# Monetary Evaluation and Comparison of Safety Improvements: The Case of Light Good Vehicles in Europe

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## Abstract

This paper focuses on the monetary evaluation and comparison of various safety measures for improving traffic safety for light goods vehicles (LGVs) in the EU-25 countries. In the last years, both the number of LGVs and their participation in accidents significantly increased. The improvements evaluated include the installation of active speed limiters with two different set speeds, electronic stability program (ESP) systems, digital tachographs, event data recorders (EDR), seat belt reminder and seat-belt lock systems, and implementation of a professional driver training program. The monetary evaluation of the various safety measures has been done using cost benefit analysis (CBA). The CBA has been carried out by means of B/C ratios and includes a sensitivity analysis, as well as a computation of the cost per life saved and the payback period. Our results indicate that speed limiter set a the lower speed, a professional driver training program and devices to increase seatbelt wearing are economically justified and should serve as the core of safety improvements for LGVs. These results remain robust even if large changes occur in the unit costs or in the safety effects of these measures.

## Introduction

Light good vehicles (LGV) are defined as commercial vehicles used for the carriage of goods with a maximum weight between 1 and 3.5 tons. The presence of these vehicles in European vehicle stocks is steadily increasing. The total stock of LGVs in the EU-25 states has increased by 36% between 1995 and 2002. This compares to an increase of only 20% in the overall vehicle stock during the same period. In 2002 they comprise about 10% of the vehicle stock in the EU-25 (CARE 2005). The participation of LGVs in crashes in the same period has also increased. Increases of 16% and 10% were recorded in the number of LGV injury crashes and fatal crashes, respectively. The problem is prominent on motorways, in which the increases in LGV injury and fatal crashes were 51% and 32%, respectively. This is compared with an overall decrease of 1.5% in crashes for the entire vehicle stock.

This paper focuses on the monetary evaluation and comparison of various safety measures that may contribute to the improvement of traffic safety for LGVs. It is based on a study which was carried out within the framework of the IMPROVER project coordinated by the German Road research Institute (BASt) and described in detail in Hoehnscheid et al. (2006). The safety measures that were considered are mostly technology-based systems that are installed in the vehicle. Six safety measures have been analyzed by means of cost benefit analysis (CBA). These measures include the installation of active speed limiters, electronic stability program (ESP) systems, digital tachographs, event data recorders (EDR), seat-belt reminder and seat belt lock systems, and implementation of a professional driver training program.

The selection of these specific measures was made taking into consideration the unique characteristics of LGVs. For example, the mass centre of gravity of LGVs is higher than that of passenger cars and so ESP might be especially useful; Seat belt wearing rates in LGVs are lower than in passenger cars and so seat belt reminder and seat belt lock systems might be functional; LGVs are generally capable of traveling at relatively high speeds, and so speed limiters may be valuable. Since the problem of LGV crashes is foremost on motorways, two limiter set speeds have been analyzed: 100 km/hr and 120 km/hr.

The monetary evaluation of each safety measures has been done using CBA, a widespread assessment method that provides insight in investments and returns from the general economic point of view. Costs and benefits to society of equipping the LGV fleet with each measure were taken into consideration. The CBA results (especially benefit-cost ratios) are generally accepted criteria in economic welfare decision-making. In addition, a sensitivity analysis has been carried out and the costs per life saved, as well as the payback periods have been computed for each safety measure. Speed limiters differ from the other measures studied since their installation in some vehicles may affect the travel speeds of other non-equipped vehicles and through that their risk of involvement on crashes. Therefore, the evaluation of this measure used a microscopic traffic simulation model, which models traffic through a detailed representation of the behavior of each vehicle in the traffic stream and captures the interactions among the various vehicles (for details see Toledo et al., 2007).

The rest of this paper is organized as follows: In the next section the safety measures are described in detail. Next, the CBA approach and assumptions are presented, followed by the results: benefit-cost (B/C) ratios, sensitivity analysis, costs per life saved, payback periods and a comparison of economically justified measures. Finally analysis and results are discussed.

## Safety Measures

The analysis focuses on six safety measures which may potentially contribute to improved safety of LGV vehicles. These safety measures are:

1. Speed limiters, which control the maximum speeds of equipped vehicles, have been proposed in recent years as efficient and powerful tools of speed management. Speed limiters designs differ in the way they operate and the technologies they use. This study focuses on active pre-set speed limiters. These systems use a fixed limiter set speed and directly control the speed by applying counter force on the gas pedal or through the engine fuel injection system. Two limiter set speeds have been analyzed: 100 km/hr and 120 km/hr. Several European countries currently consider new legislation that would mandate installation of active speed limiters in various types of vehicles, especially commercial ones (VOSA, 2005). Excessive and inappropriate speed is a critical road safety problem in

European countries (ETSC, 2007). The robust relation between speed and crash risk is well recognized (see for example reviews in Kloeden et al., 1997; Stuster et al., 1998). Most studies in this area relate safety to the mean speed (e.g. Salusjärvi, 1981; Finch et al. 1994; Kallberg and Toivanen, 1998 and the references there). A typical value often cited in the literature is that a decrease of 1 km/hr in the mean speed causes a reduction of 2%-3.5% in injury crashes and 5-6% in severe injuries and deaths (Baruya, 1998; ICF, 2003). A simulation based evaluation (Toledo et al., 2007), which captures the effect of active speed limiters on all vehicles in the traffic stream and not only equipped vehicles, showed that, depending on traffic conditions and parameters of the speed limiter, reductions of up to 10% in the mean speed can be reached in motorways when 10% of vehicles are equipped with speed limiters. Consequently, a significant desired reduction in the crash rate may be reached**.** CBA which has been carried out taking into account crashes, fuel consumption, travel times and emissions showed B/C ratios between 3.5 and 16 depending on system specification for systems with variable speed limit settings (Mäkinen and Várhelyi, 2001; University of Leeds, 2000).

