Modelling and Forecasting Traffic Safety Improvement: Infrastructure Redesign vs Driving Assistance Systems

Meng Lu, **Kees Wevers, Rob van der Heijden and Vincent Marchau**

ABSTRACT

Both large-scale physical infrastructure redesign and extensive use of in-vehicle driving assistance systems can contribute to improving road traffic safety. Limited availability of effect data (historical and estimated) for both alternatives is hampering long-term strategic analysis of their potential effects. This paper investigates the use of a first-order and one-variable grey model, denoted as GM (1,1), to forecast the trend of the reduction of traffic accident severity (in terms of fatalities and hospitalisations) through mentioned strategies and combinations thereof. Based on modelling the limited available data of the effects of the infrastructure redesign programme in The Netherlands for the period 1998-2002, we forecast the trend of fatalities and hospitalisations for the years 2003 until 2010. The result is compared with other traffic safety enhancement scenarios by using cost-effectiveness analysis (CEA). Error analysis shows that the applied model has a high degree of reliability. Therefore, the method (grey model and CEA) and the outcome of the analysis may contribute to planning and decision making concerning further appropriate steps to reach the ambitious Dutch road traffic safety goals for 2010.

Keywords: Grey model, Grey forecast, Road traffic safety scenario, Decision-making, Cost-Effectiveness Analysis (CEA)

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1. Background

Road traffic accidents are perceived as a major societal problem in the Netherlands, as well as in other countries. In the end of the 1990's the Dutch road infrastructure redesign programme "Duurzaam Veilige Infrastructuur" (DVI, "Sustainable Safe Infrastructure") was launched to improve road traffic safety. DVI is an extensive programme, covering 30 years and high investments (EUR 27.2 billion for a full implementation) (Poppe, 1996). The programme aims to adapt the road network according to three principles: functionality, homogeneity and predictability. Objective in the background is to meet the ambitious Dutch policy targets for 2010: reductions of 50% for fatalities and 40% for severe injuries with respect to the 1986 figures (Dutch authorities, 1997). A first modest implementation of DVI measures has taken place between 1998 and 2002 (Phase I). Due to new elections and political dynamics, in 2002 the Dutch Parliament failed to approve the new National Transport and Traffic Plan (NVVP), which was prepared by the former administration, and included the road traffic safety targets for 2010 and the implementation plan for Phase II of the DVI programme (Ministerie van Verkeer en Waterstaat, 2001). Meanwhile, concerns were raised about the required high investment and the long time scale, and the question presents itself to what extent DVI is still existent. In addition, the planned decentralised implementation strategy will make the success of DVI very dependent on local supporters who are prepared to invest time and energy in its success.

As an alternative or additional strategy, in-vehicle systems (IVS) may contribute to meet the policy goals. Several driving assistance applications are reaching the stage of market introduction and possible large-scale

implementation. Certain driving assistance functions have the potential to contribute to the improvement of road traffic safety by avoiding or correcting human error. Other benefits of these systems are enhanced driver comfort and increased road network throughput.

Previous research shows that strategic implementation of DVI and driving assistance systems are not only to a large extent substitutes, but also partly complementary (Lu et al., 2003). This helps to determine adequate scenarios for enhancing road traffic safety based on infrastructure measures, large-scale introduction of driving assistance systems, and feasible combinations. A notorious but relevant issue is to forecast the safety effect of such long-term scenarios. Prominent forecasting techniques are time-series methods (e.g. exponential smoothing, decomposition and Autoregressive/moving average - ARMA), causal forecasting methods (e.g. regression analysis, econometric models, input-output models and simulation modelling), Markov process, grey model, and in addition qualitative methods (e.g. product life-cycle analogy, expert knowledge and Delphi) (Makridakis and Wheelwright, 1978; Deng, 1989).

