A computational model to assess the impact of policy measures on traffic safety in Flanders:

Theoretical concepts and application.

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Samenvatting

Een rekenmodel voor het bepalen van de impact van beleidsmaatregelen op verkeersveiligheid in Vlaanderen: Theoretische concepten en toepassing

In dit rapport beschrijven we de ontwikkeling van een rekenmodel dat het effect van beleidsmaatregelen op verkeersveiligheid op het regionale niveau bepaalt en de kosten en baten hiervan vergelijkt om aldus een goede selectie van maatregelen te maken. De belangrijkste fasen in het model zijn de referentiesituatie, de baseline prognose, de maatregel prognose, de besparingen en de kosten-batenanalyse. De referentiesituatie beschrijft de huidige verkeer- en veiligheidprestatie. In de baseline prognose wordt de toekomstige verandering in verkeerprestatie (blootstelling) en in het autonome risico in rekening gebracht. De maatregel prognose fase beschrijft de situatie nadat maatregelen doorgevoerd zijn. Het verschil tussen de baseline en de maatregel prognose bepaalt dan het aantal ongevallen of slachtoffers die bespaard werden door de invoering van een bepaalde (set van) maatregel(en). In de kosten-batenanalyse tot slot wordt nagegaan of de baten van een maatregel de kost ervan overstijgen. Deze analyse helpt om maatregelen met een verschillende levensduur te vergelijken en een keuze te maken tussen mogelijke maatregelsets.

Het model heeft betrekking op verschillende weg- en kruispuntcategorieën in de regio, maar de illustratie in dit rapport gebeurt voor één bepaalde wegcategorie (namelijk autosnelwegen). Het model focust op ontwikkelingen in de toekomst waarbij het effect van maatregelen toegepast op de gehele regio of op enkele locaties wordt gekwantificeerd. Er wordt een onderscheid gemaakt tussen regionale en lokale maatregelen waarbij regionale maatregelen worden geacht een invloed te hebben op het niveau van verkeersveiligheid in de hele regio en lokale maatregelen enkel op de locatie(s) waarop ze werden toegepast. Bij de ontwikkeling van het model werden verschillende sets van maatregelen getest. Daarnaast werd rekening gehouden met een aantal belangrijke ontwikkelingen waarop de eindgebruiker van het model geen invloed heeft, zoals de groei in blootstelling en de verandering in het autonome risico. De verandering in het autonome risico is te wijten aan het collectieve leerproces gestuurd door de toegenomen kennis van het verkeersveiligheidsprobleem, de voortdurende verbetering van de prestatie van het transportsysteem, beter uitgeruste voertuigen en wegen, een verbeterde educatie, en inspanningen op vlak van wetgeving en handhaving. Toekomstige veranderingen in blootstelling worden vervat in groeiscenario's. In het rapport worden twee groeiscenario's (GS1 en GS2) bestudeerd voor de periode 2005-2030. Daarenboven wordt de methodologie geïllustreerd aan de hand van een gevalstudie uitgewerkt op autosnelwegen in Vlaanderen voor een periode van vier jaar (2003-2006). Het aantal bespaarde slachtoffers gedurende deze periode wordt bepaald rekening houdende met de algemene ontwikkelingen (de groei in blootstelling en de verandering in het autonome risico). De kosten-batenanalyse wordt enkel theoretisch behandeld en niet geïllustreerd in dit rapport omdat het doel van deze eerste analyse het bepalen van de effectiviteit van maatregelen in termen van het aantal bespaarde slachtoffers is.

Het model dat ontwikkeld wordt, biedt de gebruiker inzicht in de impact van verschillende regionale en lokale maatregelen toegepast op een bepaald tijdstip. Dit rapport beschrijft de methodologie van het rekenmodel en de eerste illustratieve resultaten. In de toekomst zal het model verbeterd worden door onder andere de afhankelijkheid tussen maatregelen te beschouwen. Ook zal een sensitiviteitanalyse uitgevoerd worden en zullen de meest onveilige plaatsen in de regio gevisualiseerd worden door middel van het linken met een geografisch informatiesysteem.

