COST/EFFECTIVENESS ASPECTS OF ROAD LIGHTING

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SUMMARY

The common method to determine the effect of road lighting on traffic safety, is to compare accident numbers during daylight and darkness, before and after the measure is taken.
This approach ignores the possibility of increased risk of collisions with road side obstacles due to the erection of lighting poles.
Both effects should be taken into account if decision making on road lighting has to be based on a cost-effectiveness-criterion for traffic safety.
A scheme for decision making, based on a more complete determination of the consequences of road lighting systems is presented.

INTRODUCTION

In road safety, as in many other fields of governmental responsibility, decision making is increasingly based on quantitative analyses of costs and beneficial effects of the measures considered. Governmental measures, certainly in the field of traffic and safety, have a strong tendency to interfere with each other. The effect of a measure may be influenced by some disturbing factor with a natural or social origin. Therefore it is seldom possible to study such measures as isolated phenomena. Consequently it is often hard to obtain sufficiently accurate data for quantitative decision-making procedures. Methodologies are developed to eliminate or reduce the influence of interfering measures and disturbing factors, e.g. comparison of the situation before and after a measure is taken or comparison of the domain where the measure is taken with a domain where it is not. Generally both methods give only a limited improvement. Considerably better is the combination of both, that is a before and after study both for a test and a control domain. This is a common approach in most studies on road lighting.
It should be noticed that this methodology does not have the power to eliminate all errors induced by interfering measures or disturbing factors, especially not those which change simultaneously with the measure. Interfering measures and disturbing factors which are not systematically linked with the measure considered will induce random errors, the average of which will decrease asymptotically with an increasing number of studies. Systematic errors, however, will not disappear.
One such systematic error occurs in most studies on the effect of road lighting. In the literature on this subject no information was found which admitted to determine the magnitude of this error. An estimate of the error could be made, however, on the basis of data available in one publication, which suggests that the error is too great to be ignored.

1. DECISION MAKING IN THE FIELD OF ROAD SAFETY

Since the funds available for road-safety measures remain far beneath the budget that would be required to realise all measures that could possibly contribute to road safety, it will be necessary, to select among these measures in such a way that per monetary unit spent for road safety the greatest possible reduction is achieved in accidents, especially those with injuries and fatalities. The study of consequences of measures relevant for decision making is generally referred to as cost/effectiveness analysis.

A cost/effectiveness analysis of a road-safety measure should imply:
1. The determination of the costs of the measure per year.
2. The determination of the reduction of the number of accidents, injuries and fatalities per year, resulting from the measure.
3. The determination of the economic advantages associated with reduction of accidents, injuries and fatalities expressed in annual monetary savings (benefits).

Many measures effecting road safety, affect other incommensurables as well, e.g. landscape, environment, mobility etc.
A sound decision-making procedure should include these effects, and consequently a complete cost-effectiveness analysis should therefore imply:
4. The determination of effects of the measure on all social indicators that are substantially changed, each of which effects should be quantified as an annual gain of some sort.
5. The determination of the economic impact of these changes, again expressed in annual benefits, whether positive of negative.

In cost/benefit analysis only financial consequences of measures are considered, i.e. the incommensurable effects are whether ignored or expressed in monetary units based on a rather arbitrary value assignment.

It should be noticed that some authors use the terms cost/effectiveness analysis and cost/benefit analysis as synonyms, while other distinguish between both in a way comparable with the above given distinction. Cost/effectiveness analysis is used by some authors in the more restricted way: cost analysis of measures having a comparable effect in incommensurables.

In decision making three types of problems can be distinguished:
1. The decision whether to accept or to reject a particular measure.
2. The decision to prefer a particular measure above alternative possibilities.
3. The selection of a particular set of measures from a greater collection.

The guiding principle for decision making in each of these cases is to acquire sufficient, and preferably the highest "value" for money. Value means here primarily safety i.e. reduction of accidents, injuries and fatalities. In a more general sense, however, "value" is associated with improvement of a general level of well-being.

In specific fields of decision making "value" functions should be defined in terms of costs and effects on social indicators. The "value" has to increase with improvement of social indicators and with reductions in costs. These requirements are satisfied by a variety of functions. Monotonous relations are sufficient. The simplest form of monotony is linearity.