The Dutch Institute for Road Safety Research SWOV has carried out the VVR project (*Verkenner Verkeersveiligheid in de Regio*), in which the costs and expected effects of various elements of DVI implementation were estimated for 30 years (1998-2027) on a country-wide and on a region by region basis. One of the aims of this project was to allocate to the regions a fair share of the national targets and the available national budgets. The estimation is based on the horizontal (or stationary) pattern of time-series method. It assumes that both costs and effects are nearly constant with respect to time. The result shows that the DVI programme is very promising, with reductions of fatalities and hospitalisations of around 16 and 131 per year respectively (or totals of 197 and 1,571 respectively for the period 1998 until 2010). Thus, with some additional contribution from other measures (such as legislation and education) until 2010 the Dutch goal could be achieved.

Taking into account the effects of DVI implementation, the total numbers of fatalities and hospitalisations in 2010 are estimated as 952 and 17,049 respectively. However, it is questionable if this subjective method provides a sufficiently reliable and valid forecast of the cost-effectiveness of DVI, since it ignores uncertainties, such as overlaps with safety effects from other factors, of which the main ones are: 1) legislation and regulation; 2) change of driving behaviour promoted by enforcement, information, education and driving instruction; 3) general trend of improvement of the safety-related quality of vehicles by new or improved components: passive components like car structure, head restraint, seatbelts and airbag, and active components like quality of tyres, electronic stability control (ESC), anti-lock braking (ABS); 4) improvement of road quality, e.g. open asphalt on motorways; 5) other random and unknown factors. In view of these uncertainties, the long-term forecasting horizon (more than 2 years), and the limited availability of empirical data (five years), we propose a so-called grey prediction model for more reliable forecasting of the safety benefits.

The next section introduces the grey prediction model. In Section 3 we model the reduction of fatalities and hospitalisations by DVI for 1998-2002 and forecast the trend for 2003-2010 based on DVI implementation as originally foreseen. Section 4 discusses alternative IVS based and combined scenarios. And Section 5 models IVS based effects for 1998-1002 obtained from comparative analysis, and forecasts their effects for 2003-2010. The DVI and IVS forecasts are compared by using cost-effectiveness analysis (CEA). The results of the analysis are discussed and a conclusion is drawn in Section 6.

2. Grey System Theory based Grey Model

Grey system theory was initially proposed by J.L. Deng in 1982 (Deng, 1982). This theory has a multidisciplinary character.

It aims to cope with the uncertainty of a system (so-called "grey system", especially for multi-variable, discrete and incomplete data) by using elements of relational analysis, operational research, system control, system modelling and system forecast. The latter two items are based on the grey model, denoted as GM(n,h), which is an n-th order partial differential equation of h variables. This paper only focuses on the case of a first order ordinary differential equation ($n = 1$ and $h = 1$), for which the grey model can be denoted as GM(1,1). This advanced numerical model has been applied in the Chinese speaking area for more than two decades, and its performance in modelling and forecasting, e.g. for agriculture, environment, earthquakes and stock-price indices, was widely acknowledged (e.g. (Zhang and Luo, 1985; Yu, 1986; Cheng and Chang, 2001; Chang, Wen and Hsu, 2004)).

2.1 GM(1,1) essential principle and algorithm

The underlying premise for every quantitative forecasting method (and for some qualitative methods) is that the pattern of the past will continue into the future (i.e. the *assumption of constancy*). In grey modelling it is assumed that the pattern of the data series to be processed is exponential, or can be transformed to an exponential pattern by some form of pre-processing. Grey model aims to describe this exponential pattern (so-called dynamic systems behaviour) between each series and the discrete elements in the series. The fundamental schema behind the grey model is to deal with the causality between the different elements of the data set, given or represented as an exponential discrete series. The grey model provides a tool for dynamic modelling discrete series based on few data (a minimum of four data values is needed). This is a unique and distinguished characteristic of the model.