2. Electronic Stability Program (ESP) systems, which use several sensors that detect wheel speed, steering angle, sideways motion and spin to control and apply braking power to the front or rear axles and so help keep the vehicle on its intended path. ESP is becoming increasingly popular in the past few years. ESP is especially helpful in providing an extra measure of control in slippery conditions and crash-avoidance situations. With tall, top-heavy vehicles, such as sport utility vehicles (SUV) and pickups, it may be in particular useful in keeping the vehicle from getting into roll over situations. Sferco et al. (2001) estimated that 40% of LGV crashes are ESP-sensitive. The US Department of Transportation reported a reduction of 35% of single vehicle crashes in all vehicles with ESP and 67% with SUV crashes (Dang, 2005). Gwehenberger et al. (2004) estimated B/C ratios between 2.6 and 4.4 for ESP systems.

3. Digital tachographs, which record driving and rest times for drivers, vehicle speed, distance traveled and other parameters. The system requires a personalized driver smartcard, which stores the driver's activities over a period of 28 days. Digital tachographs are gradually replacing analogue tachographs. Digital tachographs aim to prevent fatigue and sleep-related crashes. The UK Department for Transport estimated that 16% of all crashes are sleep-related; fatigue is a partial cause in 10% to 15% of all severe crashes (UK DfT 2001, 2002, Schagen, 2003).

4. Event Data Recorders (EDR), which record information on various vehicle parameters for a short time period before, during and after crash events and stores the information in the unit. This information is later used to investigate and analyze the circumstances leading to the crash. EDRs are widely installed and used by vehicle manufactures, insurance companies, law enforcement agencies and researchers. Langeveld et al. (2004) estimate a B/C ratio of 3.2 for EDRs, under the assumption of 40% equipment rate and 20% crash-avoidance efficiency.

5. Seat belt reminder and lock systems, which are intended to increase seat belt usage by issuing reminders to non-wearing passengers in front seats. The standard device gives a sound warning whenever a seat is occupied, but the seat belt is not fastened. It is assumed that these systems can increase seat belt usage rates in LGVs to the levels of passenger cars, which is around 90% of drivers and front seat passengers in most EU-25 states (Broughton, 2003; Cedersund, 2002). The approach commonly used to analyze the impact of these devices in the literature is to compare fractions of killed and injured car occupants

and drivers for seat-belt wearing and non-wearing persons involved in car crashes (Nilsson, 2005).

6. Implementation of professional driver training courses. In evaluating this measure it is assumed that one driver needs to be trained for each LGV. However, the actual number of drivers may be larger, since young and new drivers are licensed over time and re-training is required in order the keep drivers well-trained. Therefore, costs are involved along the project lifetime. Elvik and Vaa (2004) report results of only a single relevant study that found 20% reduction in the crash rate.

## Approach and Assumptions

CBA is well established for evaluating whether a design alternative is economically justified and for comparison of mutually exclusive designs. The CBA results, primarily the B/C ratios, are generally accepted criteria in economic welfare decision-making.

The cost of each safety measure has to be compared with the possible social benefit. The benefit is the value of avoiding a (statistical) fatality or casualty on motorways, as a result of equipping the LGV fleet with the safety measure. Benefits were estimated based on the application of the official UK and German national crash costs and were weighted by the Gross Domestic Product (GDP) of each EU-25 country. The resulting B/C ratios were then calculated, as the adjusted present worth (PW) of benefits divided by the PW of costs. B/C ratio greater than 1 indicates that a safety measure is economically justified.

The CBA in our analysis is based on a fixed 20 year period. An annual interest rate of 3% is assumed. Since the data for each EU-25 country were weighted by the GDP (using the UK or German crash cost figures as a base) meaningful overall comparison over countries is feasible. An annual penetration rate of 10% is assumed, thus full penetration and full benefits are reached after 10 years; however, the price per unit, as well as the annual interest rate, remain constant during the lifetime.

### *Potential crash reduction rates and costs*

The potential crash reduction rates refer to a current situation in which is assumed that LGVs are not equipped with any of the measures. The potential reductions were assumed based on a literature review of the safety measures. The cost used for each measure is the price of equipping the LGV fleet with a new unit (retrofitting is impossible or extremely expensive in most cases). The cost of each measure is related to the penetration rate.

Table 1 presents a summary of potential crash reduction rates and instrumentation costs for each measure which were used in our analysis.

| Measure | Crash reduction rate | Unit cost (in Euro) | Source |
|---|---|---|---|
| Speed limiters | Up to10% reduction in the average speed, 3% reduction of crashes for 1% speed reduction | 150 | ICF (2003); Toledo et al. (2007); Hoehnscheid et al. (2006) |
| ESP | 25% | 450 | Gwehenberger et al. (2004) |
| Digital tachograph | 16% | 650 | UK DfT (2001, 2002) |
| EDR | 20% | 920 | Langeveld et al. (2004) |
| Seat belt reminder | 16.5% | 75 | Nilsson (2005) |
| Professional driver training | 20% | 159 weekdays<br>189 weekend | Elvik and Vaa (2004) |

**Table 1: Potential crash reduction rates and costs**

### *Assessment of the benefits*

The monetary evaluation of the benefits of the various measures is based on the value of avoiding a fatality or casualty. Benefits for each measure are based on the potential crash reduction rate as discussed above. Datasets for EU-25 countries including fleet statistics and crash and casualty statistics for LGVs were collected from three main sources: the CARE (2005), EUROSTAT (2005) and Association Auxiliaire de l'Automobile (2005) databases. Two cost estimates were used, based on the official national crash cost figures for the UK and for Germany, which differ in the methods used in the valuation (Blaeij et al., 2004). These cost figures are summarized in Table 2.

| Country | Fatality | Severe injury | Valuation method |
|---|---|---|---|
| UK | 2,107 | 237 | Willingness-to-pay |
| Germany | 1,266 | 94 | Damage-cost approach |

**Table 2: UK and German crash costs in 2002 thousands Euro**

The willingness to pay (WTP) method, on which the UK figures are based, is the method adopted by the EU and commonly used in many other countries including the USA. Values obtained from these countries are in line with the UK official safety values. The following discussions and conclusions refer mainly to the UK figures. However, the results based on the German figures are also provided as a lower-bound conservative estimate of the safety benefits of the various measures.