For decision making in the field of road safety the "value" function

$$V_i = R_i - q\,N_i = R_i - q\,(K_i - \beta .\,R_i) \qquad (1)$$

is proposed, in which

i = the index of the measure considered
R = the reduction in accident numbers proportionally including injury and fatality numbers
K = the initial costs of the measure
β = the economic savings per accident avoided
N = the net costs of the measure
q = a decision criterion.

In the three decision problems mentioned the value function is used as follows:

1. A measure i is accepted if $V_i > V_o$ where V_o is some critical value e.g. $V_o = 0$.
2. A measure i is preferred above alternatives j if $V_i > V_j$.
3. A set of measures S_I exhausting a given budget is preferred above other sets S_J exhausting the same budget and selected from the same collection C, if

$$\sum_{i=1}^{I} V_i > \sum_{j=1}^{J} V_j$$

The value function (1) does separate relevant variables and parameters in two groups:
1. Variables that can be determined by objective measurements.
2. Parameters that have to be determined through a process of subjective judgement.
K, R and β are of the first type, q is of the second type.

The value function might serve as a reference frame for the communication between policy makers and research workers.

Special cases of the value function are found:
a. if q = 0. Then measures with a favourable effect on road safety will be realised, no matter what the costs are.
b. if $q \rightarrow \infty$. Then the value function reduces to a benefit minus cost criterion for decision making.

$$V_i^{*} = B_i - K_i = \beta . R_i - K_i \qquad (2)$$

It should be noticed that both value functions V and V^{*} are expressed in the same variables R_i, K_i and β.
Apparently the cost/effectiveness criterion and the cost/benefit criterion for decision making require the same quantitative data.

The main problem of road safety research is to provide decision makers with sufficiently accurate predictions of costs and effects of road safety measures.

A graphical representation of the value-function (2) is given in Figure 1a. The origin of the axis corresponds with the critical value $V^{*} = 0$ or $B = K$. Measures will be accepted or rejected when represented by points at the right or the left of the origin respectively.

A graphical representation of the value-function (1) is given in Figure 1b. The critical line in the diagram corresponds with the critical value $V = 0$ or $R = q\ (K - \beta\ R)$. Measures will be accepted or rejected when represented by points at the right upper side or the left lower side of the critical line respectively.

According to the cost/benefit criterion measures will always be rejected when the costs exceed the benefits. According to the cost/effectiveness criterion, however, measures with costs exceeding benefits will be accepted or rejected depending on their accident reduction/net cost ratio.

2. METHODOLOGICAL ASPECTS

In the previous section the determination of costs and effects of road-safety measures was mentioned as a major research problem. This is partly due to methodological problems. Generally a fairly accurate value for the costs of a measure can be given. It may be very difficult, however, to determine the effect of a measure on the number of accidents, not only in the case of unique measures, but also for measures that are taken at many times in many different places because they are believed to be effective. Some of the methodological aspects of this problem are illustrated with the help of Figure 2. A particular measure m is taken in none of the domains considered during period p_1. It is taken in domain d_1 during period p_2 and later periods, in domain d_2 during p_3 and later periods etc.

Comparing a test domain d_4 with a control domain d_5 during period p_5, we may find different accident numbers. The difference could be ascribed to the measure taken in the test domain. Generally, however, many other differences between both domains could explain the different accident numbers.
Comparing accident numbers in domain d_1 over periods p_1 and p_2 we may find a difference that could be ascribed to the measure m, taken during period p_2. Generally, however, many other differences may occur in the domain between both periods considered.
Differences in accident numbers either between domains or periods are not conclusive with respect to the effect of the measure if other explanations are available.

The effect of the disturbing factors mentioned can be reduced if not eleminated, if the following conditions are fulfilled:
1. Some of the differences between two periods considered affect accident numbers proportionally in the domains considered.
2. Some of the differences between two domains considered affect accident numbers proportionally in all periods considered.
Then a comparison can be made e.g. between accident numbers in the domains d_3 and d_4 during the periods p_3 and p_4 i.e. a before and after study of a test domain versus a control domain.

The term domain can be taken litterally i.e. as a particular type of road location or as geographical domain. We may as well compare the "domains" of single and multiple accidents, or, as often is done in road-lighting research, we may compare the "domains" of daylight and darkness.

Differences between periods or domains which are not eliminated in a single before and after study with a test- and a control domain, may be statistically eliminated in a sequence of studies on different combinations of domains and periods, provided that these differences are not correlated and certainly not systematically connected with the measure considered.
The consequences of such a systematic connection will be illustrated in the next chapter for the case of road lighting.

