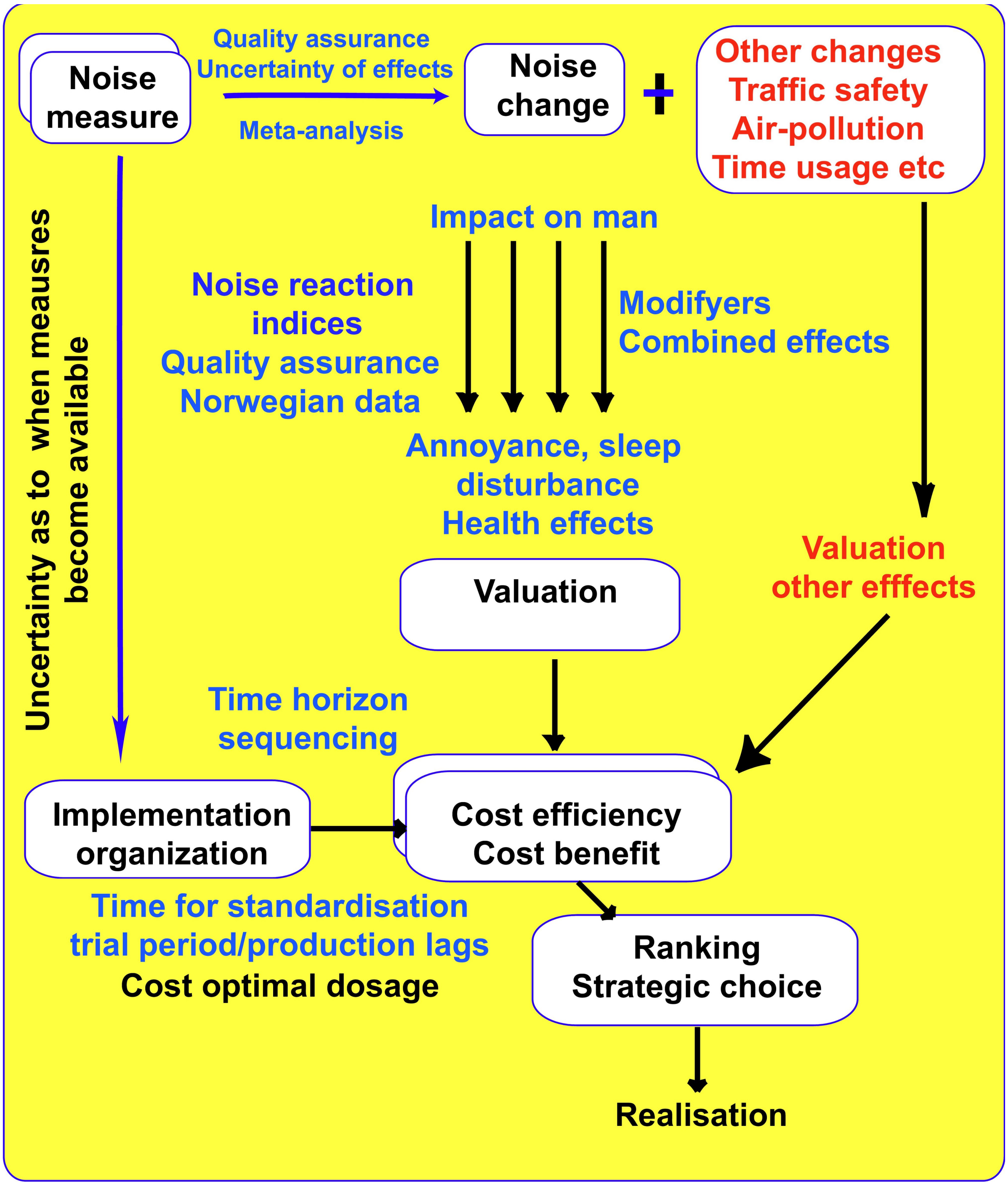

Figure 1: The structure of TORNADO, a tool for ranking noise reduction measures.