The basic principle and algorithm of GM(1,1) are described as follows:

The grey model uses a pseudo one variable first order differential equation, which is a difference equation that has the form of a conventional differential equation:

$$\frac{dx^{(1)}}{dt} + ax^{(1)} = u \qquad (1)$$

where $x^{(1)} = (x^{(1)}(1),\ x^{(1)}(2),\ \ldots,\ x^{(1)}(k)) =$

$$\left(\sum_{k=1}^{1} x^{(0)}(k), \sum_{k=1}^{2} x^{(0)}(k), \cdots, \sum_{k=1}^{n} x^{(0)}(k) \right) \qquad (2)$$

($k = 1,2,\ \ldots,\ n$) is called the background value (i.e. discrete function) of $\dfrac{dx^{(1)}}{dt}$, which essentially is the series of partial sums of the original series $x^{(0)} = (x^{(0)}(1),\ x^{(0)}(2),\ \ldots,\ x^{(0)}(k))$. The operation to create this series is called the accumulated generating operation (AGO). In Eqn. (1), a denotes the exponential developing coefficient with domain $a \in [-2, 2]$, and parameter u is the grey actuating variable, which reflects the variation of data. Assume that the grey difference equation is

$$x^{(0)}(k+1) + a \times \frac{1}{2}\big(x(k+1) + x(k)\big) = u \ , \ \text{where}$$

$\dfrac{1}{2}\big(x(k+1) + x(k)\big)$ is called the mean value generating operation (MGO). Then, the optimised solution of the parameters a, u is derived by the least-square method as:

$$\mathbf{\Theta} = \begin{bmatrix} a \\ u \end{bmatrix} = (\mathbf{B}^{\mathrm{T}}\mathbf{B})^{-1}\mathbf{B}^{\mathrm{T}}\mathbf{Y} \qquad (3)$$

where

$$\mathbf{B} = \begin{bmatrix} -\frac{1}{2}\big(x^{(1)}(1) + x^{(1)}(2)\big) & 1 \\ -\frac{1}{2}\big(x^{(1)}(2) + x^{(1)}(3)\big) & 1 \\ \vdots & \vdots \\ -\frac{1}{2}\big(x^{(1)}(n-1) + x^{(1)}(n)\big) & 1 \end{bmatrix} \quad \mathbf{Y} = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(n) \end{bmatrix} .$$

The solution (so-called discrete time response series) of the GM (1,1) pseudo differential equation is given by

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{u}{a} \right)e^{-ak} + \frac{u}{a} \qquad (4)$$

where $x^{(0)}(1) = x^{(1)}(1)$, $\hat{x}^{(1)}(k+1)$ denotes the estimated value.

2.2 Grey modelling prerequisite

In general, the grey model is only applicable to a series with non-negative elements,

except for static GM(0,h) that can deal with mixed positive and negative data.

In GM (1,1) the required exponential pattern of the data series is obtained by data pre-processing, i.e. by applying the AGO. The AGO can be carried out one time or several times until the series satisfies the exponential requirement, i.e. all successive terms $\sigma(k) = \dfrac{x(k-1)}{x(k)}$ are close to a constant c, where $c \in \left[e^{-2/(n+1)}, e^{2/(n+1)} \right]$ (proof see (Deng, 2002)). By this data pre-processing randomness and noise of the original data series are decreased, and (exponential) regularity and smoothness are increased (Deng, 1989). For a treatment of the fundamental conditions of the exponential requirement for improving the reliability of the grey model see also (Shen, 2001; Chen, Wen and Wen, 1999).

2.3 Modelling and forecasting process of GM(1,1)

The process of modelling and forecasting by GM(1,1) is as follows:

1. data pre-processing

Applying the AGO, see Eqn. (2), if necessary repeatedly until the series satisfies the exponential requirement (Section 2.2), to get the so-called first-order accumulated generating series.

