Safety and travel time in cost-benefit-analysis: a sensitivity analysis for North Rhine-Westphalia

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Abstract

Decisions on large-scale infrastructure concepts are frequently based on cost-benefit-analysis (CBA). Using 431 road projects evaluated in the integrated transport planning process in North Rhine-Westphalia, Germany (IGVP NRW) this paper examines the evaluation dimensions traffic safety (fatalities) and travel time in private passenger transport. The unit values of traffic fatalities and travel time are varied, and the effects of the variations on the rank order of the projects are examined. Target conflicts between safety and travel time are studied as well as the contribution of these two dimensions to the total benefit values. The sensitivity analysis shows that the evaluation results are fairly stable against variations in unit values of travel time and fatalities. The relevance of traffic safety in terms of its contribution to total benefit as well as in terms of the unit value appears to be relatively minor. The unit value of travel time is higher than that of life time. Some projects turn out as feasible in the evaluation even though they are likely to increase the number of fatalities. The paper therefore suggests the higher weighting of traffic safety in CBA.

Keywords: cost-benefit-analysis, traffic safety, value of travel time, value of life

1 Introduction

Cost benefit analysis (CBA) is a crucial component of transport planning when the allocation of scarce means for investment has to be justified. The bulk of benefit commonly arises from travel time savings that are achieved by network expansions (Metz, 2004, p. 338). On the other hand, increasingly high thresholds with respect to traffic safety are set as goals to be achieved. Among the most prominent examples is the 'Vision Zero' in Sweden that states as a long-term goal "that nobody should be killed or seriously injured in the transport system" (Rosencrantz, Edvardsson and Hansson, 2007).

Although the two goals of increasing speed and more safety do not necessarily conflict with each other, there may well be a trade off in some cases. Hauer (1994) illustrates this with respect to a study that gives guidance to replacing 'stop' signs at intersections with 'yield' (give way) signs. The main benefit of yield signs is to save time for vehicle occupants, while "the main drawback is that it degrades safety" (ibid., p. 109).

This paper contributes to discussion of the valuation of safety and travel time with a secondary analysis of CBA results for 431 road projects in the federal state of North Rhine-Westphalia (NRW), Germany. CBA plays a key role in the allocation of financial means for infrastructure upgrade and expansion in Germany. This is true for federal transport infrastructure planning (Bundesverkehrswegeplanung, BVWP) as well as for integrated transport planning in NRW (Integrierte Gesamtverkehrsplanung Nordrhein-Westfalen, IGVP NRW). Although the IGVP NRW includes cost efficiency analyses as well, political decisions in the transport ministry are mainly based on the CBA results. The methodology is reported in detail by the project group (Projektgruppe IGVP, 2005).

In this paper we present findings from a sensitivity analysis that aims to examine the sensitivity of the rank order of road projects against variations in the values of traffic fatalities and travel time in private (non-business) passenger transport.

The next section presents a short description of the relevant elements of CBA with a particular focus on the problem of uncertainty. Our research approach is subsequently described, followed by an overview of our data and methodology. Sections 4 and 5 present the results. The paper finishes with some policy recommendations and an outlook.

2 Background

2.1 Methodology of cost benefit analysis

CBA is a widely acknowledged and widely used methodology for the economic appraisal of infrastructure projects (Nas, 1996; Vickerman, 2007) including transport projects (Bristow and Nellthorp, 2000; Mackie and Nellthorp, 2001). The effects of an investment are assessed as benefits and monetised. Over and above their economic impact, this may include social or environmental effects that have to be transformed into monetary units. Negative effects such as additional emissions are treated as negative benefits. The benefits are compared with the project costs, which include construction and maintenance. Benefits as well as costs are discounted over an assumed project lifespan and they may be annualised. If the benefit sum exceeds the costs the project yields a positive economic benefit (i.e. if the benefit cost ratio BCR>1). The BCR of various projects can be used to compare and rank the projects.

In transport planning practice, not all projects with BCR>1 are completed. For instance, in earlier federal transport plans in Germany a threshold of BCR>3 was set for 'urgent need' that then implied that the project had at least a chance of realisation. The recent BVWP no longer uses such a fixed threshold. In the IGVP NRW a 'rough threshold' for orientation of BCR>2 is used[1].

[1] The IGVP NRW considers projects with BCR>2.2 as being feasible. This threshold is derived from the available budget rather than from methodological considerations, and it was reduced in a political adjustment process to BCR>2.0. In reality, however, considerable deviations from this threshold are

2.2 Uncertainty in cost benefit analysis

A large proportion of the benefit of transport infrastructure projects is often due to travel time savings. In fact, in CBA ensuring and improving accessibility, the key goal of transport planning, is implicitly often operationalised as increasing travel speed and thereby reducing the generalised cost of travel, although there is consensus in transport science that "there's more to it [i.e. to accessibility] than just summing up travel cost reductions" (Zondag et al., 2007).

Besides such conceptual shortcomings, there are a number of other problems in CBA, including mathematical problems, monetisation problems, the assumption of mutual substitutability of positive and negative effects, and the problem of recognising target conflicts. What is more, ex ante appraisals in planning processes always involve uncertainties. In CBA these mainly relate to three elements: transport forecast, the estimation of effects, and monetisation.

Transport forecast

Assessing a project by CBA requires transport forecasting. Besides travel time changes, the transport effects of a project may include changes in the origin-destination matrix, travel mode choice and route choice. All these effects may result in further travel time changes. In the IGVP NRW the transport effects of the projects were estimated using a transport model for the affected partial networks. The forecast is uncertain even though the approach used was highly ambitious.

In a review of experience from mega transport projects Flyvbjerg, Bruzelius and Rothengatter, (2003, p. 22ff) conclude that travel demand has been systematically overestimated. Van Wee (2007), in a comprehensive review of demand and cost forecasts for which ex post evaluations were available, finds that the quality of the forecasts is often very poor, and "overestimation of demand is more common than underestimation" (ibid., 614). He also notes having found "only a few references in which a systematic comparison between forecasts and actual demand is made. This in itself is striking" (ibid., p. 613).

De Jong et al. (2007) study uncertainty in input variables as well as in model coefficients for traffic forecasts in the Dutch context. In a similar vein to Van Wee they note that "the literature on quantifying uncertainty in traffic forecasts is fairly limited" (ibid., p. 391). In their own study they find "substantial, but not very large uncertainty margins" (ibid., p. 392) for the whole study area of Rotterdam as well as for selected links.

Estimation of effects

The estimation of traffic effects, e.g. on safety and the environment, involves uncertainties as well. The estimation of safety effects in the IGVP NRW may serve as an example. Safety effects are estimated here by using generalised accident parameters for different road types (Projektgruppe IGVP, 2005, p. 58). The relevant network links are classified (e.g. single-lane extra-urban road) and the traffic volumes on a link are multiplied by the mean accident rate of the respective road type. Changes in safety result from changes in transport demand, from shifts in transport demand towards links of a different type, and from the planned project (e.g. upgrade from a single-lane to a two-lane road). The actual accident situation in the planning area is not considered and may considerably differ from the parameters used. As a consequence, the future accident situation may also markedly differ from the expected situation. To the best of our knowledge there is no study for Germany that includes comparisons of accident rates before and after the realisation of projects, or comparisons between forecast and actual accident rates. In the UK this is carried out in the POPE scheme (Post Opening Project Evaluation). Results show

evident due to 'urgently required projects' with lower BCR values. As a threshold for comparison, we regard projects with a BCR>2.0 as feasible in this paper.

close correlation between accident predictions and outcome within five years after implementation. However, this conclusion is based on the very limited data referring to nine projects that is available to date (Highways Agency 2009, p. 20ff).