3. THE EFFECT OF ROAD LIGHTING ON ROAD SAFETY

In studies of the effect of road lighting on road safety, it is common practice to compare accident numbers during daylight and darkness before and after the installation of road lighting. See Figure 3a + b. The effect of road lighting on road safety is expressed in the formula

$$r = \frac{a/b}{A/B} \tag{3}$$

The expression for A and a given in Figure 3 reflect the assumption that except for the relative influence δ_1 of road lighting during darkness, the relative trend correction is equal for darkness and daylight. We find then

$$r = \frac{(1 + \delta_t)\ (1 - \delta_1)}{1 + \delta_t} = 1 - \delta_1 \tag{4}$$

According to these assumptions the effect of road lighting on road safety would be an accident reduction

$$R = \delta_1 \cdot b\ (1 + \delta_t) \tag{5}$$

Generally, however, the installation of road lighting requires the installation of lighting poles, often increasing the risk of collisions with road furniture. Therefore the correct expression for r is

$$r = \frac{(1 + \delta_t)\ (1 + \delta_p)\ (1 - \delta_1)}{(1 + \delta_t)\ (1 + \delta_p)} = 1 - \delta_1 \tag{6}$$

where δ_p represents the relative risk caused by the lighting poles.

Introducing the effect of the lighting poles in the expression for the accident reduction, we find:

$$R = \left\{\delta_1 \cdot b - \delta_p\ (b + B)\right\}\ (1 + \delta_t) \tag{7}$$

With the traditional methodology it is possible to determine the value of δ_1 if values of B, b, A and a are registrated. It is not possible, however, to determine with these data also the value of δ_p. Consequently it is then impossible to calculate the value of R, required for a cost/effectiveness analysis.

In Figure 4 a scheme is presented to study the effects of trends δ_t, of the installation of lighting poles δ_p and of road lighting δ_1 separately.
The scheme is based on the assumption that the installation of lighting poles, along the road may introduce or increase the risk of certain accident types but has little or no influence on the risk of other accident types. The accident types distinguished are not pairwise synonymous. Multiple accidents may come to an end off the road in a collision with a lighting pole, while single accidents may occur completely on the road. It is assumed, however, that the expressions given in Figure 4 for the values of A_m, a_m, A_s and a_s are reasonable first approximations.

Other schemes could be chosen as well e.g. comparing an area with road lighting in the after period and an area without road lighting. It was considered more likely, however, that from previous studies on the effect of road lighting on road safety data could be obtained to follow the scheme of Figure 4.

So far no data were found in literature corresponding perfectly with the scheme.
In the 1963 TRRL publication: "Research on Road Safety" results are given of before and after studies of lighting improvements in 64 sites (Figure 5). The effect of the improvements on the number of injury accidents was determined separately for pedestrian accidents and other accidents. It is a reasonable assumption, that single off the road injury accidents with pedestrians are extremely rare.
The number of pedestrian injury accidents in the after period will not be affected by the installation of lighting poles, and the equations given in Figure 4 for on the road accidents can be applied to pedestrian accidents.

Similarly the equations for off the road accidents can be applied to the category "other accidents".

With the scheme presented here a computational problem is raised. In the scheme of Figure 3a two equations with two variables δ_t, δ_1 can be solved. In the scheme of Figure 3b two equations with three variables are available of which δ_1 can be solved while the combined effect of δ_t and δ_p can be determined.

In the scheme of Figure 4 four equations are given with three variables. We may solve the variables using only three equations. If the values of the variables are subsequently introduced in the fourth equation, generally a contradiction results. This problem can be solved by adding a fourth variable, assuming e.g.

a. that the effect of lighting δ_1 is different for multiple and single accidents;

b. that the effect of poles δ_p is different for daylight and darkness;

c. that the trendeffect δ_t for multiple daylight accidents differs from δ_t for the other three accident groups.

Trying these assumptions for the data in the TRRL publication, the assumptions a and b lead to the conclusion that the accident reduction due to road lighting is completely cancelled by the risk caused by the lighting poles.
The assumption c leads to the even more dramatic conclusion that a trend-wise accident reduction of 25 percent would have occurred if no measures were taken.