2. grey modelling by GM(1,1)

As described in Section 2.1, the optimised solution of the parameters a, u is determined by Eqn. (3), and the solution of $\hat{x}^{(1)}$ at any time is obtained as Eqn. (4). From the estimated values $\hat{x}^{(1)} = x^{(1)}(2), \hat{x}^{(1)}(3), \cdots, x^{(1)}(n)$. The original series $x^{(0)}$ is restored by inverse AGO (IAGO): $\hat{x}^{(0)}(1) = x^{(0)}(1), \hat{x}^{(0)}(k) = x^{(1)}(k) - x^{(1)}(k-1)$, $k = 1, 2, \ldots, n$, which can also be expressed as

$$\hat{x}^{(0)}(k+1) = \left(1 - e^a\right)\left(x^{(0)}(1) - \frac{u}{a}\right)e^{-ak}.$$

3. model accuracy verification

Because grey system studies discreet data series with limited data, it is not possible to rigorously validate the model. The outcome of the model is allowed to be non-unique,

with different data pre-processing giving different results. Quite some discussion is ongoing about the accuracy analysis (You and Wen 2000; Wu and Wen 2001). The main error analysis methods that are used are residual checking, post-error inspection, rolling checking and envelope residual model. These methods can also be used for analysing model error (for detailed procedures see (Wu, Deng and Wen 1996). In this paper the method of residual checking of the error value is used:

$$e(k) = \frac{x^{(0)}(k) - \hat{x}^{(0)}(k)}{x^{(0)}(k)} \times 100\% \quad (5)$$

4. grey forecasting

By extrapolating the modelled series, the value of $\hat{x}^{(1)}(n+1)$, $\hat{x}^{(1)}(n+2)$, ..., $\hat{x}^{(1)}(n+m)$ can be predicted, where m is the expected forecast number. Generally, the smaller the m is, the higher the accuracy of the result would be. Note that the forecasting process can be applied iff the grey modelling results are sufficiently accurate. In fact, model error analysis is used as a substitute for model validation.

3. Applying GM (1,1) for Modelling and Forecasting DVI Effect

After five years of implementation of the DVI programme, data on partial traffic safety improvement (concerning fatalities and hospitalisations) have been obtained, as well as on costs (see Table 1). This section applies GM(1,1) to model fatalities and hospitalisations respectively for the years 1998 to 2002, and to predict the DVI effect in the coming years (2003-2010). The results are compared with the Dutch goal for 2010, i.e. 750 fatalities and 14,000 hospitalisations.

3.1 Modelling fatalities for DVI Phase I (1998-2002)

For the modelling process see Section 2.2. The established time response series resulting from the GM(1,1) analysis for fatalities is provided in Eqn. (6):

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{1.0974}{0.0392} \right) e^{-(0.0392)k} + \frac{1.0974}{0.0392} \quad (6)$$

where $k = 1, 2, 3, 4$

The simulated fatality values for DVI Phase I and residual error of the modelling are presented in Table 2

3.2 Modelling hospitalisations of DVI Phase I (1998-2002)

Similarly, we established the GM(1,1) time response series for hospitalisations, which is provided as Eqn. (7), and the simulated hospitalisation values for DVI Phase I, which are presented in Table 3.

$$\hat{x}^{(1)}(k+1) = \left(x^{(0)}(1) - \frac{1.0688}{0.0186} \right) e^{-(0.0186)k} + \frac{1.0688}{0.0186} \quad (7)$$

where $k = 1, 2, 3, 4$

3.3 Prediction of safety improvement (fatality and hospitalisation) by DVI (2003-2010)

From the low residual error of the modelling result, it may be concluded that it is acceptable to apply the model for making a forecast for the period 2003-2010, by taking $k = 5, 6, ..., 12$ for Eqn. (6) and Eqn. (7). The forecast results are presented in Table 4.

The forecast results show a significant traffic safety improvement by DVI implementation until 2010. However, the ambitious Dutch policy targets of fatality and hospitalisation for 2010 are not met. For decision making, it would be interesting to know if other alternatives, e.g. driving assistance systems or combination, could help to further enhance traffic safety, as well as to reduce costs.