The estimation of project costs is another example of uncertainty. Nijkamp and Ubbels (1999) find that generally cost estimates are fairly reliable in the Netherlands and Finland. By contrast, Flyvbjerg, Skamris Holm and Buhl (2003) find substantial cost escalation for a large sample covering 258 rail, road, tunnel and bridge projects in 20 countries all over the world. According to their results, the tendency to overrun cost is common for different project types and different geographic regions, and has not improved over the past 70 years. Flyvbjerg, Bruzelius and Rothengatter (2003, p. 11ff) find a systematic underestimation of costs in transport projects. Lee (2008) finds cost overruns of an average of 27.9 percent for a sample of 161 Korean road, rail, airport and port projects. Odeck (2004) finds an average cost overrun of 'only' 7.9 percent for road projects in Norway, with a substantial variation of misestimates. Van Wee (2007) concludes from his literature review that "all the studies show that cost overruns are common" (ibid., p. 617). In Switzerland, CBA includes a buffer of 20 percent of estimated costs for schemes unless they include an additional risk analysis. For tunnels and bridges the buffer is even 40 percent (VSS, 2006, p. 32).

Monetisation

All non-monetary effects of a project have to be monetised in CBA. For instance, in the IGVP NRW a traffic fatality is valued by 1.2 million €. One hour of travel time in non-business workday passenger transport is valued by 6.52 € (Projektgruppe IGVP, 2005, p. 30).

Both the value of travel time savings and the value of life are subject to debate in transport studies. Methodologies of measurement include two basic approaches. First, human capital theory claims that lost time is lost productivity. Empirically this leads to the estimation of future earnings lost by accidents (or by time spent travelling). Secondly, willingness-to-pay approaches measure the value of time either by revealed preferences, i.e. by some measure of observed behaviour, or (more often) by stated preferences, i.e. by what people say about what they would do in a hypothetical situation. Initial research on the value of travel time was undertaken in the 1960s in the UK (Beesley, 1965), as well as the US (Lisco, 1967). Generally it is agreed upon that time is a scarce resource (Mackie, Jara-Diaz and Fowkes, 2001). Thus, travel time is assumed to be valued negatively by travellers, and, accordingly, travel time savings are valued positively. However, there are some objections to this interpretation.

First, travel time may be valued positively or not at all. Cirillo and Axhausen (2006) analyse a six-week travel diary and find that a small but relevant proportion of the population may not value travel time savings. Jain and Lyons (2008) conclude from their qualitative research that travel time may even be perceived as a gift, rather than a burden. This can be due to some kind of recreational experience taking place during the journey, or to productive activities being undertaken on the way (Lyons and Urry, 2005). What is more, travel time savings in CBA are the sum of a very large number of marginal savings which may well be below a perception threshold of about five minutes (Gunn and Burge, 2001, Accent and Hague 1999) or they may be of no use to an individual because not all activities are movable in time (for a critical discussion see Mackie, Jara-Diaz and Fowkes, 2001, for an international comparison handling this issue Bickel et al., 2005).

Second, values of travel time have been found to be mode specific and to reflect the mode the users have chosen. It is therefore difficult to establish whether differences reflect mode effects or users' self-selection effects. Empirically there is evidence for self-selection (Fosgerau, Hjorth, Lyk-Jensen and Allé, 2007), similar to the residential self-selection debate (Scheiner and Holz-Rau, 2007).

Third, the widely observed stability of travel time expenditures over time and space on the aggregate level challenges the notion of travel time savings (Metz, 2004; Mokhtarian and Chen, 2004; Metz 2008 and the discussion in Transport Reviews vol 28, issue 6). Transport users seem to reinvest the time they save by increased travel speed in travelling longer distances rather than in recreational, productive or social activities of any kind. If at all, some observations suggest an increase in per capita travel time over time (see Banerjee, Ye and Pendyala 2007 for a review). This questions the benefit of travel time savings, although one may assign a benefit to the longer distances and the increase in access they permit.

Value of life is less debated in transport science than value of time, possibly due to the moral and emotional implications of assigning a monetary value to a person's life. From a humanistic perspective it seems absurd, if not brutal, to trade off lives against travel time (Hauer, 2010), but nevertheless the value of life is an integral part of CBA. The seminal work of Jones-Lee (1976, 1989) provides the theoretical groundwork, and Trawén, Maraste and Persson (2002) present empirical estimations for nine European countries. Hauer (1994) emphatically expresses his concern in recognising that the value of an hour of life lost through a traffic accident is lower than the value of an hour of time lost in congestion. He concludes his paper by suggesting that public decisions on investment should be given legitimacy by some kind of ballot mechanism rather than by cost-benefit computations.

The extent of the uncertainty of assumptions in CBA can probably best be assessed by ex-post comparisons between forecasts and actual outcomes. However, this exercise is rarely undertaken. Van Wee (2007) concludes from his review that transport demand is more likely to be overestimated than underestimated, while costs are mostly underestimated. Both types of misestimation commonly lead to overestimations of BCR and support investment in questionable projects. Van Wee attributes this not so much to a lack of quality in the techniques of forecast but rather to the strategic behaviour of key actors. In addition, there is uncertainty in the estimation of discount factors, plus the question of whether or not to discount lives and time at all as, in contrast to money, "neither lives nor time can be banked or passed on" (Hauer, 2010, p. 8).

In this paper we do not aim to contribute to the fundamental theoretical, methodological and even philosophical debates surrounding the issues of the discounting and trading off of lifetime and travel time in CBA (again, for an excellent discussion see Hauer, 2010). By weighing lifetime against travel time we do not aim to support the notion of such a trade off. We rather aim to examine the sensitivity of CBA outcomes against variations in input variables in a practical exercise. Although such sensitivity analyses do not show how close to or how far from future reality the results are, they do indicate the variability or stability of results, and therefore allow an appraisal of their trustworthiness.

2.3 Research approach – sensitivity analysis

Uncertainty is not necessarily a problem for political decision-making as long as the uncertainty level remains within a range small enough not to have an effect on the decision to be made. In other words, given that the aim is to realise all projects with a cost benefit ratio of BCR>3 (as has long been the case in Germany, see BMV, 1992), it does not matter much whether the BCR of a suggested project equals 4.1 or 4.8, as long as a thorough sensitivity analysis suggests that the difference between the true ratio and the estimated ratio is unlikely to be more than 0.5 and that thus the threshold of 3 will in any case be reached.

In our study the results of CBA are examined in a sensitivity analysis of road projects in the IGVP NRW. We limit ourselves to monetisation and some further considerations on safety. The extent to which changes in the unit values of traffic fatalities and travel time in private transport affect the ranking order of the projects is tested. This focus is set for three reasons.

Firstly, the monetisation of fatalities is a particularly critical element of CBA. Fatalities account for most human suffering and almost half the macro-economic cost of traffic injuries in Germany (BASt, 2004).

Secondly, benefits from time savings in private transport are subject to a long-standing debate, because these travel time savings are reinvested in longer distances (at least in the long term) rather than being used as savings.

