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Measurement of Accident Risk and a Case Study from Hungary

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Abstract
For the cost-benefit analysis of road safety measures, it is essential to estimate the national value of statistical life. By calculating the updated values, it is possible to assess the aggregate national value of statistical life for road traffic crashes, thereby also characterizing the road safety situation in the country. It is important that the values set and the methods used are compatible with the practices of the European Member States. It must be stressed that updating the values is of major importance both for the cost-benefit analysis of the various road safety measures and for raising public and decision-makers' awareness of the huge losses. The full identification and use of loss figures is an important element of road safety. In this article we present possible methods for estimating the value of statistical life.

Keywords
road safety, accident risk, road crashes, value of statistical life

1 Introduction

First of all, there is no such thing as a "cost of human life". Human life is unique and unrepeatable, and as such, it is conceptually different from money (Holló and Sipos, 2020).

Road traffic crashes are the eighth leading cause of death worldwide, with more than 1 million people estimated to die on the world's roads each year; a further 20–50 million people suffer non-fatal injuries each year as a result of road accidents (Mekonnen, et al., 2023). Even if the loss of life is invaluable, it puts a value on the resources we are prepared to give up reducing the risk of this dreadful outcome; resources that we, both as individuals and as a society, are prepared to spend on traffic safety activities (Baranyai and Sipos, 2022). This paper discusses this monetary value: direct economic cost, indirect cost, and the risk valuation or value of statistical life (VSL) (Nash, 2015).

1.1 Introduction of the value of statistical life

In the late 1600s, a method was introduced to include the value of labour in the estimation of national wealth. This human capital was calculated as the present value of the future wage bill using the interest rate as a discount factor. Similar methods were used by plantation managers in the US and British West Indies in the early 1800s to establish a value of their 'asset for distribution to their heirs and to insure enslaved people. Another approach was to measure the value of a man to his dependents as the difference between future income and the discounted present value of future consumption expenditure, i.e., the present value of the individual's net income. This prospective approach is mainly used today in valuing human capital. Giles (2003) refers to using this method in the field of national road crashes and adding a component to value non-market work. Schelling (1968) was concerned with the value to be used for the prevention of death, and not to assess the value of human life and suggested that a potential change in the fatal accident rate may be regarded as a change in the probability of death for any particular individual. The focus of research has since been to develop the valuation for various changes in probabilities of accident outcomes and to estimate a value of statistical life (VSL). The methodology used to value statistical life has significantly changed, and the approach

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has changed over the last decades. For example, initially, researchers did not even try to identify the human aspects of loss (pain, grief, etc.), but now they are considered. Despite being developed more than 20 years ago, the COST 313 guideline (Alfaro et al., 1994) is still considered the most comprehensive methodology to value statistical life (Holló and Sipos, 2020).

The value of statistical life is the level of investment that can be justified to save one life. It is the valuation of a change in risk such that one life will be saved rather than the valuation of the worth of a specific individual's life. (McMahon and Dahdah, 2008)

1.2 Basic concepts

Different measures of exposure may be used to present fatality risks when comparing countries or preparing an impact assessment: fatalities per 100.000 population, fatalities per million vehicle-kilometres, fatalities per 10.000 vehicles, fatalities per million trip-kilometres (Mekonnen et al., 2022). Mortality is only one of the possible outcomes of an accident.

A single scale for definitions of injuries does not exist. Not even fatality has a single definition, even if a 'dead within 30–day' definition is often used. A common impact definition in the transport sector is based on the four categories below:

- Fatality: causes of death resulting from an accident and occurring within 30 days;
- Serious injury: a person who was hospitalised and sustained permanent injuries but did not die within the registration period of fatal accidents;
- Slight injury: injured persons whose injuries do not require hospital treatment or, if they do, the effects of the injury quickly disappear;
- Damage-only accident: accident without injuries.

Usually, accident data are collected by the police, although some countries also use hospital records. Under-reporting for fatalities is generally low for highly motorised countries (2–5%), while it could be substantial and between 25–50% for low motorised countries.

The data quality is also poor for injuries in highly motorised countries, especially for modes other than the car. Appropriate information on accident risk and its consequences, taking into account under-reporting the current situation and the proposed measure, is an important starting point for any economic assessment of expected accident reductions. The valuation of the reduction of accidents can be divided into three components; direct economic costs, indirect economic costs, and a value of safety per se:

- The direct cost is observable as expenditure today or in the future. The cost consists of medical and rehabilitation costs, police costs, court costs, private crash investigations, and insurance costs, and in addition, the cost of emergency services and property damage should be included.
- The indirect cost of accidents consists of the value to society of goods and services that the person could have produced if the accident had not occurred.
- The money measure in VSL (value of statistical life) studies covers all aspects of health change born by the individual, i.e., any changes in expected utility due to changes in labour income and purchases of health services. Today's standard method to avoid double counting is to subtract the deceased person's consumption from the gross lost production and express it as net lost production.