## Results

### *B/C ratios*

The CBA yielded a B/C ratio greater than 1 for EU-25 and for most of the EU-25 member states for the speed limiter set at 100 km/hr, professional driver training program and devices to increase seatbelt wearing. These ratios indicate that these safety measures are economically justified for LGVs. ESP, EDR, digital tachograph, and the speed limiter set at 120 km/hr yielded B/C ratios around a unit or lower, which indicate that these measures are not economically justifiable for LGVs. These overall conclusions are similar for the UK and for German crash cost figures. Figure 1 summarizes the inclusive B/C ratios for the EU-25.

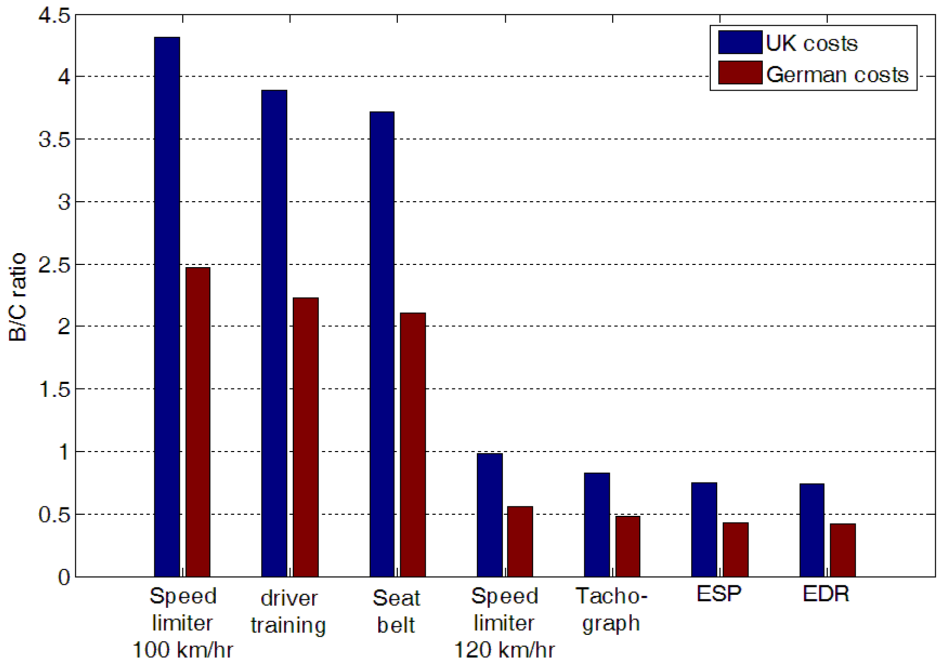


**Figure 1: B/C ratios for various measures in EU-25 based on UK and German crash costs**

The B/C ratios for each of the EU-25 member states, based on the UK and German cost values, are presented in Table 3 and Table 4, respectively.

As can be seen in Tables 3 and 4 the evaluation of a safety measure may vary among countries. For example, the B/C ratio for speed limiter at 100 km/h set speed is greater than 1 in most, but not in all, of the EU-25 countries. The safety benefit associated with this measure depends on factors (e.g. the posted speed limit on motorways) that vary among countries (for detailed evaluation of the impact of speed limiters, see Toledo et al., 2007).

| **State** | Speed | Speed | ESP | Digital | | Seat belt | |
|---|---|---|---|---|---|---|---|

| **State** | Speed limiter (100 km/hr) | Speed limiter (120 km/hr) | ESP | Digital tacho-graph | EDR | Seat belt reminder | Professio-nal driver training |
|---|---|---|---|---|---|---|---|
| Austria | 16.49 | 3.23 | 1.37 | 1.52 | 1.34 | 6.79 | 7.10 |
| Belgium | 9.89 | 0.82 | 1.83 | 2.03 | 1.79 | 9.06 | 9.46 |
| Cyprus | 0.35 | n/a | 0.37 | 0.41 | 0.37 | 1.85 | 1.94 |
| Czech | 6.03 | 1.18 | 1.79 | 1.98 | 1.75 | 8.84 | 9.24 |
| Denmark | 0.66 | 0.33 | 1.15 | 1.27 | 1.12 | 5.69 | 5.94 |
| Estonia | 0.84 | n/a | 0.66 | 0.73 | 0.65 | 3.27 | 3.42 |
| Finland | 0.22 | 0.11 | 0.77 | 0.85 | 0.75 | 3.81 | 3.98 |
| France | 0.13 | 0.01 | 0.02 | 0.03 | 0.02 | 0.12 | 0.12 |
| Germany | 23.73 | 6.52 | 1.09 | 1.21 | 1.07 | 5.42 | 5.66 |
| Greece | 2.25 | 0.19 | 1.40 | 1.55 | 1.37 | 6.93 | 7.24 |
| Hungary | 1.39 | 0.12 | 1.08 | 1.20 | 1.06 | 5.35 | 5.59 |
| Ireland | 0.37 | 0.18 | 1.92 | 2.13 | 1.88 | 9.52 | 9.95 |
| Italy | 7.60 | 1.49 | 0.81 | 0.90 | 0.80 | 4.03 | 4.21 |
| Latvia | 1.74 | 0.87 | 1.28 | 1.42 | 1.25 | 6.32 | 6.61 |
| Lithuania | 6.73 | 0.56 | 2.07 | 2.30 | 2.03 | 10.26 | 10.72 |
| Luxembourg | 19.66 | 3.85 | 3.08 | 3.41 | 3.01 | 15.25 | 15.94 |
| Malta | n/a | n/a | 0.15 | 0.16 | 0.14 | 0.72 | 0.75 |
| Netherlands | 4.01 | 0.33 | 1.25 | 1.39 | 1.22 | 6.19 | 6.47 |
| Poland | 1.40 | 0.28 | 0.69 | 0.76 | 0.67 | 3.41 | 3.56 |
| Portugal | 1.16 | 0.10 | 0.83 | 0.92 | 0.81 | 4.12 | 4.31 |
| Slovakia | 2.09 | 0.41 | 1.07 | 1.18 | 1.04 | 5.27 | 5.51 |
| Slovenia | 10.14 | 1.99 | 1.75 | 1.94 | 1.72 | 8.68 | 9.07 |
| Spain | 1.25 | 0.10 | 0.84 | 0.93 | 0.82 | 4.15 | 4.34 |
| Sweden | 1.04 | 0.52 | 0.72 | 0.80 | 0.71 | 3.58 | 3.74 |
| UK | 0.57 | 0.29 | 0.82 | 0.91 | 0.81 | 4.08 | 4.27 |
| **EU25** | **4.31** | **0.98** | **0.75** | **0.83** | **0.74** | **3.72** | **3.89** |