Thirdly, the likely trade off between speed and safety plays a key role for sustainable transport. Holz-Rau, Kasper and Scheiner (2004, p. 191) as well as Holz-Rau (2005, p. 14) define the first guideline for sustainable transport planning: 'Accessibility, safety and security are more important than speed'. In both studies, accessibility is placed in the context of transport options as well as the micro-spatial environment, rather than as a synonym for high travel speed. In other words, accessibility is seen as the ease of reaching opportunities (Litman, 2007, p.3) rather than the ease of overcoming space.

Our focus implies that the sensitivity of the projects against other variations is not considered. These include:

- the forecast of frame conditions and general transport trends
- the forecast of transport demand changes on the relevant link
- the estimated effects of changes in transport demand
- the unit values of other dimensions of benefit, such as business travel times, or emissions
- the estimated project costs
- the predicted discount rate.

In addition to general sensitivity against input variations (section 5), four more questions are discussed (section 4):

- Which project types generally show above-average valuations?
- How important are safety and travel time in private transport for the valuation results?
- Are there any target conflicts between safety and travel time?
- What is the value of one hour of life?

3 Data and Methodology

The data used include all 431 road projects in the IGVP NRW. The projects include 277 bypasses, 31 railway crossings, 103 other upgrade projects, and 17 other new construction projects. For three projects information on the project type is not available. None of the projects are mutually exclusive.

For all projects, our data include information on project type, BCR, annual project cost (discounted), contribution of travel time savings, contribution of traffic safety, and contribution of other benefits to the overall benefit. The benefit from reductions in traffic fatalities was estimated from the total traffic safety benefit (see below). The data were provided by the consultant TCI Röhling in agreement with the NRW Ministry of Building and Transport (MBV). The analysis is not intended to make statements on single projects. Thus, outliers or other striking results concerning single projects are not investigated in detail.

We limit our sensitivity analysis to the rank order of road projects without addressing the BCR itself. We believe that CBA is most suitable for comparing CBRs for fairly similar projects, and we are mainly interested in the stability of the rank ordering against variations in input values, rather than absolute changes of BCR values.

Our analysis is mainly based on descriptive statistics. This includes cross-tabulations and comparisons of mean values requiring a grouping of the projects into rank categories of BCR (see Table 1).

Rank	Exact BCR	Approximate BCR
1-50	> 4.95	> 5
51-100	2.945 – 4.95	3 - 5
101-150	1.95 – 2.945	2 - 3
151-220	0.995 – 1.95	1 - 2
221-431	< 0.995	< 1

Table 1: Rank categories of BCR

What is more, the effects of annual project costs and project type (four dummy variables) on BCR are estimated using OLS regression. This includes interaction variables as the impact of project costs may vary by project type. Tests of significance are not undertaken because the analysis is based on the whole population of road projects in the IGVP NRW, rather than on a random sample.

The sensitivity analysis is based on variations of the value of a life, as well as of the value of an hour of travel time.

Concerning the value of life, three variants were calculated complementing the value used in the IGVP NRW. These variants increase the unit values for fatalities stepwise:

Variant 0: The same unit values as in the IGVP NRW are used as a reference variant.

Variant 1: A unit value of 1.8 million € per fatality is used. This is consistent with the value of travel time used in private passenger transport. One hour of lifetime equals 5.80 € and matches one hour of travel time in private transport (average of workdays and weekends).

Variant 2: A unit value of 3.6 million € per fatality is used. This value matches twice the value of an hour of travel time in private transport. It reflects a high weighing of life against travel time, an exercise for which there are good reasons (see Hauer, 2010, p. 3).

Variant 3: A unit value of 9.34 million € per fatality is used. This matches five times the value of an hour of travel time in private transport and reflects an extremely high weighing of life against travel time.

Self-evidently, when higher unit values for safety are used, the total benefit values of the projects change. However, the sensitivity analyses conducted here do not study the BCR itself, but are limited to consideration of changes in the rank order of the projects.

As the CBA in the IGVP NRW does not make an explicit distinction between fatalities and the injured, but uses average accident cost rates for all physical injuries taken together, one has to estimate the impact of a higher value for fatalities on the accident cost rate.

Based on the available project evaluations of the IGVP NRW the average costs per accident involving physical injuries are 86 500 €, ranging between 64 000 € and 124 000 €. The range is due to the specific situations in the affected partial networks. The proportions of accidents with fatalities, seriously injured and slightly injured persons can be estimated by linear interpolation for each project using the respective accident costs. These proportions can be linked for each project to the higher unit values for fatalities. The higher unit values defined in the variants above can thus be introduced into the calculations.

The variations of the unit value of travel time lead to two further variants:

Variant 4: The value of travel time savings in private transport is reduced to 50 percent of the value assigned in IGVP NRW.

Variant 5: Travel time savings in private transport are not valued as economic benefits at all.

While in the variants 1 to 3 the variations in the unit values are limited to fatalities, the variants 4 and 5 are limited to alterations of the unit values of time. We thus study variations in the two evaluation dimensions separately to shed more light on their separate effects.

4 Results I: some hypotheses on safety and time savings

Before we turn our attention to the sensitivity analysis, four questions are discussed, as noted above (section 2.3). These questions are based on a number of hypotheses that are explicitly referred to in the next sections.

Rank category	(approx. BCR)	Bypass	Railway crossing	Other new construction	Other upgrade	Total
1-50	(> 5)	44 (16%)	1 (3%)	3 (18%)	2 (2%)	50 (12%)
51-100	(3 - 5)	43 (16%)	0 (0%)	2 (12%)	4 (4%)	50 (12%)
101-150	(2 - 3)	48 (17%)	1 (3%)	0 (0%)	1 (1%)	50 (12%)
151-220	(1 - 2)	50 (18%)	3 (10%)	5 (29%)	12 (12%)	70 (16%)
221-431	(< 1)	92 (33%)	26 (84%)	7 (41%)	84 (82%)	209 (49%)
Total		277 (65%)	31 (7%)	17 (4%)	103 (24%)	428 (100%)

Table 2: Rank categories of BCR by project type

4.1 Which project types generally show above-average valuations?

The first question to be examined is based on an implicit hypothesis:

Hypothesis 1: Assessment results vary by project type.

In Table 2 the projects are classified by rank categories and project type. The findings show that bypasses dominate in the upper three rank categories. Only one third of all bypasses (i.e. from rank 221 to the last rank) exhibit BCRs<1. Other new construction projects are similarly well evaluated, although the lower two rank categories dominate somewhat more here. Railway crossings and other upgrade projects tend to exhibit considerably worse evaluations.

Hypothesis 2: Low-cost projects are evaluated more positively than more expensive projects.

For this analysis the projects are categorised into quintiles according to the expected annualised construction and maintenance costs (from here: annual costs).

The share of projects with a BCR<1 varies between 42 and 61 percent without showing a clear trend for the quintiles (Table 3). However, there is a tendency to value the more costly projects *better* than the cheaper ones, contrary to expectation. This is mainly due to the relatively expensive new construction projects that often achieve high CBRs.