2 Theoretical introduction to the value of statistical life

2.1 Mortality

The standard theoretical model is based on a single-period expected utility framework where the individual maximises the expected utility (EU) (Eq. (1)):

$$\mathrm{EU} = pu(w) - (1-p)v(w). \tag{1}$$

The probability of surviving the period is p, $u(w)$ is the utility of wealth w if the person survives, and $v(w)$ is the utility if he or she dies. The model is further based on the assumption that it is better to be alive than dead ($u \times v$), the marginal utility to be alive is larger than the marginal utility to be dead ($u' \times v'$), and both are non-negative and decreasing ($u'' \# 0$, $v'' \# 0$). The willingness-to-pay (WTP) for an increased survival probability (Δp) compared with the baseline risk (e.g., a risk reduction) may be introduced as the CV in the expected utility (Eq. (2)):

$$V = (p+\Delta p)u(w-\mathrm{CV}) + (1-(p+\Delta p))v(w-\mathrm{CV}). \tag{2}$$

If we reduce the wealth with CV and at the same time increase the survival probability with Δp, the expected wealth (V) will be constant. VSL measures the WTP for an infinitive slight risk reduction or the marginal rate of substitution (MRS) between wealth and survival probability (Eq. (3)):

$$\mathrm{VSL} = \frac{-dw}{d\Delta p} = \frac{u(w)-v(w)}{pu'(w)+(1-p)v'(w)} = \frac{\Delta u(w)}{Eu'(w)}. \tag{3}$$

The VSL can be interpreted as the utility difference between survival and death (numerator) divided by the expected marginal utility-cost of funds (denominator). VSL is strictly positive as both the nominator and denominator are positive. Some other characteristics of VSL are the following:

- VSL will increase with income.
- VSL is generally not constant and depends on income and the baseline risk. For small risk reductions, we expect WTP to be near-proportional to Δp.
- VSL will increase with baseline death risk (or reduced survival probability p). This is sometimes called the 'death anyway' effect.
- VSL will decrease with increasing competing mortality risks.
- Risk aversion has an ambiguous effect on VSL. (If the term risk-averse is understood as an indication of the importance a person places on risk-reducing measures, there is a positive correlation between risk aversion in this meaning and VSL).
- The theory does not say anything about context and VSL. VSL can vary by a factor of more than three for different contexts (transport mode, health and traffic risk) depending on control, voluntariness, responsibility and fear etc.

2.2 Age dependency and value of life years lost

Information on how VSL varies with age is of great interest to decision-makers designing risk policies in different contexts. To address that issue, a multi-period model is necessary where the individual derives utility from consumption over future years and faces a survival probability each year in the future. (Krizsik et al., 2023)

The utility is derived from consumption c at each time interval t discounted with the (age-independent) discount rate r. The probability for a person of age t to survive until period t is expressed by a conditional survival function m. A key to understanding the marginal rate of substitution (MRS) between wealth and risk reduction over age is to understand the consumption path.

The individual is assumed to choose the consumption path to optimise welfare concerning a dynamic budget constraint (without insurance). VSL may increase, be constant or decrease depending on the age pattern of optimal consumption. Even if the state-of-the-art regarding age dependency is inconclusive, assuming that each year of life has the same value has been appealing. The value of life years lost (VOLY) or the value of a statistical life year (VSLY) is the hypothetical measure of this. VSL needs to decrease with age to estimate a constant VOLY, but it is not evident that such a decreasing value should exist, and it is more appropriate to estimate a VSL for the specific age group in focus.

2.3 Altruism

The individual concerned may have relatives or friends outside the close family who care about their risk exposure and are therefore willing to pay for risk reduction. Theoretically, we need to add a second (or more) person's expected utility to the basic standard model. This added person may have concern over the affected individual in two different ways:

- Purely altruistic: The friend would care about the affected individual's full utility and respect that person's choice between different attributes. In this case, the estimate reflecting the value judgement of relatives and friends should not be considered for public investments. A pure altruist would care about the security of others and the welfare loss associated with the cost of paying for greater security.
- Safety-paternalistic: The friend only cares about the safety attribute in the affected person's utility. In this case, relatives and friends would like to restrict the individual's choice and impose a more robust safety standard on his behavior. This value is then relevant for inclusion in a CBA.