**Table 3: B/C ratios for EU states based on UK crash costs**

| | limiter (100 km/hr) | limiter (120 km/hr) | | tacho-graph | EDR | reminder | Professio-nal driver training |
|---|---|---|---|---|---|---|---|
| Austria | 9.45 | 1.85 | 0.79 | 0.87 | 0.77 | 3.90 | 4.07 |
| Belgium | 5.67 | 0.47 | 1.04 | 1.16 | 1.03 | 5.13 | 5.42 |
| Cyprus | 0.20 | n/a | 0.21 | 0.24 | 0.21 | 1.06 | 1.11 |
| Czech | 3.45 | 0.68 | 1.02 | 1.13 | 1.00 | 5.05 | 5.29 |
| Denmark | 0.38 | 0.19 | 0.65 | 0.73 | 0.64 | 3.21 | 3.40 |
| Estonia | 0.48 | n/a | 0.38 | 0.42 | 0.37 | 1.87 | 1.96 |
| Finland | 0.13 | 0.06 | 0.45 | 0.49 | 0.43 | 2.21 | 2.28 |
| France | 0.07 | 0.01 | 0.01 | 0.02 | 0.01 | 0.07 | 0.07 |
| Germany | 13.60 | 3.74 | 0.58 | 0.69 | 0.61 | 2.88 | 3.24 |
| Greece | 1.29 | 0.11 | 0.87 | 0.89 | 0.78 | 4.29 | 4.15 |
| Hungary | 0.79 | 0.07 | 0.62 | 0.69 | 0.61 | 3.06 | 3.20 |
| Ireland | 0.21 | 0.11 | 1.16 | 1.22 | 1.08 | 5.76 | 5.70 |
| Italy | 4.35 | 0.85 | 0.47 | 0.52 | 0.46 | 2.30 | 2.41 |
| Latvia | 1.00 | 0.50 | 0.73 | 0.81 | 0.72 | 3.61 | 3.79 |
| Lithuania | 3.86 | 0.32 | 1.19 | 1.32 | 1.16 | 5.87 | 6.14 |
| Luxembourg | 11.26 | 2.21 | 1.78 | 1.96 | 1.73 | 8.79 | 9.13 |
| Malta | n/a | n/a | 0.08 | 0.09 | 0.08 | 0.42 | 0.43 |
| Netherlands | 2.30 | 0.19 | 0.66 | 0.79 | 0.70 | 3.26 | 3.71 |
| Poland | 0.80 | 0.16 | 0.39 | 0.44 | 0.39 | 1.95 | 2.04 |
| Portugal | 0.66 | 0.06 | 0.50 | 0.53 | 0.47 | 2.47 | 2.47 |
| Slovakia | 1.20 | 0.23 | 0.61 | 0.68 | 0.60 | 3.02 | 3.16 |
| Slovenia | 5.81 | 1.14 | 1.00 | 1.11 | 0.98 | 4.96 | 5.20 |
| Spain | 0.72 | 0.06 | 0.49 | 0.53 | 0.47 | 2.43 | 2.49 |
| Sweden | 0.60 | 0.30 | 0.39 | 0.46 | 0.41 | 1.94 | 2.14 |
| UK | 0.33 | 0.16 | 0.45 | 0.52 | 0.46 | 2.24 | 2.44 |
| **EU25** | **2.47** | **0.56** | **0.43** | **0.48** | **0.42** | **2.11** | **2.23** |

**Table 4: B/C ratios for EU states based on German crash costs**

### *Sensitivity Analysis*

All CBA results are highly sensitive to the assumptions that are used in the analysis; e.g., the crash reduction rates, crash costs, and the unit costs of the safety measures.
We conducted a sensitivity analysis with respect to the two main source of uncertainty in our analysis: the crash reduction rate and the unit cost of equipping an LGV with each safety measure. A sensitivity analysis has been carried out also for the cost of a crash.

### Crash reduction rates and unit costs

With regard to the crash reduction rates, the literature in some of the cases provides insufficient data or a wide range of values. For example, the crash reduction estimate for the professional driver training measure is based on the result of a single study reported by Elvik and Vaa (2004). The unit cost of the various safety measures are likely to decrease as they become more common due to diminishing development expenses.