Rank category	(approx. BCR)	<= 0.132 m. € / year	0.133 - 0.173 m. € / year	0.174 - 0.238 m. € / year	0.239 - 0.373 m. € / year	>= 0.374 m. € / year	Total
1-50	(> 5)	20 (23%)	8 (9%)	4 (5%)	11 (13%)	7 (8%)	50 (12%)
51-100	(3 - 5)	7 (8%)	9 (10%)	13 (15%)	9 (10%)	12 (14%)	50 (12%)
101-150	(2 - 3)	7 (8%)	6 (7%)	11 (13%)	11 (13%)	15 (17%)	50 (12%)
151-220	(1 - 2)	10 (11%)	11 (13%)	16 (19%)	17 (20%)	16 (19%)	70 (16%)
221-431	(< 1)	43 (49%)	53 (61%)	41 (48%)	38 (44%)	36 (42%)	211 (49%)
Total		87 (20%)	87 (20%)	85 (20%)	86 (20%)	86 (20%)	431 (100%)

Table 3: Rank categories of BCR by categorised annual project costs

	B	Standard deviation	Beta (standardised)
Constant	0.485	0.679	
Annual project cost (million €, discounted)	-0.274	2.806	-0.032
Project type (reference: other upgrade)			
Bypass	2.233	0.715	0.350
Other new construction	2.196	1.158	0.140
Railway crossing	-0.360	1.073	-0.030
Interaction between project cost and project type (reference: annual project cost other upgrade)			
Annual project cost bypass	-0.110	2.836	-0.014
Annual project cost other new construction	-0.898	3.496	-0.026
Annual project cost railway crossing	-0.694	4.000	-0.017

Table 4: OLS regression of BCR

Simultaneous test of hypothesis 1 and 2

Because project type and project cost are not independent of one another, the effect of costs and project type on BCR were analysed simultaneously using OLS regression. The results can be summarised as follows (Table 4):

- The model achieves a variance explanation rate of 12 percent. The model fit is therefore far from being close. It is only possible to forecast the BCR from annual project costs and project type to a very limited degree.
- Project type has a stronger effect on BCR than cost. Bypasses and other new construction projects achieve relatively high BCR values, while railway crossings exhibit low values.
- With increasing annual costs the BCR values decrease.
- The interaction terms suggest that the cost effect varies by project type. Annual costs affect other new construction projects and railway crossings more than bypasses and other upgrade projects.

4.2 How important are safety and travel time?

Traffic safety and travel time in private transport are two of 13 CBA assessment criteria applied in IGVP NRW. Concerning the relevance of these two criteria, we study the following hypothesis:

Hypothesis 3: Travel time savings in private transport contribute more to evaluation results than safety gains.

Rank category	Contribution of accident cost to BCR	Contribution of travel time cost to BCR	BCR
1-50	0.78	3.21	8.38
51-100	0.54	1.41	3.67
101-150	0.33	0.98	2.42
151-220	0.09	0.70	1.46
221-431	-0.08	0.13	-0.13
Total	0.17	0.83	1.85

Table 5: Contribution of traffic safety and travel time to the BCR by rank category

The table shows the mean contribution within the rank categories of traffic safety and travel time in private transport.

Project type	Contribution of accident cost to BCR	Contribution of travel time cost to BCR	BCR
Bypass	0.1784	1.1201	2.5855
Other new construction	0.2030	1.0426	2.3307
Railway crossing	-0.1717	0.0673	-0.0955
Other upgrade	0.2224	0.2279	0.3990
Total	0.1646	0.8260	1.8550

Table 6: Contribution of traffic safety and travel time to the BCR by project type

See Table 5 for further notes.

Annual project costs	Contribution of accident cost to BCR	Contribution of travel time cost to BCR	BCR
<= 0.132 m. €	0.043	1.137	2.390
0.133 - 0.173 m. €	0.180	0.638	1.354
0.174 - 0.238 m. €	0.295	0.735	1.587
0.239 - 0.373 m. €	0.127	0.889	2.072
>= 0.374 m. €	0.185	0.730	1.850
total	0.165	0.826	1.851

Table 7: Contribution of traffic safety and travel time to the BCR by annual project costs

See Table 5 for further notes.

The relevance of travel time and safety in CBA may be judged from the share these two criteria achieve in the total BCR (Table 5).

In total the benefits from travel time savings in private transport on the road are five times as large as the safety benefits. In all rank categories the contribution of time savings exceeds safety effects. On average, the size relation between benefits from time savings and safety in projects with a BCR>1 (i.e. the upper four categories) is 3.7 v. 1. On average, in each of these categories more than one third of the total benefit results from time savings in private transport. The contribution of traffic safety, in contrast, is less than ten percent.

Categorised by project type, the contribution of travel time savings to the total benefits is particularly high for bypasses and other new construction projects (Table 6). Time savings are dominant in all cost categories (Table 7), particularly in low-cost projects.

4.3 Are there any target conflicts between safety and travel time?

According to the findings above, non-business travel time costs are far more important than accident costs for the evaluation results of the projects studied. It may therefore be stated that the guiding principle of transport planning formulated above – "safety is more important than speed" –

is not reflected in CBA results. However, this is not a problem unless projects are evaluated positively although they increase the risk of accidents. We thus develop our fourth hypothesis:

Hypothesis 4: Some projects are evaluated positively (i.e. as worth carrying out), at least partially due to travel time savings, although they increase the risk of fatalities.

To study this hypothesis the projects are split into positive and negative according to the criteria traffic safety and travel time. As a first step the project is classified as positive or negative (i.e. as decreasing or increasing accident costs) by considering the sign of the difference in accident costs between the situation with the project and the situation without it. Travel time costs are considered in the same way. As a second step, projects with only marginal effects on accidents and/or travel times are classified as having 'almost no effect'. This category includes all cases in which the difference in accident costs (or travel time costs) is less than 5 percent of the total BCR.

The results suggest that three of ten projects have a negative impact on traffic safety (Table 8). The large majority of these 'safety critical' schemes are evaluated either negatively (BCR<1) or with a BCR of less than 2. According to the rules of IGVP NRW, these projects are not earmarked for realisation. They therefore do not contribute to conflict between the evaluation results and the target of more traffic safety[2]. However, no less than 23 of 150 projects with a BCR>2 are indeed safety critical. Among the 50 best evaluated projects, ten actually increase the accident risk (Table 8). On the other hand, only 11 percent of the projects show negative effects on travel time. Not more than two of 150 projects with a BCR>2 result in time losses in private transport.

	Safety effects			Travel time effects		
Rank category (approx. BCR)	negative	almost zero*	positive	negative	almost zero	positive
1-50 (> 5)	10 (20%)	2 (4%)	38 (76%)	0 (0%)	0 (0%)	50 (100%)
51-100 (3 - 5)	6 (12%)	2 (4%)	42 (84%)	0 (0%)	0 (0%)	50 (100%)
101-150 (2 - 3)	7 (14%)	2 (4%)	41 (82%)	2 (4%)	1 (2%)	47 (94%)
151-220 (1 - 2)	20 (29%)	7 (10%)	43 (61%)	1 (1%)	0 (0%)	69 (99%)
221-431 (< 1)	85 (40%)	59 (28%)	67 (32%)	43 (20%)	42 (20%)	126 (60%)
total	128 (30%)	72 (17%)	231 (54%)	46 (11%)	43 (10%)	342 (79%)

Table 8: Safety and travel time effects by rank categories

* effect almost zero: difference in safety cost (or travel time cost) is less than 5 percent of the total BCR.