4. Scenarios for Improving Road Traffic Safety

As discussed in Section 1, the development and deployment of in-vehicle driving assistance systems are progressing. Previous research (Lu et al., 2005a) has concluded that technologies of speed assistance, navigation and lane departure warning are state-of-the-art, and that large-scale implementation of such systems could start before 2010. These sys-

tems (with three different functional levels: information, warning and overrideable control) are already on the market, but with low penetration. The main DVI measures that are being implemented are 30 km/h residential zones, roundabouts, plateaux, separated bicycle lanes, parallel roads, absence of parked vehicles on the road, consistent road markings, semi-paved shoulders, obstacle free zones, reduction of crossings and shoulder protection.

We make four scenarios, described below, based on the following assumptions: the system life cycle is assumed to be the same as the vehicle life cycle, which is five years. Therefore, we determine *five-year* as yardstick for analysing safety effects (i.e. fatality and hospitalisation) of the scenario in the period of 2003 to 2007. The system penetration rate depends on the implementation schema, market-pull or government policy-push. Market-pull implies that the authorities take no action, but leave the adoption of a system to the market forces. Policy-push means that the government interferes with the market forces by fiscal measures or lower car insurance premiums, which may contribute to foster system acceptance if authorities decide for voluntary introduction. Authorities may also choose for mandatory introduction, e.g. as a better tool for speed limit enforcement.

4.1 Scenario 1: driving assistance systems by market-pull

Speed assistance (information), navigation (information) and lane keeping assistance (warning), implemented by market-pull, market penetration from 2003 to 2007 would be 5.0%, 6.5%, 7.5%, 9.5% and 12.0% for navigation, 0.5%, 2.0%, 3.5%, 5.2% and 7.8% for speed assistance, and 0.5%, 0.5%, 0.5%, 1.0% and 1.0% per year for camera based lane keeping assistance.

4.2 Scenario 2: driving assistance systems by policy-push and market-pull

Speed assistance (including partial intersection support) implemented by policy-push, market penetration rate from 2003 to 2007 would be 50%, 80%, 90%, 95% and 100%. Note that the considered speed assistance sys-

tem has a sophisticated flexible layout that differentiates according to road type and traffic safety requirements (Lu et al., 2003): 1) mandatory full control on roads and crossings with mixed traffic; 2) mandatory overrideable control (haptic throttle) on single carriageway roads with separation of traffic categories; and 3) voluntary warning on dual carriageway roads specifically designed for motor vehicles.

Navigation and lane keeping assistance are implemented by market-pull, market penetration rates are assumed to be the same as for Scenario 1.

4.3 Scenario 3: combination of partial DVI and in-vehicle systems by market-pull

Speed assistance, navigation and lane keeping assistance implemented by market pull (same penetration assumption as of Scenario 1). These functions are taken as substitutes of some DVI measures that may influence speed and conflict with on-coming vehicles (especially on single-carriageway roads), i.e. speed humps, plateaux, semi (or hard) separation, partial (50%) roundabout and partial (50%) reduction of cross point.

4.4 Scenario 4: combination of partial DVI and in-vehicle systems by policy-push and market-pull

Speed assistance (including partial intersection support) is implemented by policy push and the flexible system design (i.e. three levels) is the same as in Scenario 2; navigation and lane keeping assistance are implemented by market pull. These three functions have different market penetration rates, with the same values as in Scenario 2, are taken as substitutes for some DVI measures that may influence speed and conflict with on-coming vehicles (especially on single-carriageway roads), i.e. speed humps, plateaux, semi (or hard) separation, partial (50%) roundabout and partial (50%) reduction of cross point.

5. Cost-effectiveness Analysis of Strategic Scenarios

In this section, we analyse (2003-2007) and predict (2008-2010) the cost-effectiveness of each scenario as an assumed follow-up programme of DVI for enhancing traffic safety. The effects analysis (concerning fatalities and hospitalisations) of the scenarios for each year (2003-2007) is based on the application of a microscopic model for comparative analysis of various traffic safety measures (Lu et al., 2005b). DVI costs (2002-2010) are estimated by the SWOV, and the in-vehicle system costs are estimated by expert knowledge and market analysis (e.g. by comparison with navigation system, air-conditioning and radio/CD/DVD). Furthermore, we assume that the effects of driving assistance systems are expected mainly during the first three years, i.e. 35%, 25%, 15%, 10% and 5% per year respectively.