The sensitivity analysis has been carried out based on both the UK and German crash costs. The B/C ratio is positively related to the crash reduction rate and negatively related to measure unit cost. Figure 2 and Figure 3 present sensitivity analyses for the various safety measures for LGVs based on the UK and German crash costs, respectively. For the measures that are not economically justified (ESP, EDR and digital tachograph; speed limiter set at 120km/hr is not justified based on the German costs and borderline with the UK costs) moderate changes in the crash reduction rate (an increase of up to 20%) or in the unit cost (a decrease of about 20%) can lead to break-even B/C ratios based on the UK costs. Based on the German crash costs, only large decreases (about 50-60%) in the unit cost would lead to break-even B/C ratios. The results of the sensitivity analysis of the three safety measures that are economically justified (Speed limiter at 100 km/hr, seat belt reminder and driver training) are robust; that is, they are justified even if the unit costs are markedly higher than estimated. A large reduction in the crash reduction rates, of about 40-60%, will cause the B/C ratios for these measures to break-even. For example, with the professional driver training measure for which our assumption of 20% crash reduction was based on the results of a single study, the analysis shows that keeping other assumptions constant, 5% and 9% crash reduction rates would yield break-even B/C ratios for the UK and German costs, respectively. As can be seen in Figures 2 and 3 the shape of the curves illustrating the economically justified measures is similar; the shape of the curves illustrating the non-economically justified measures is similar; that indicate the difference in effectiveness between them.

### Value of fatality

Different evaluation methods (e.g., Willingness-to-pay which is used in UK, Damage-cost approach which is used in Germany) result in a large domain of the value of fatality, which is the main element in crash cost figures. As shown in Table 2, UK uses a value of 2,107 thousands Euro and Germany uses a value of 1,266 thousands Euro. Portugal, for example, uses a value of 320 thousands Euro (all values are for the year 2002). The lack of consensus on a specific value is discussed in the literature (see for example, Blaeij et al., 2004; the HEATCO project (Odgaard et al., 2005)). Figure 4 presents the impact of the value of fatality on the B/C ratios for each safety measure.

As shown in Figure 4 the B/C ratio is positively related to the value of fatality. The measures that were found to be not economically justified (ESP, EDR and digital tachograph; speed limiter set at 120km/hr) yield B/C ratios around 1 only if a relatively high value of fatality (approximately 2,500 thousands Euro) is used. The measures that were found to be economically justified (seat belt reminders, training and speed limiter set at 100km/hr) yield B/C ratios around 1 also if a relatively low value of fatality (approximately 500 thousands Euro) is used.