Without exception, all of the 23 safety critical projects with a BCR>2 are bypasses. Taking the 135 bypasses earmarked for realisation (BCR>2) as a basis, every sixth bypass may be characterised as safety critical. The negative safety effects essentially result from the longer distances that are usually required for newly constructed bypasses as compared to cross-town links, as well as from the higher accident rates and more severe effects of accidents on extra-urban roads, although it should be noted that we deal with crude standard values based on road type. On the other hand, 106 of 135 bypasses lead to more than marginally positive safety effects.

To sum up, hypothesis 4 may be confirmed. Among the projects with a positive – or even a very positive – BCR there are many bypasses which if completed are expected to impair traffic safety (according to the methodology applied by IGVP NRW). This contradicts the guideline "safety is more important than speed". In order to achieve travel time savings and other positive effects, a

[2] Assuming full confidence in CBA, projects with a BCR>1 could be completed. In planning practice, the threshold is commonly set higher (see section 2.1). Extending the analysis to projects with 2>BCR>1 would exacerbate the target conflicts discussed in the following.

reduction in traffic safety is clearly accepted, but this is not made transparent in the published evaluation results.

4.4 What is the value of one hour of life?

The determination of a unit value for fatalities in the framework of CBA appears to be particularly problematic to many. This value was set to 1.2 million € for Germany (BASt, 2004, p. 2), an amount that is deemed to reflect the macro-economic damage of a traffic fatality. This raises the question as to whether 1.2 million € is a high or a low value for a fatality. The following hypothesis has been formulated:

Hypothesis 5: The value assigned to one lost hour of life is lower than the value assigned to an additional hour of travel time in CBA.

This hypothesis may sound provocative, it has however been confirmed by Hauer (1994) for the US. In any case, the values of life differ significantly between different countries (Elvik et al., 2009, p. 124, Bickel et al., 2005, p. 29f) and between various studies within a country (Hauer, 2010, p. 2f). A comparison of nine European countries for the base year 1999 results in a range from 900 000 US $ in Austria to 2.2 million US $ in Norway. The German value of 1.2 million € is in the middle (Trawén, Maraste and Persson, 2002). Desaigues and Rabl (1995) find unit values for the period 1982 to 1990 ranging between 1.2 million and 3.8 million US $.

Another comparison can be made within the scope of a given evaluation system. The travel time savings that are often decisive for the evaluation of a project are usually determined by hourly rates. In the IGVP NRW these rates are 3.26 € for private passenger transport on Sundays and 6.52 € on workdays (Projektgruppe IGVP, 2005, p. 30). The large difference is a result of variations in travel purposes (commuting vs. other). For business transport they range between 24.89 € and 35.56 € according to vehicle type (ibid., p. 77). How do these unit values for additional travel time and for losses in life time relate to one another in CBA?

	road accident fatalities*			lost life expectancy **		sum of lost
	total	male	female	male	female	life expectancy
age group	(number)			(years)		(years)
<6	7	5	2	73.8	79.1	527
6 - <10	6	3	3	68.9	74.2	430
10 - <15	11	6	5	64.4	69.7	735
15 - <18	41	22	19	60.5	65.8	2 582
18 - <21	76	59	17	57.6	62.3	4 459
21 - <25	83	66	17	54.2	59.4	4 589
25 - <30	46	34	12	49.9	55.0	2 356
30 - <35	57	52	5	44.9	49.9	2 585
35 - <40	65	52	13	40.2	45.1	2 678
40 - <45	53	45	8	35.6	40.4	1 924
45 - <50	70	56	14	31.0	35.7	2 236
50 - <55	46	35	11	26.6	31.0	1 272
55 - <60	46	34	12	22.5	26.6	1 085
60 - <65	49	37	11	18.4	22.1	923
65 - <70	50	33	17	14.9	18.0	797
70 - <75	37	28	9	11.6	14.0	449
75+	120	59	61	7.4	7.9	921
sum	863	626	236			30 550

Table 9: Fatal accidents and lost life expectancy in North Rhine-Westphalia 2004

* source: LDS 2005, p. 64
** own calculations based on http://gerostat.prz.tu-berlin.de (see footnote 4)

Each accident victim would have had a certain statistical life expectancy. For instance, the life expectancy of a 20-year-old male in Germany is 57.12 years[3]. Statistics for traffic fatalities in NRW in 2004 include 865 fatalities, subdivided by age group and gender (LDS, 2005, p. 64). These can be used to estimate years of lost life expectancy, categorised by gender and age group. These years can be multiplied by the number of fatalities in the applicable category, and the categories can be summed up. This procedure shows that the NRW traffic fatalities in 2004 had a life expectancy of 30 550 years in total, and that an average victim had a life expectancy of 35.4 years, or 311 000 hours (Table 9).

Thus, a unit value of 1.2 million € per fatality means that one hour of lost lifetime is valued at 3.85 €. This unit value is lower than the values the IGVP NRW uses for an hour of travel time in private travel, let alone business travel. It is almost identical to the unit value for an hour of travel time used in the BVWP (3.83 €, see BMVBW, 2002, p. 34).

Ultimately, one hour of lifetime is valued less in the IGVP NRW than one hour of travel time, although a fatal accident represents the only real loss of time in traffic[4]. In contrast to the guiding principle 'Accessibility, safety and security are more important than speed' (see section 2.2) the unit values for lifetime and travel time used in the IGVP NRW may be characterised by the principle: 'Better get there fast than safely – speed is more important than safety'.

Additional time by speed limit (10^6 vehicle hours/year)*	17.11
Additional travel time by speed limit (10^6 person hours/year)**	32.22
Avoided fatalities by speed limit***	383
Saved life expectancy by speed limit (10^6 person hours/year)****	100.65
Difference (saved life expectancy minus additional travel time) (10^6 person hours/year)	68.43
Ratio (saved life expectancy / additional travel time)	3.1

Table 10: Effects of a speed limit of 100 km/h on extra-urban roads on travel time and life time

* Projektgruppe 'Tempo 100' (1975, p. 427)
** car occupancy rate = 1.88 persons / car (calculation based on BMV 1975, p. 149 and p. 114)
*** Projektgruppe 'Tempo 100' (1975, p. 426)
**** based on the assumption of 30 years of lost life expectancy per victim. Because for the 1970s there are no gender and age specific accident statistics available, the value of 35.5 years of lost life expectancy for 2004 was reduced to 30 years by rule of thumb due to the shorter life expectancy in the past.

4.5 Digression: saving time by limiting speed

Debates about speed limits have always been controversial in Germany. This is true for the introduction of the limit of 50 km/h in towns in 1957 as well as for the introduction of the 100 km/h limit on extra-urban roads in 1972, and it is even more true for the numerous attempts to introduce a general speed limit on federal highways (Praxenthaler, 1999).

The introduction of the 100 km/h limit was accompanied by comprehensive scientific studies in the 1970s. This included the estimation of losses in travel time and saved fatalities. The results of

[3] The loss in life expectancy of accident victims can be derived from mortality tables, categorised by age and gender. The German Centre of Gerontology provides a database (http://gerostat.prz.tu-berlin.de) that is based on the mortality tables of the German Federal Statistical Office. This database was used to calculate life expectancies based on the mortality rates of the three-year interval 2003 to 2005 in the old Bundesländer (former West Germany). The results were used to derive and sum up gender and age-group specific mean values of lost life expectancies for the population of NRW in 2004.
[4] The use of unit values is subject to another type of logic, i.e. loss in productivity. The value of travel time and the value of life may well be offset against each other in macro-economic terms. However, this surely does not offer the particular sensibility required for the handling of fatalities.

the project group at that time (Projektgruppe 'Tempo 100', 1975) can be linked to the considerations in this paper on lifetime lost by accidents. This yields an astounding result: the introduction of 'Tempo 100' led to considerable time savings. The lifetime gained by increased safety was more than three times as long as the travel time losses caused by the speed limit (Table 10).