The results are summarised in Table 5. By the same process of grey modelling and forecasting as presented in Section 2.3, we get the results for fatalities and hospitalisations (2003-2010) for each scenario. Therefore, the total effects of fatality reduction (E_{fa}) and hospitalisation reduction (E_{ho}) are computed and presented in Table 6, as well as the cost-effectiveness analysis (CEA) compared with assumed DVI programme (2003-2010).

It appears that none of the scenarios could finally reach the Dutch traffic safety goal for 2010. However, the forecast effect of Scenario 4 (combination of partial DVI and in-vehicle systems by policy push and market pull) is slightly better (759 fatalities and 15,101 hospitalisations in 2010) than for other scenarios, and also better than the expected outcome for the DVI programme (775 fatalities and 15790 hospitalisations in 2010). Also, the implementation of driving assistance systems by policy push and market pull (Scenario 2) and combination of partial DVI and in-vehicle systems by market pull (Scenario 3) are closer to the aim of traffic safety improvement. The resulting ranking (from high to low) of the scenarios and DVI with respect to the effects on fatalities in 2010 is (see Table 5) $S4 \succ S2 \succ S3 \succ DVI \succ S1$; and with respect to the effects on hospitalisations $S4 \succ S2 \succ S3 \succ S1 \succ DVI$. If we take the costs

into account, the ranking (both for fatalities and hospitalisations) becomes S2≻S3≻S4≻ DVI. The CEA results clearly show that Scenarios 2, 3 and 4 have similar effects as DVI. However, they are all more cost-effective than DVI, due to the relatively high costs of the DVI programme. Sensitivity analysis has not been done, since Scenario 2 has a distinguished higher E/C ratio than other scenarios and DVI. Therefore, it should definitely have priority for decision making. Note that even if the authorities would not take further action (i.e. no cost for Scenario 1), the outcome is still a substantial safety improvement for 2010.

6. Discussion and Conclusion

GM (1,1) provides a powerful tool for modelling discrete series with few data, and long-term forecasting, based on determination of a fundamental exponential pattern. While GM(1,1) is theoretically very appealing, language obstacles and ambiguous assumptions, prerequisite and restrictions of the model have hindered its widespread adoption. During the past decades, substantial efforts have been made to improve the model based on the results of error analysis, and by development of model extensions. To make the model more reliable and robust, additional theoretical research into the foundations of the model are required, including clarification of constrains and prerequisites of the model.

The paper applies the GM(1,1) - first-order ordinary differential equation - to model the potential safety effects concerning fatalities and hospitalisations of DVI in Phase I (1989-2002), and to predict future effects until 2010. In order to conduct a comprehensive and systematic comparative analysis, four additional scenarios (including functions of driving assistance systems) are determined. Costs and potential safety effects are analysed and forecast for these scenarios for the period 2003 to 2010. Finally, the effectiveness-cost ratio is used for getting a clear-cut rank of these five alternatives. The paper presents some interesting results.

"Predictions are difficult - especially about the future," the Danish nuclear physicist and Nobel laureate Niels Bohr (1885-1962) once said ironically. In principle, it is impossible to forecast the future. However, certain methods can provide scenarios of the future and estimate their likelihood based on current circumstances and knowledge. As such, they can provide useful planning information for decision making.