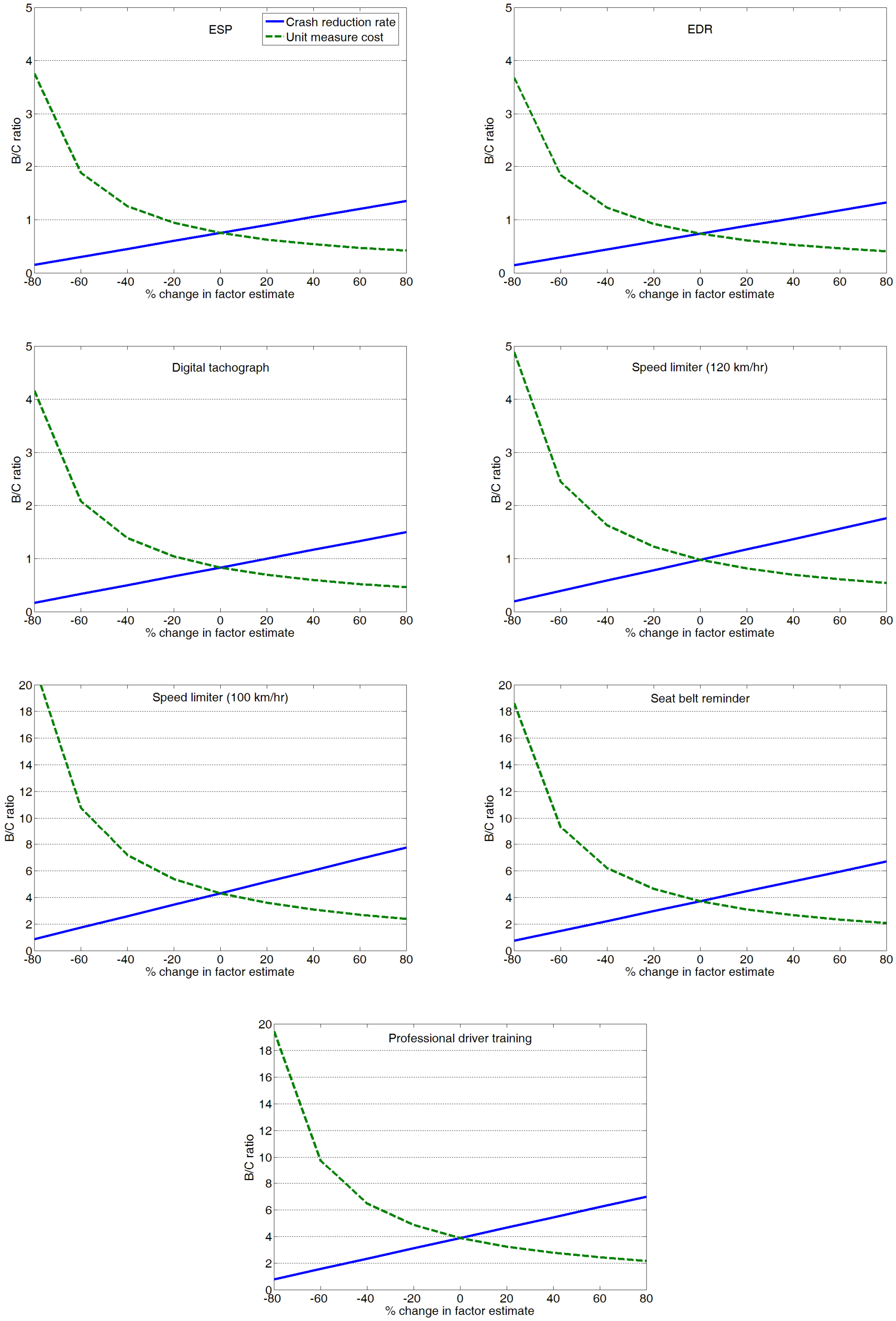


**Figure 2: Sensitivity of B/C ratios to the crash reduction rate and measure unit cost based on UK crash costs**

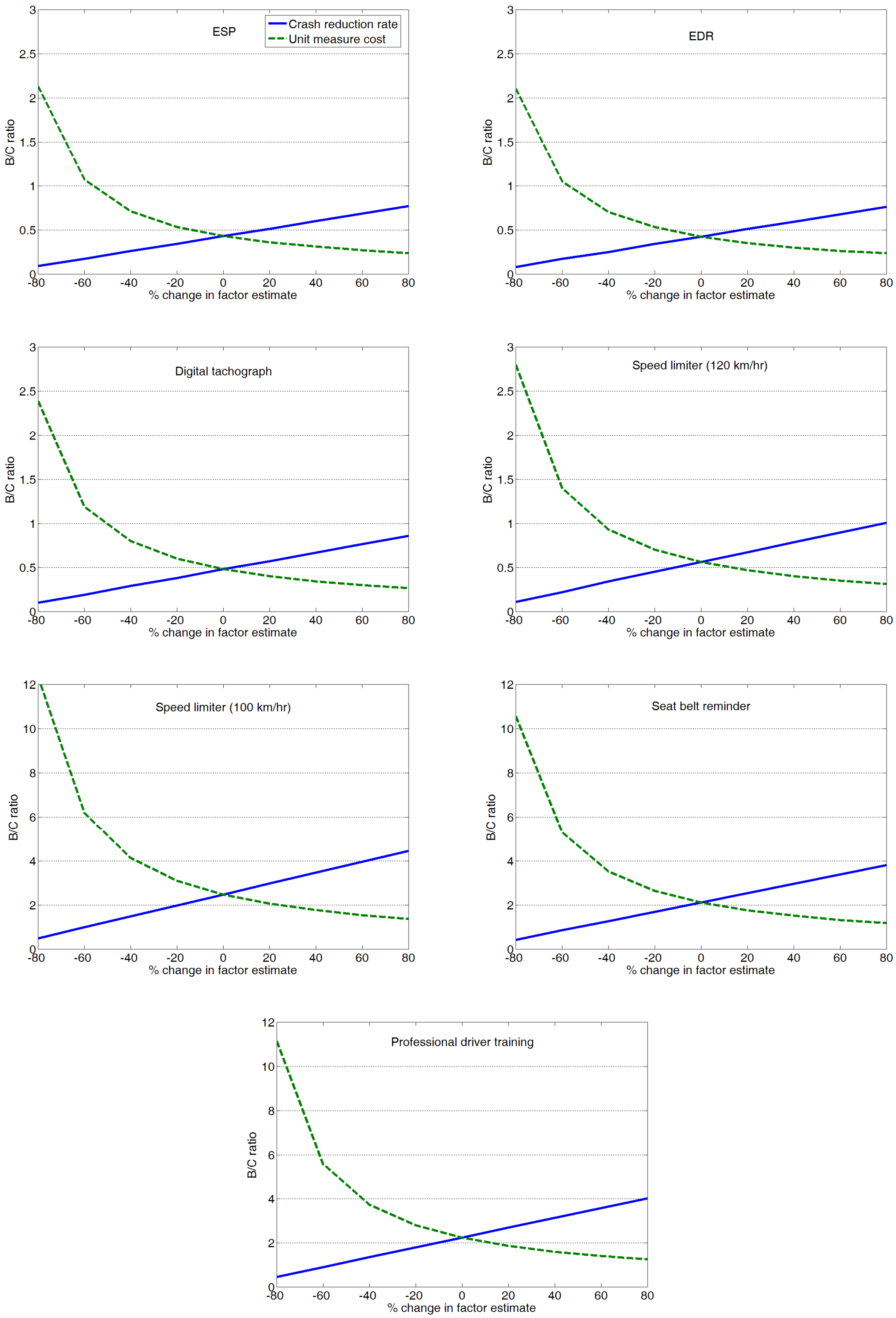


**Figure 3: Sensitivity of B/C ratios to the crash reduction rate and measure unit cost based on German crash costs**

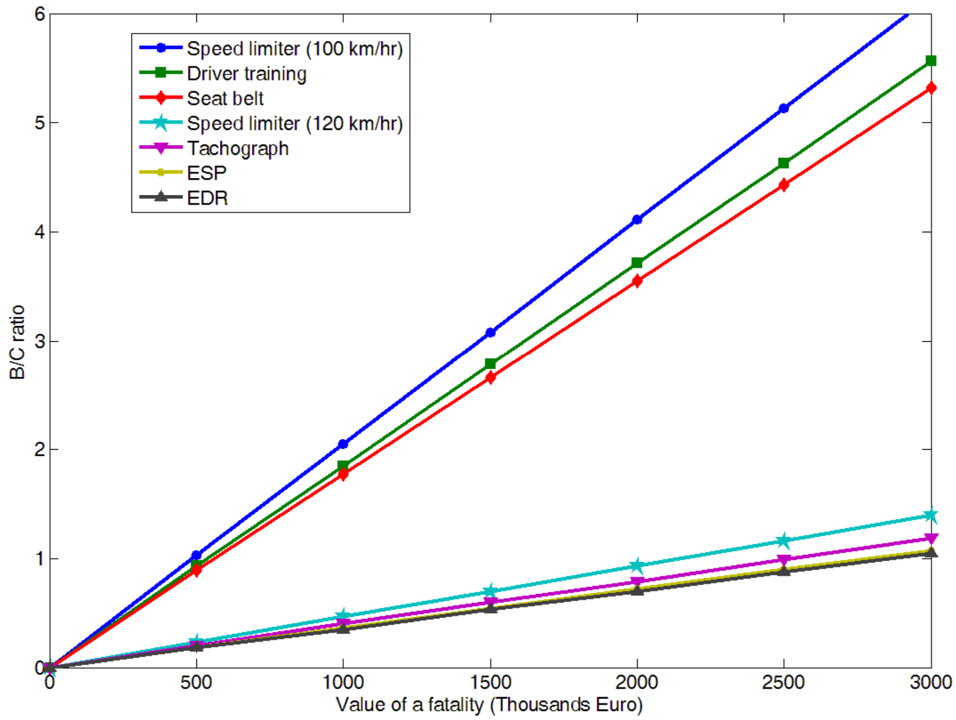


**Figure 4: The impact of the value of fatality on B/C ratios**

### *Cost per Life Saved*

The value of cost per life saved for each safety measure can be derived from the CBA. Low value indicates that the measure is cost effective, i.e., a statistical life can be saved at a low cost. The calculation is based on direct comparison of the installation costs and the lives saved associated with each measure. In general, the effectiveness of a measure in means of cost per life saved is negatively related to its cost per life saved. Figure 5 presents the cost per life saved for each safety measure. As can be seen significant lower cost per life saved is associate with three safety measures: speed limiter at 100 km/hr, seat belt reminder and driver training.

The US Department of Transportation considered $3 Million as an acceptable value per life saved in 2002 (Kahane, 2004). Based on the exchange rate at that time this corresponds to 2,850 thousands Euro. Compared to this figure all the safety measures presented in Figure 5 are cost effective. Based on