5 Results II: sensitivity analysis

Following this overview of the relevance of time and safety effects, and target conflicts between the two, we turn our attention to the sensitivity analysis and examine the way in which the assessment results react to variations in the unit values.

5.1 Higher valuation of lifetime

Applying higher unit costs for fatalities in three variants (see section 3) leads to modified accident costs for the with and without case of each project that in turn lead to three variants of BCR.

On the basis of the IGVP NRW results and the three modified BCR values road projects included in the study were ranked. The ranks are compared in the following, starting with a comparison between the IGVP NRW results and variant 1.

Variant 1: Unit value of lifetime equals unit value of travel time

This variant leads to very limited shifts in the rank order of the projects. The rank correlation equals r_S=0.998 and reflects the extremely high correlation between the ranks. In Figure 1 projects above the diagonal are evaluated more poorly by the modified unit values, i.e. their rank declined. Projects below the diagonal improved their rank. The figure shows an additional axes of coordinates. The axes mark rank no. 150 (vertically for the IGVP NRW evaluation, horizontally for the modified evaluation of variant 1). This rank relates to a BCR of 2.0 in the original evaluation. Projects to the left of the vertical axis are considered to be feasible according to IGVP NRW. The projects below the horizontal axis represent the best 150 projects according to the modified evaluation. In addition to the close interrelation between the ranks in the two variants, Figure 1 shows hardly any transitions between the quadrants.

- Projects in the first quadrant (top right) are evaluated (relatively) negatively in both variants (BCR<≈2) and their rank is 149 or lower in both variants. This quadrant contains 278 out of 431 projects.
- Projects in the second quadrant (bottom right) have a rank under 150 in the IGVP NRW evaluation, but over 150 in the modified evaluation. In other words, projects in this quadrant are evaluated in variant 1 with a BCR>≈2, but in the original CBA they were evaluated with a BCR<≈2. This applies to two projects.
- Projects in the third quadrant (bottom left) are evaluated (relatively) positively in both variants (BCR>≈2) and their rank is 150 or better in both variants. This includes 149 projects.
- Projects in the fourth quadrant (top left) have a rank of 150 or higher in the IGVP NRW evaluation, but lower in the modified evaluation. Again this refers to two projects, one of which has declined considerably from rank 129 to rank 170.

One may pose the question as to whether the sensitivity of the projects against variations in the unit values for fatalities differs between the project types. The figure includes information on the project type, although it has to be noted that the data overlay each other. This effect diminishes in the following figures due to increasingly scattered results. In this first figure the categorisation by project type does not yield significant differences between the project types in terms of their sensitivity against variations in the unit values for fatalities.

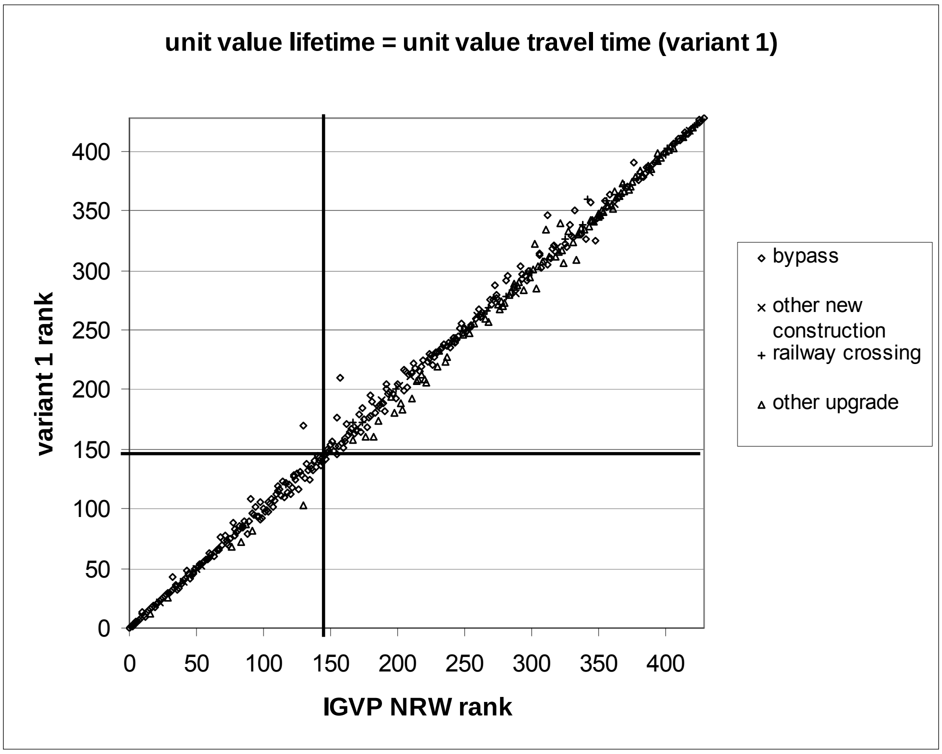

Figure 1: Rank order of the project evaluations by project type according to IGVP and variant 1

In total, a minor modification of the unit values for fatalities leads to rather insignificant shifts in the rank order. This result confirms expectations, as the relevance of accident costs in the CBA is relatively low.

Variant 2: Unit value of lifetime equals twice the unit value of travel time

Variant 2 uses a unit value of lifetime that equals twice the unit value of travel time (Figure 2). This doubling of an hour of lifetime against an hour of travel time leads to a more scattered picture in the rank comparison. The rank correlation is still very strong (r_S=0.978). Among the 150 projects evaluated best in the IGVP NRW, 142 are still among the 150 best projects in variant 2. However, there are some striking outliers, particularly one project that declines from rank 129 to rank 378. Bypasses tend to be downgraded while some of the other upgrade projects improve their position and reach a place among the 150 best projects.

Variant 3: Unit value of lifetime equals five times the unit value of travel time

The five-fold weighting of an hour of lifetime against an hour of travel time leads to an even more scattered picture in the rank comparison (Figure 3). The rank correlation is further reduced to r_S=0.908. Among the 150 projects evaluated best in the IGVP NRW, 129 cases are still among the 150 best in the modified evaluation. Categorising by project type reveals that other upgrade projects tend to improve their position (second quadrant), while bypasses tend to worsen their position. Among the 20 demoting projects (fourth quadrant) there are 19 bypasses. The number of outliers is considerably larger than in variant 2.

Summary of variants 1 to 3

Despite marked changes in the unit values for fatalities the correlation between the ranks in the original evaluation and those in the three studied variants is very high. However, despite high correlations the ranks of some projects change considerably. Consequently, other upgrade projects which in most cases yield only minor travel time benefits, tend to improve their position in comparison with bypasses that dominate the highest rank positions in the IGVP NRW due to their travel time benefits (Table 11).