Acknowledgements

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Table 1 Real number of fatalities, hospitalisations and costs of DVI Phase I (1998-2002)

year	1998	1999	2000	2001	2002
road traffic fatalities	1149	1186	1166	1083	1066
hospitalised traffic victims	18620	19410	19040	18510	18420
costs of DVI (mil. EUR)	404.5	388.6	373.6	360.0	345.9

Table 2 Fatalities (1998-2002 DVI Phase I) modelling result and residual error

year	1998	1999	2000	2001	2002
original fatality value	1149	1186	1166	1083	1066
simulated fatality value	1149	1192	1147	1102	1060
residual error (%)	0.00	-0.53	1.66	-1.79	0.56

Note: average residual error is 1.135% (1999-2002)

Table 3 Hospitalisations (1998-2002 DVI Phase I) modelling result and residual error

year	1998	1999	2000	2001	2002
original hospitalisation value	18620	19410	19040	18510	18420
simulated hospitalisation value	18620	19374	19017	18667	18322
residual error (%)	0.00	0.18	0.12	-0.84	0.53

Note: average residual error is 0.418% (1999-2002)

Table 4 Forecasting result of fatalities and hospitalisations by DVI and estimated costs

year	2003	2004	2005	2006	2007	2008	2009	2010
fatalities	1019	980	942	906	871	838	806	775
hospitalisations	17985	17654	17328	17009	16695	16389	16084	15790
DVI costs (mil. EUR)	332.7	320.0	307.7	295.9	284.1	273.2	262.7	252.7

Table 5 Results of analysis (2003-2007) and forecast (2008-2010) of safety effects (fatalities and hospitalisations) and costs by various scenarios

year	2003	2004	2005	2006	2007	2008	2009	2010
S1 cost (mil EUR)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
S1 fatality - analysis	1034	995	956	920	884			
S1 fatality - simulation	1034	995	956	920	884	850	817	786
residual error (%)	0.00	0.00	0.00	0.00	0.00			
S1 hosp. - analysis	18107	17771	17441	17117	16799			
S1 hosp. – simulation	18107	17770	17441	17118	16801	16490	15884	15299
residual error (%)	0.00	0.00	0.00	-0.01	-0.01			
S2 cost (mil EUR)	150.0	90.0	30.0	15.0	15.0	150.0	90.0	30.0
S2 fatality - analysis	1003	964	927	891	857			
S2 fatality - simulation	1003	964	927	891	857	824	792	761
residual error (%)	0.00	0.00	0.00	0.00	0.00			
S2 hosp. - analysis	17857	17528	17206	16892	16582			
S2 hosp. - simulation	17857	17527	17205	16889	16580	16277	15684	15114
residual error (%)	0.00	0.01	0.00	0.02	0.01			
S3 cost (mil EUR)	166.4	160.0	153.9	148.0	142.0	136.6	131.4	126.4
S3 fatality - analysis	1002	964	926	891	857			
S3 fatality - simulation	1002	963	926	891	857	824	792	762
residual error (%)	0.00	-0.06	0.00	0.00	0.00			
S3 hosp. - analysis	17850	17524	17203	16889	16580			
S3 hosp. - simulation	17850	17523	17204	16891	16583	16281	15693	15123
residual error (%)	0.00	0.01	-0.02	-0.01	-0.02			
S4 cost (mil EUR)	316.4	250.0	183.9	163.0	157.0	286.6	221.4	156.4
S4 fatality - analysis	1002	963	925	890	855			
S4 fatality - simulation	1002	963	925	889	855	822	790	759
residual error (%)	0.00	0.00	0.00	0.07	0.00			
S4 hosp. - analysis	17847	17516	17194	16880	16571			
S4 hosp. - simulation	17847	17515	17194	16878	16569	16266	15672	15101
residual error (%)	0.00	0.01	0.00	0.01	0.01			

Table 6 Results of cost-effectiveness analysis of scenarios and DVI (2003-2010)

Scenario #	costs (C)	fatalities reduction (E_{fa})	E_{fa}/C	hosp. reduction (E_{ho})	E_{ho}/C
S1	0.0	248	-	2,808	-
S2	570.0	242	0.4246	2,743	4.8123
S3	1,164.5	240	0.2061	2,727	2.3418
S4	1,734.5	243	0.1401	2,746	1.5832
DVI programme	2,329.0	244	0.1048	2,195	0.9425