UK and German crash costs, 2,107 thousands Euro and 1,266 thousands Euro are acceptable costs per life saved, respectively. It should be taken into consideration that since the acceptable cost per life saved varies among countries the acceptability of measures varies accordingly. However, the lowest obtained cost per life saved is in an indicator about the best measure.

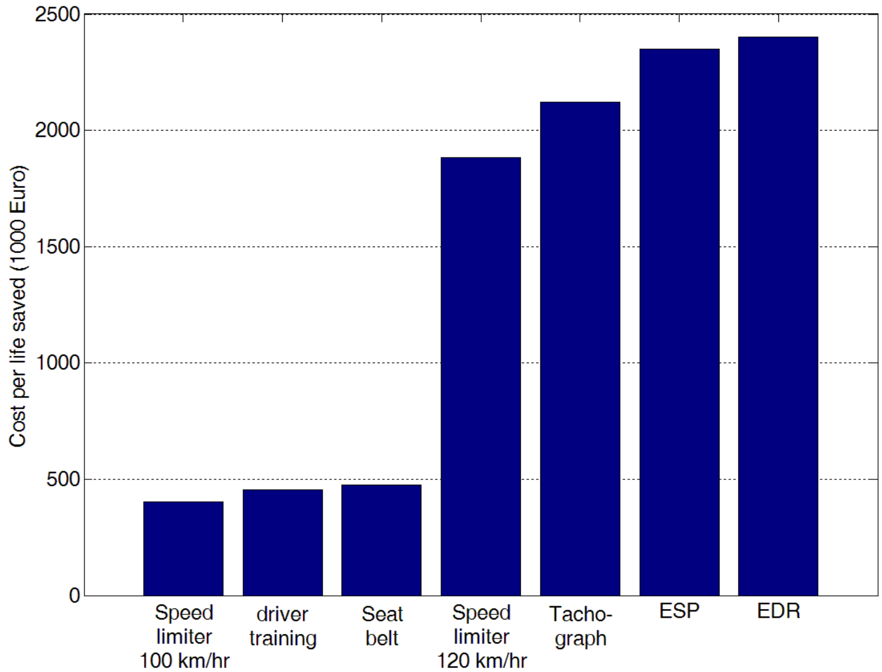


**Figure 5: Costs per life saved for the various measures**

### *The Payback Period*

The payback period method provides information about the number of years required for the cumulative discounted benefits to equal costs. This method serves as an indicator to the time period required before the measure costs are recovered. A shorter payback period is desirable.

Figure 6 presents the net present worth of each safety measure as a function of time. The payback period for each measure (based on UK crash costs) is the number of years before the present value for this measure equals zero. For three safety measures (speed limiter at 100 km/hr, seat belt reminder and driver training) the payback period is during the 7$^{th}$ year. The other safety measures exhibit significantly longer payback periods, between 17 and 19 years. It should be noted that based on German crash costs, which provide more conservative estimates of the safety benefits, the payback periods are longer than these reported here.