Other results more congruent with our expectations, might possibly be found when starting from different sets of assumptions.
Such arithmetic exercises demonstrate that many sets of assumptions are not numerically in contradiction with the accident data used.
To discriminate between various models, represented by those sets of assumptions, additionel data are required. These may be found in existing literature of have to be collected afresh in the framework of a more detailed evaluation study.

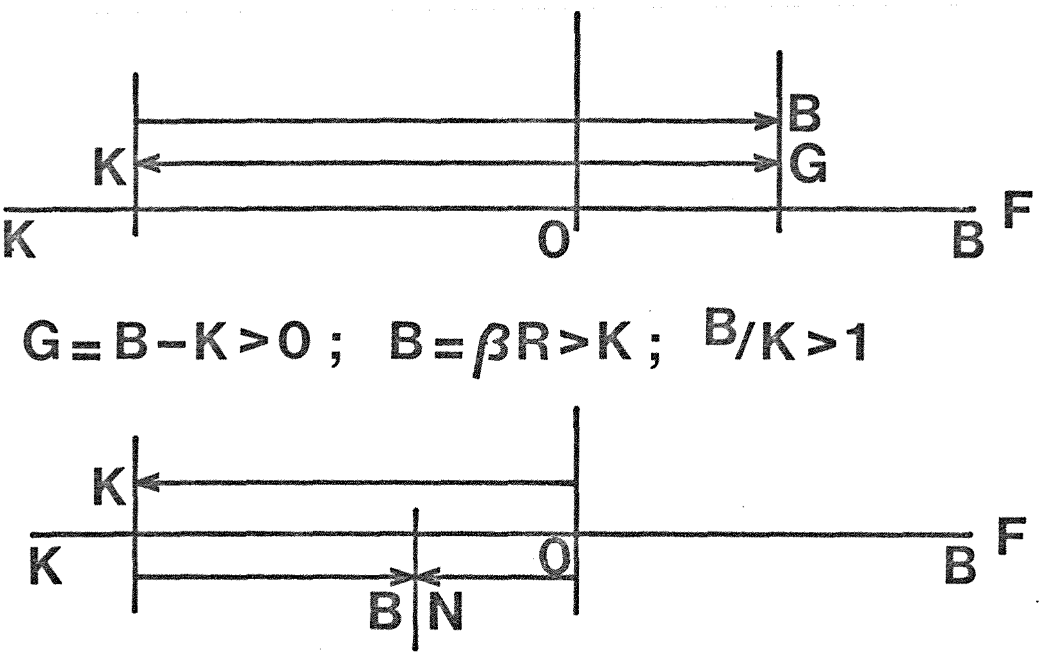

Figure 1a.