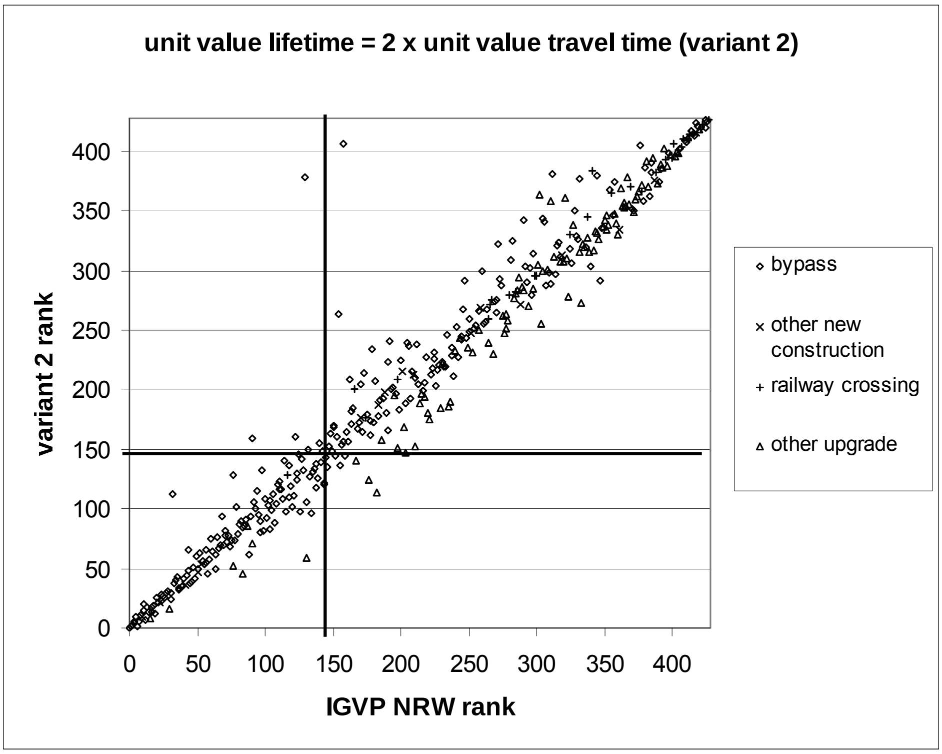

Figure 2: Rank order of the project evaluations by project type according to IGVP and variant 2

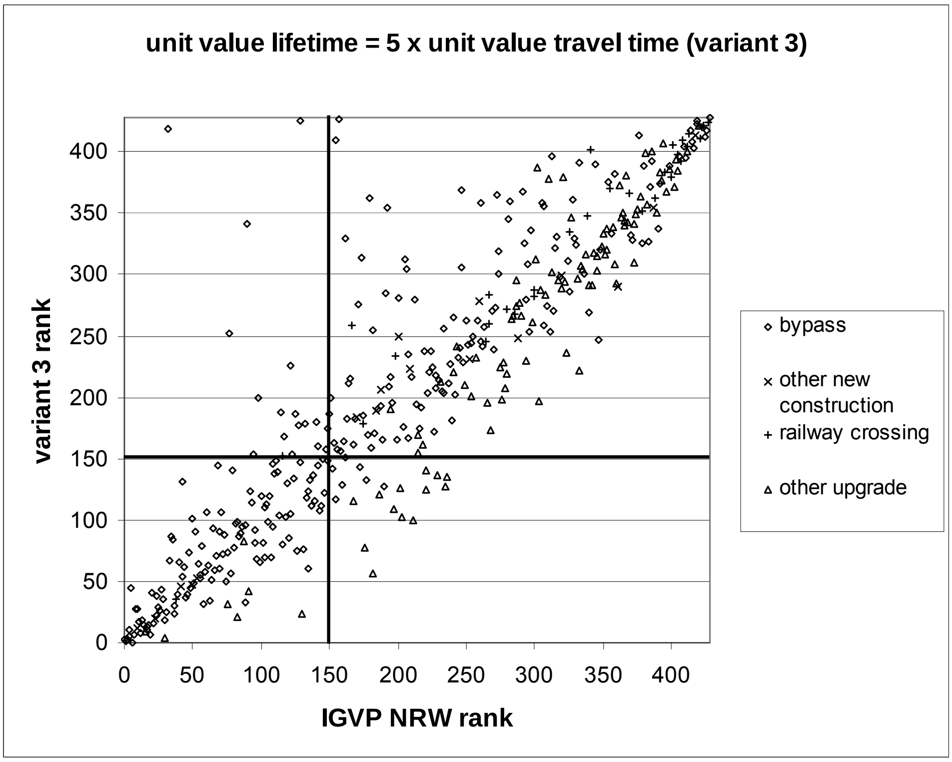

Figure 3: Rank order of the project evaluations by project type according to IGVP and variant 3

Rank category (approx. BCR)	IGVP NRW	Variant 1	Variant 2	Variant 3*
Bypass	44 (88%)	43 (86%)	42 (84%)	38 (78%)
Other new construction	3 (6%)	4 (8%)	4 (8%)	4 (8%)
Railway crossing	1 (2%)	1 (2%)	1 (2%)	1 (2%)
Other upgrade	2 (4%)	2 (4%)	3 (6%)	6 (12%)

Table 11: Projects with rank 1 to rank 50, by project type and variant

* In variant 3 one project is among the upper 50 whose project type can not be determined. Therefore the sum of variant 3 is only 49.

5.2 Lower valuation of travel time

The macro-economic evaluation of travel time gains in private transport assumes that these gains are indeed accrued over a long period and that savings in travel time benefits the societal production process (at least to a considerable extent). In travel behaviour studies, however, a more or less constant travel time budget has been observed on an aggregate basis (see section 2). This means that the travel time saved is reinvested into travel time in the long run. This raises the question as to whether such time gains should be valued as benefits in terms of a macro-economic evaluation (see Hauer, 2010, p. 10 for discussion). Variants 4 and 5 change the unit values for travel time savings in private transport accordingly.

Variant 4: Unit value of travel time is reduced to 50 percent

When the unit value of travel time in private transport is reduced to 50 percent (variant 4) changes in the rank order are more pronounced than in variant 1, in which the unit value of a fatality is increased to the level of travel time (compare Figure 1 with Figure 4). The ranks are still very strongly correlated (r_S=0.991). Seven projects that fall within the upper 150 lose these favourable ranks without inducing priority shifts between the project types.