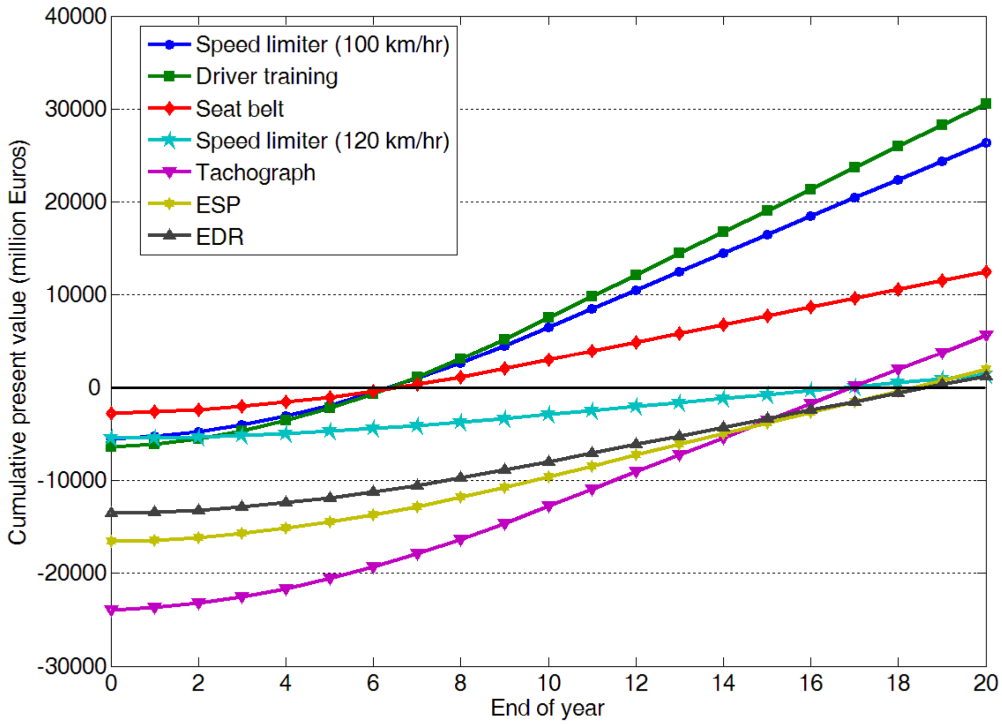


**Figure 6: Cumulative present value for the various measures**

### *Comparison of the top safety measures*

The B/C ratios, the cost per life saved and the payback period point towards three safety measures which are desired for improving the safety of LGVs. These safety measures are a 100 km/h speed limiter set, a professional driver training program and devices to increase seatbelt wearing. An incremental benefit-cost procedure was conducted in order to compare these three safety measures. With this method, the cheapest safety measure, seat belt reminder, serves as a baseline. The other measures are compared based on the cost efficiency of the additional costs and benefits associated with their implementation. Table 5 shows the results of this analysis. Based on UK costs, the cost increments associated with a 100 km/h speed limiter set and with the driver training program are both justified. This indicates that a professional driver training program is the first-best safety measure. Based on the lower German crash costs only the increment to the 100 km/h speed limiter set is economically justified, and so this measure is the first-best safety measure. It should be noted, however, that the incremental benefit-cost procedure does not reflect the combined benefit of these safety measures that might be lower than the sum of individual benefits.

| Increment | UK costs | | German costs | |
|---|---|---|---|---|
| | **Δ B/C ratio** | **Increment justified?** | **Δ B/C ratio** | **Increment justified?** |
| Seat belt →<br>Speed limiter (100 km/h) | 4.9 | Yes | 2.8 | Yes |
| Speed limiter (100 km/h) →<br>Driver training | 1.3 | Yes | 0.7 | No |

**Table 5: Incremental comparison of economically justified measures**

## Discussion and Conclusion

This paper focuses on the monetary evaluation and comparison of various safety measures that may contribute to the improvement of traffic safety for LGVs. These measures include the installation of active speed limiters, ESP, digital tachographs, EDR, seat-belt reminder and seat-belt lock systems, and implementation of a professional driver training program. In evaluating the impact of speed limiters two limiter set speeds were used: 100 km/hr and 120 km/hr. The monetary evaluation of these safety measures have been carried out using CBA by means of B/C ratios, the cost per life saved and the payback period.

The CBA yielded a B/C ratios substantially greater than 1 for the EU-25 as a whole and for most of the member states for a speed limiter set at 100 km/hr, a professional driver training program and devices to increase seatbelt wearing, indicating these safety measures are economically justified for LGVs. In addition, as shown in the sensitivity analysis, these results remain robust even if large changes occur in the unit costs or in the crash reduction rates of these measures. These three safety measures were also found to be the most cost effective in means of cost per life saved and have the shortest payback period. Our results specify, therefore, that these measures should serve as the core of safety improvements for LGVs. Comparison of these top safety measures by incremental B/C ratios indicate that a professional driver training program is the best measure with the UK crash costs, and the speed limiter set at 100 km/hr is the best measure with the German crash costs. The speed limiter set at 100 km/h is also the safety measure having the lowest cost per life saved.

The other safety measures, ESP, EDR, digital tachograph, and a speed limiter set at 120 km/hr yield B/C ratios of around 1 or lower, indicating that these measures are not economically justifiable for LGVs. Their costs per life saved values might be acceptable, but significantly higher than these of the other safety measures. The payback period of these measures is also notably longer. Therefore, the results indicate that these safety measures are inferior.

It should be noted, however, that our results are greatly sensitive to the assumptions that were used in the analysis, mainly regarding the crash reduction rate, the penetration rate and the price of a new unit. When technologies mature, lower costs can be expected, which will make these systems more cost beneficial. In addition, since for most measures full benefits are reached only after 10 years, an analysis period longer than 20 years, would lead to higher B/C ratios for all measures**.** However, this should not affect the results obtained from comparing the safety measures. Relaxation of assumptions can lead to somewhat other conclusions. This may explained that some results regarding B/C ratios are not too comparable with other studies; e.g., B/C ratios vary between 3.5 and 16 depending on system specification for speed limiters (Mäkinen and Várhelyi, 2001), B/C ratios between 2.6 and 4.4 for ESP (Gwehenberger et al., 2004), and a B/C ratios of 3.2 for EDR (Langeveld et al., 2004). Moreover, it seems that the available literature still lack the understanding of the impact of ESP on driver behavior; various drivers may adopt more aggressive and reckless driving patterns as they perceive a higher safety level insured by ESP.

Furthermore, some aspects of the safety measures that based on our analysis are suggested to serve as the core of safety improvements for LGV, are not comparable. For example, the seat belts have an effect only on the driver and the specific vehicle passengers and can not prevent a crash. LGVs drivers may tend to find ways to fault the seat belt reminders as these systems are trigger when a load is placed on a passenger seat (which is not uncommon for LGVs). To eliminate this undesirable behavior, a periodical test for LGV should include an examination of the seat belt reminders. The effectiveness of driver training depends upon the kind of training program; large companies having a high variable fleet of vehicles might be interested in a more universal training for their drivers. Active speed limiters have an effect on all vehicles in the traffic stream but their impacts arise only on freeways. Generally, the impact of speed limiters is more pronounced when their settings are more restrictive compared to uncontrolled traffic speeds in the section (e.g., the impact of a 100 km/hr speed limiter set compared to the impact of a 120 km/hr speed limiter). Nevertheless, the other effects of active speed limiters, e.g., negative time saving, fuel consumption, as well as barriers to implementation and public opinion, should also be considered. A comprehensive evaluation, which respects also the undesirable effects, may lead to lower effectiveness of active speed limiters that varies among different set speeds.

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