Individuals are often less willing to pay for a public risk reduction than a private one. Possible reasons for the result can be mistrust of public administrations or a positive value on the option to buy later with a private good.

2.4 Morbidity

Morbidity is far from a single defined state, and the standard classification from road traffic accidents, severe and slight injury, is often not detailed enough. An index such as Injury Severity Score (ISS) or EQ–5D may be used.

A quality-adjusted life year (QALY) is used to compile the level of health with longevity. The health utility of that health condition weights the time spent in a health condition. One year in perfect health is needed to produce one QALY, while one year in health with a value of 0.5 equals half a QALY. This can be used in cost-effectiveness studies where interventions with different costs can be compared. However, it is questioned if QALY is consistent with economic welfare theory. Alternatively, Cost of Illness (COI) approaches similar to the human capital approach have been used, which measure the direct and indirect cost of morbidity in terms of medical costs and lost income. However, COI does not cover the non-monetary cost of illness, such as pain and suffering. A more direct approach is to define a specific injury and examine the WTP for its elimination, similar to VSL.

2.5 Empirical accident valuation

The rate at which people are willing to substitute money for mortality risk (or morbidity risk) can be estimated using revealed or stated preference methods. Traffic safety is not directly traded on the market.

The starting point in the revealed preference approach is the insight that goods (or services) can be seen as composite goods with many different characteristics. Utility is derived from the characteristics of the goods and not from the goods themselves. The most frequently revealed preference studies for safety characteristics are wage-risk studies which estimate the wage premium associated with the fatality risk at work. Revealed-preference methods are usually considered more reliable than stated preference methods as it is assumed that people's choices about real risks are based on better information and are more carefully made than their responses to survey questions about hypothetical risks.

However, revealed-preference estimates can only be obtained in settings where the alternatives that an individual considers can be identified, and the differences in risk, cost, and other essential dimensions can be estimated. It is not evident that we can transfer studies from the labour market to the transport sector; the target population may include different types of people, and wage-risk studies are based on the preferences of people who accept high-risk jobs.

People are asked for their WTP for a hypothetical risk reduction (contingent valuation method-CVM) in stated-preference methods. The questionnaire could be open-ended or in a discrete choice format. Stated preference techniques lead to higher estimates than revealed preference techniques. Two problems need to be highlighted when examining stated-preference studies, the first is hypothetical bias, and the second is what we call here scale and scope bias. Most stated-preference studies are generally plagued by hypothetical bias, leading to an exaggeration of WTP. Cheap-talk calibration is one approach where the respondent is informed about the hypothetical bias problem and is asked to consider this in their response carefully. Certainty calibration is another approach where the respondent is asked to state the certainty of their response for example, on a scale from 1 to 10. The scale bias refers to the tendency of the respondents to report the same WTP irrespective of the size of the risk reduction.

3 McMahon-Dahdah methodology

McMahon and Dahdah's (2008) research provides a practical, actionable answer for any country at any stage of its economic development. The iRAP (International Road Assessment Programme, UK) is using the recommended approach outlined in this paper in its work worldwide to create targeted programmes with high return on investment safety counter-measures where the most lives can be saved for the money available.

Two main methods are used to assess the benefits of preventing road fatalities: the human capital (lost output) method and the willingness-to-pay method. The willingness-to-pay approach is conceptually attractive but has practical problems, as the methodological approach required to produce the estimates is costly and requires sophisticated estimation techniques.

Therefore, an alternative approach was explored, based on the data available in different countries and the results of studies on willingness-to-pay and human capital, to investigate the practical feasibility of deriving a relatively simple "rule of thumb".

It is based on the hypothesis that a country's income level is the primary determinant of the value of statistical life. This is true for values based on the human capital approach and WTP values since willingness to pay is influenced by the ability to pay. Data were collected for a set of developed and developing countries, and the ratio of the value of statistical life (VSL) to GDP per capita was calculated.

The advantage of the rule of thumb approach is that it ensures consistency across countries and avoids biases arising from surveys of unknown reliability. Its disadvantage is that it has to rely on evidence from a limited number of countries for which reasonably reliable estimates of the value of statistical life are available.