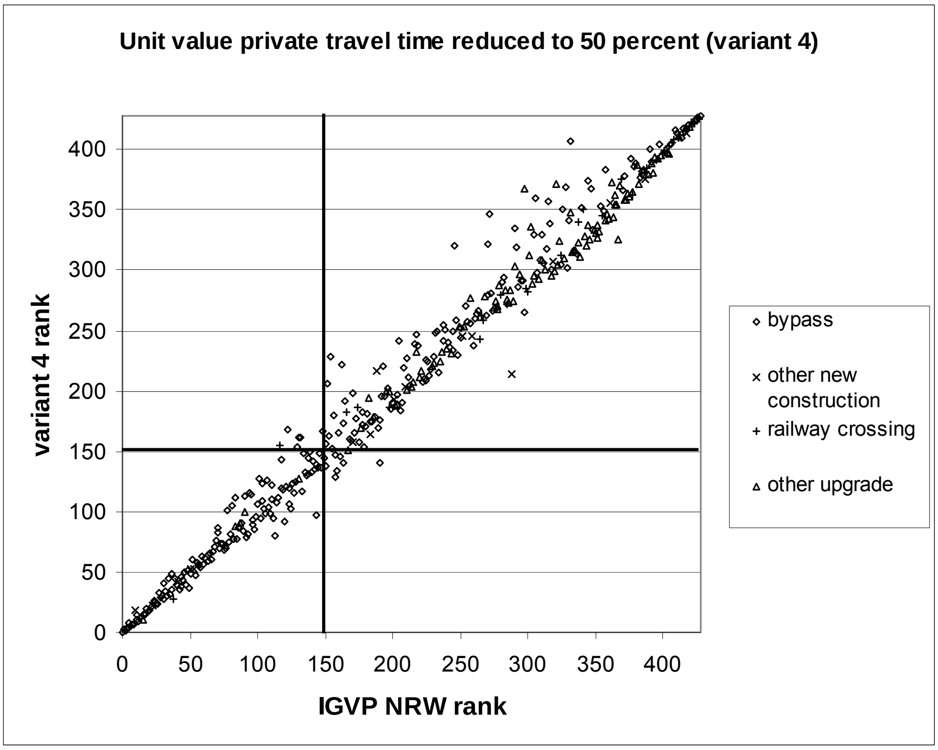

Figure 4: Rank order of the project evaluations by project type according to IGVP and variant 4

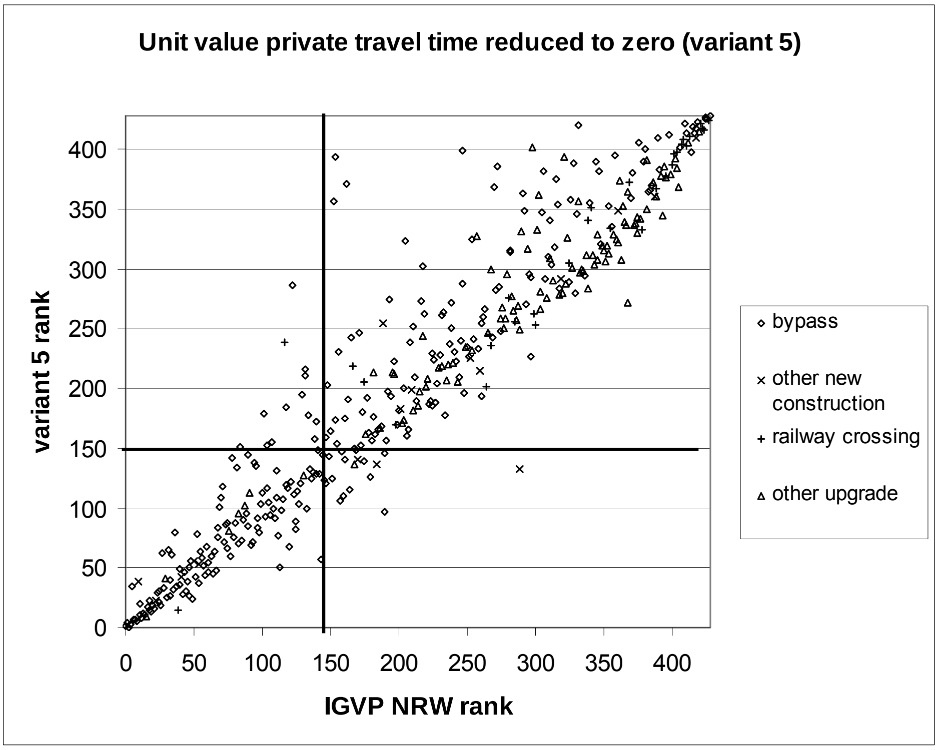

Figure 5: Rank order of the project evaluations by project type according to IGVP and variant 5

Variant 5: Unit value of travel time is reduced to zero

When travel time benefits in private transport are excluded from evaluation (i.e. they are set to zero), the rank order changes are stronger (Figure 5). However, the ranks are still very strongly correlated (r_S=0.949). Sixteen projects that range among the upper 150 lose their favourable positions. As opposed to variant 3 that varies the unit value of lifetime, there is no conspicuous change in the structure of the project types among the upper ranks.

6 Conclusions and outlook

In this paper we used a population of 431 road projects evaluated in the integrated transport plan of the federal state of NRW, Germany (IGVP NRW) to study the sensitivity of the project rank order against variations in the unit values of traffic fatalities and travel time in private (non-business) passenger transport. The findings suggest that the evaluation results yielded by the original CBA are fairly stable even against considerable variations in the unit values of fatalities and travel time. However, the variations lead to marked changes in rank order for a small number of projects.

What is more, there are considerable target conflicts between safety and travel time benefits. Some projects achieve a favourable evaluation result and are earmarked for realisation even though they contribute to a reduction in traffic safety and are thus likely to increase the number of fatalities. One of the most striking findings is that the unit values used by the IGVP NRW value an hour of travel time more highly than an hour of lifetime. This finding, to express it brutally, implies 'that it is preferable to be dead than stopped in traffic', as Hauer (1994, p. 110) notes after recognising the same disproportion for the US.

To cope with such conflicts, the following approaches are worthy of consideration:

First, the underrating of lifetime as compared to travel time suggests the unit value of fatalities could be increased in assessment procedures.

Second, a comprehensive indicator such as the BCR hides negative benefits in certain dimensions of evaluation. To avoid favourable evaluation results for projects that appear to contribute to an increase in traffic fatalities, this dimension of benefit (and, possibly, others as well) should be assessed separately. This assessment step could be linked to a rule of legitimacy or permissibility (similar to iterative assessment procedures based on pairwise comparisons, NERA, 2002) that prevents projects which reduce traffic safety. A less rigorous alternative would be to make close inspection of safety issues obligatory as soon as a project appears to be safety critical. This should include the analysis of the actual accident situation in the project's impact area, rather than just relying on standardised road-type specific parameters.

Third, the finding that there are a small number of projects whose rank order position changes markedly by varying unit values suggests it may be appropriate to introduce these rather simple sensitivity analyses for all projects. The unit values for important benefit dimensions should be varied within a reasonable scope. Projects that react particularly sensitively to the variations should be examined in more depth in order to confirm or modify the evaluation results, as the case may be.

Our examination of evaluation results was limited to the relevance, and some modification, of unit values for fatalities and travel times in non-business passenger transport. Transport modelling provides a highly developed, powerful tool for the estimation of travel time effects. The estimation of safety effects appears to be considerably more difficult. The issue of traffic safety could be much more thoroughly addressed within the scope of strategic transport infrastructure planning. We offer two suggestions with respect to this issue:

First, analyses of the accident situation 'as is' should be an inherent part of any project planning. In the present evaluation procedure, the likely relatively high safety gains of projects that improve a particularly problematic situation are not accounted for, because safety effects are estimated purely on the basis of generalised road-type specific accident rates. On the other hand, the present procedure is likely to overestimate the safety benefit of projects located in a situation where an above-average safety level (compared to all roads of this type) is already achieved, and where further increases in safety may not be expected.

Second, completed transport infrastructure schemes from the IGVP NRW should be evaluated ex-post with respect to their safety effects. This also relates to other planning procedures and planning levels such as the BVWP on the federal level in Germany. This could help improve assessment procedures. At the same time it could contribute to improved design of infrastructures.

The findings presented in this paper consider only a few aspects of assessment and focus on road projects. There are a number of further uncertainties relating to transport forecast, cost estimations, impact assessment, monetisation and discounting, to other benefit dimensions, and to other transport sectors such as the railway. These uncertainties mean that assessment results should be handled with great care.

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