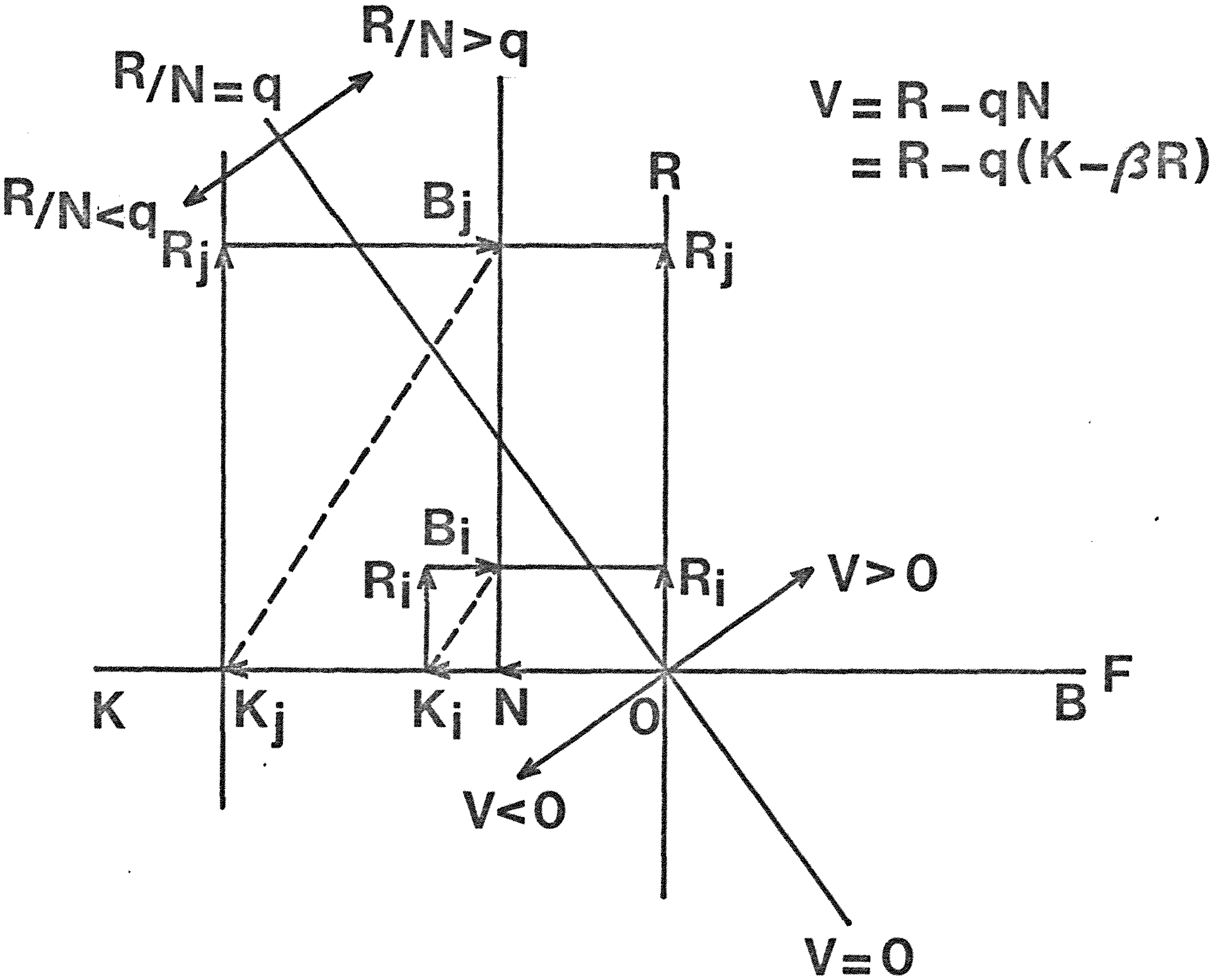

Figure 1b.

period	p_1	p_2	p_3	p_4	p_5	
domain						
d_1		m	m	m	m	
d_2			m	m	m	
d_3				m	m	
d_4					m	
d_5						

Figure 2.

Accidents	Before	After
Daylight	B	$A = B\ (1 + \delta_t)$
Darkness	b	$a = b\ (1 + \delta_t)\ (1 - \delta_1)$

Figure 3a.

$$r = \frac{a/b}{A/B} = \frac{(1 + \delta_t)\ (1 - \delta_1)}{1 + \delta_t} = 1 - \delta_1$$

$$R = \delta_1 \cdot b\ (1 + \delta_t)$$

Accidents	Before	After
Daylight	B	$A = B\ (1 + \delta_t)\ (1 + \delta_p)$
Darkness	b	$a = b\ (1 + \delta_t)\ (1 + \delta_p)\ (1 - \delta_1)$

Figure 3b.

$$r = \frac{a/b}{A/B} = \frac{(1 + \delta_t)\ (1 + \delta_p)\ (1 - \delta_1)}{(1 + \delta_t)\ (1 + \delta_p)} = 1 - \delta_1$$

$$R = \{\ \delta_1 \cdot b - \delta_p\ (b + B)\ \}\ (1 + \delta_t)$$

Accidents		Before	After
multiple	day	B_m	$A_m = B_m (1 + \delta_t)$
on road	dark	b_m	$a_m = b_m (1 + \delta_t) (1 - \delta_1)$
single	day	B_s	$A_s = B_s (1 + \delta_t) (1 + \delta_p)$
off road	dark	b_s	$a_s = b_s (1 + \delta_t) (1 + \delta_p) (1 - \delta_1)$

Figure 4.

	Total		Pedestrians		Others	
	Daylight	Darkness	Daylight	Darkness	Daylight	Darkness
Before	1248	505	319	159	929	346
After	1425	403	334	91	1091	312
q (After/Before)	1.14	0.80	1.05	0.57	1.17	0.90
R (q night/q day)	0.70		0.55		0.77	
Significance level	0.1%		0.1%		1%	

Figure 5. Public lighting and injury accidents on 64 sites in UK.