Values based on willingness to pay are preferable to values based on human capital, but only a few countries currently use such values. If estimates use WTP or include human costs, the VSL to GDP per capita ratio will likely be in a relatively narrow range of 60 to 80. (McMahon and Dahdah, 2008) have suggested that a reasonable rule of thumb for the default values of the economic valuation model is 70 as the central ratio value and a range of 60 to 80 for sensitivity analysis. This approach gives value to the benefits of reducing fatalities that reflect each country's income level. However, since the estimates are based primarily on data from developed countries, the values may also reflect the higher level of demand for safety in these countries.

As for the valuation of a fatality, it is not practicable to attempt to provide empirical estimates for the countries. Such estimates would require good information on range of injuries in the severe category, medical costs and lost output, and a reliable willingness-to-pay estimate of human costs. None of these are likely to be available.

Comparing serious injury values used in different countries is more complex than comparing mortality values. What constitutes a serious injury varies considerably even between developed countries.

Some countries consider an injury serious if the victim requires hospitalisation, while others use a more comprehensive definition. Injury data are often less reliable than mortality data and more prone to under-reporting, especially for less serious injuries. This can skew data towards the more extreme end of the injury spectrum in countries with poor data collection methods. The distribution of travel modes also influences the severity distribution in a country, so countries with more pedestrians, cyclists and motorcyclists tend to have a distribution of injuries weighted towards more severe injuries.

Taking all this into account, and in the absence of a reliable injury accident data system and valuation of different injury types in each country, a reasonable value for serious injuries in the economic valuation model is recommended to be in the range of 25% of the value of fatalities, and in the range of 20–30% for sensitivity testing.

The corresponding values for the GDP per capita multiplier are the central value of 17 as the GDP per capita multiplier, with a range of 12 to 24 for the sensitivity analysis.

It should be stressed that this recommendation is based on the judgement from the limited data available and is, therefore, less reliable than the recommendation for the assessment of deaths. Nevertheless, this recommendation provides a consistent basis for assessment across countries.

The default ratio of serious injuries to fatalities is recommended to 10, and this ratio varies between 8 and 12 in the sensitivity analysis. Table 1 shows the prevention values for fatalities and severe injuries as percentages of GDP per capita recommended for use as default values and for sensitivity analysis for the Economic Appraisal of the counter-measures generated from the iRAP inspections. It also shows the value of severe injury and the ratio of serious injuries to fatalities to be used. (McMahon and Dahdah, 2008)

Table 1 iRAP economic appraisal model values

	Lower	Central	Upper
Value of fatality	60 × GDP/ Capita	70 × GDP/ Capita	80 × GDP/ Capita
Value of serious injury	12 × GDP/ Capita (20% VSL)	17 × GDP/ Capita (25% VSL)	24 × GDP/ Capita (30% VSL)
Ratio of severe injuries to several fatalities	8	10	12

4 Value in practice

The OECD has recently proposed a procedure to facilitate a transfer of VSL estimates from existing studies in environmental, health and transport policy based on a meta-analysis. The steps in the procedure to find a value are:

1. identify and describe the change in mortality risk to be valued;
2. identify the affected population in your policy question;
3. conduct a literature review to identify relevant primary studies;
4. assess the relevance and quality of the primary study;
5. summarise the data available from the study;
6. transfer value estimate from study to policy context.

The OECD suggest estimating VSL for individual countries within the OECD (policy) with a transfer of VSL from a study with similar population characteristics and an income adjustment based on GDP per capita (Y) and an income elasticity of 0.8 (0.7–0.9).

There is a big difference in official values in practice between the US and Europe. The former are often based on labour market studies, while the latter relies on SP studies. The OECD has recently recommended a base VSL value for OECD countries of $3.4 million (1.5–5.1 million) and $4.0 million (2.0–6. million) for EU–27.

4.1 Value of statistical life in the EU Members

The total cost of road accidents in Europe is estimated at €280 billion (Schoeters et al., 2022). This is equivalent to nearly 2% of the EU GDP. However, this is still likely to underestimate the total cost of traffic accidents, as many countries do not correct for under-reporting. It is estimated that if unreported accidents and casualties are considered, the total cost is at least 3% of GDP (Wijnen et al., 2019).

Accident cost estimates show that the share of injuries in the total cost is, on average, 2.4 times higher than the share of fatalities. However, these results vary significantly between countries and can be explained by differences in the definition of serious injury and reporting rates. The total cost of road accidents as a percentage of GDP varies widely, ranging from 0.4% to 4.1% (Fig. 1).

Better road safety performance should lead, ceteris paribus, to lower road accident costs. However, road safety performance does not explain the overall variation. We find only a weak positive relationship between fatality rates and costs as a percentage of GDP (statistically significant at the 10% confidence level).

Differences in the methodology used to calculate total costs may explain the variations. In addition to the differences in the methods used to estimate the cost per accident, this relates, in particular to the extent to which all severity levels are included in the total cost and the extent to which corrections for under-reporting have been made. Regarding severity levels, all countries include fatal, serious and slight injuries in the total cost estimate, but accidents causing property damage only (PDO accidents) are not included in 44% of countries. (Wijnen et al., 2019)

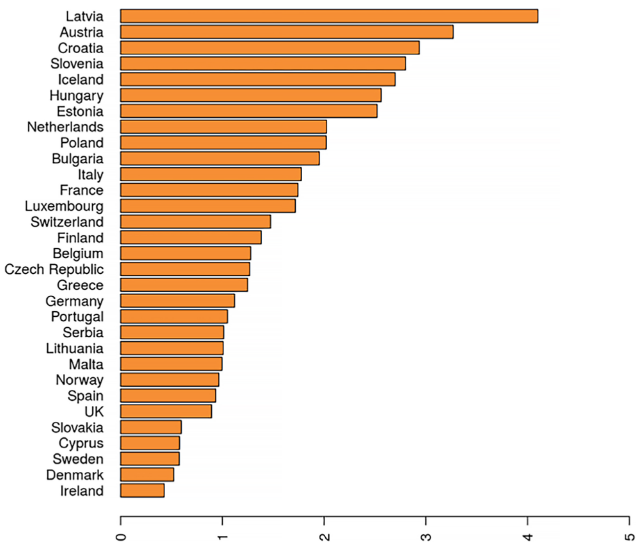

Fig. 1 Total costs of road crashes as percentage of GDP (Wijnen et al., © 2017)

4.2 Value of statistical life in Hungary

It was last produced in Hungary by the KTI in the 2010s with the involvement of TÁRKI, in which 1.000 people were interviewed using the WTP method, but also the reduction in production capacity was quantified using the human capital method. In a paper reporting the results (Holló et al., 2013), the authors were the first in Hungary to test the (McMahon-Dahdah, 2008) simplified procedure and, among other things, that the result obtained is of a magnitude of the barely and costly method, which has been used for many years i.e., the detailed survey.

According to (Holló and Sipos, 2020), it is better to use a simple, approximate method rather than a lengthy process that is expensive and requires a considerable amount of work and a reliable subcontractor. Its undoubted flaw is that it does not estimate light casualties.

Table 2 shows the estimates of the value of fatalities and serious injuries based on the (McMahon-Dahdah, 2008) methodology. While the value of fatalities was 200 million Ft/fatality in 2011, in 2021, it will almost reach 400 million Ft/fatality. A similar rate of increase also applied to the seriously injured: 45 million Ft/injured in 2010, but it has more than doubled, to 96 million Ft/injured in 2021. Wijnen et al., 2017.

Table 2 The VSL and number of personal injury crashes in Hungary

Year	Value of fatalities [Ft/fatality]	Value of serious injured [Ft/injured]	Number of fatal crashes	Number of seriously injured crashes	Total crashes
2010	185 590 797 Ft	45 072 051 Ft	649	4 941	16 308
2011	200 415 248 Ft	48 672 275 Ft	563	4 527	15 827
2012	204 674 302 Ft	49 706 616 Ft	541	4 355	15 174
2013	214 835 904 Ft	52 174 434 Ft	540	4 687	15 691
2014	232 815 278 Ft	56 540 853 Ft	573	4 713	15 847
2015	248 731 580 Ft	60 406 241 Ft	585	4 913	16 331
2016	258 302 291 Ft	62 730 556 Ft	565	4 910	16 627
2017	280 926 087 Ft	68 224 907 Ft	575	4 897	16 489
2018	310 720 744 Ft	75 460 752 Ft	567	4 896	16 951
2019	340 507 081 Ft	82 694 577 Ft	530	4 834	16 627
2020	346 594 233 Ft	84 172 885 Ft	423	4 105	13 778
2021	398 353 263 Ft	96 742 935 Ft	467	4 005	14 233

5 Conclusion

The monetary valuation of accidents, mortality, and morbidity has a long history. VSL is the dominant part of accident valuation, but direct and indirect economic costs should also be considered. VSL has a firm theoretical base in economic theory but is much more challenging to estimate empirically.

Both revealed, and stated preference techniques are used. Reducing fatalities and a policy shift into planning for non-car users will increase the need for values for reduced morbidity. In the future, the standard classification of road accidents must probably be more specific.

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