English summary

The aim of this report is to describe the development of a computational model to assess the effect of policy measures on safety at the regional level and compare their costs and benefits in order to select measures with the most beneficial cost-benefit ratios. The main stages of the model include the reference situation, the baseline prognosis, the measure prognosis, the savings and the cost-benefit analysis. The reference situation describes the current traffic performance and safety situation. The baseline prognosis takes the future change in traffic performance and autonomous risk into account. The measure prognosis relates to the situation after applying measures. The number of savings is the difference between the baseline and the measure prognosis. The cost-benefit analysis is used to determine whether the benefits of a measure outweigh its costs. This analysis helps to compare measures with a different life span and to make a choice between possible combinations of measure sets.

The model incorporates several road and intersection categories in the region yet the illustration in this report relates to only one road category (being highways). The model focuses on developments in the future, thereby quantifying the effect of measures applied either at a regional or a locational level. Regional measures are assumed to have an impact on road safety in the entire region while locational measures have an impact on road safety at the location they are applied. During the development of the model, several sets of measures were tested. Besides, a number of important developments on which the user of the model has no influence such as the change in traffic performance and in autonomous risk are taken into account. The autonomous risk change captures the collective learning process caused by the growing knowledge of the road safety problem, the constant improvement of the safety performance of the road transport system, better equipped motor vehicles and roads, the improvement of road safety education and, increasing legislation and enforcement. Future changes in traffic performance are represented by growth scenarios. Here, two growth scenarios (GS1 and GS2) are studied for the period 2005-2030. Also, a case study is carried out for a period of four years (2003–2006) on highways in Flanders to illustrate the methodology. The safety situation in terms of the number of saved casualties during the four years is assessed taking into account general developments i.e growth in traffic performance and autonomous risk. The cost-benefit analysis is only discussed in theory but not illustrated in this report since the aim of the first analysis concerns assessing the effectiveness of measures in terms of the number of saved casualties.

The developed model allows the user to get insight into the impact of different regional and locational measures applied at certain moments in time. This report describes the methodology of the computational model and some first illustrative results. In the future, the model will be improved to account for dependency among measures. Also, a sensitivity analysis will be carried and the most unsafe areas in the region will be displayed by linking it to a geographical information system.

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1. INTRODUCTION

At this moment, Flanders does not dispose of a computational model to calculate the effects of measures regarding road safety at a regional level. In the past, the Policy Research Centre Traffic Safety has already executed a number of studies (e.g. De Brabander et al., 2005; Nuyts, 2004) about the effects of measures such as roundabouts and the installation of speed cameras at a locational level (the level of road segments and intersections). However, an approach investigating the effect of policy measures on a broader area and in a broader context of sustainable development is still lacking in Flanders. In this respect, an estimation method which assists regions to calculate the road safety effects of both regional and locational measures and to aid in selecting measures resulting in the most efficient cost-benefit ratios is a valuable tool. The regional road safety explorer (RRSE) model developed by the SWOV (Reurings and Wijnen, 2008) is used as a starting point for Flanders. In the road network of Flanders, there are various road and intersection categories. The model to be developed will thus cater for the entire road network although at present the methodology is only illustrated for the road category of highways. However, in the future more road categories such as secondary roads and various intersection categories are to be integrated.

The model consists of the following main stages: the reference situation, the baseline prognosis, the measure prognosis, the number of saved casualties and the cost-benefit analysis. To estimate the effectiveness of measures and their cost-benefit ratio, data are required. These include data in the reference period, data in the baseline prognosis, data in the measure prognosis and cost-benefit data. The data in the reference period describe the current traffic performance and road safety situation per road and intersection category. Generally, traffic consists of motorized vehicles and other road users such as pedestrians and cyclists who play an important role in road safety. However, due to data scarcity and the fact that the first application focuses on highways, these vehicle kilometres provide useful traffic performance information. In the current model, traffic performance is defined as the number of motorized vehicle kilometres on a particular road category and the number of motorized vehicles passing through an intersection category. The road safety situation is reflected by the number of injury accidents, the number of slight casualties, the number of serious casualties and the number of fatalities per road or intersection category. The baseline prognosis takes the change in traffic performance and autonomous risk into account and acts as a reference to which the effectiveness of measures is compared. The autonomous risk change takes into account the collective learning process caused by the growing knowledge of the traffic safety problem, the constant improvement of the safety performance of the road transport system, better equipped motor vehicles and roads, improvement of traffic safety education and, increasing legislation and enforcement. The measure prognosis relates to the situation after applying and estimating the effectiveness of measures on road safety. The main outputs of the model are the number of saved casualties and the cost-benefit ratio of the applied measures. The number of saved casualties is the difference between the number of casualties in the baseline prognosis and in the measure prognosis. The saved casualties can be expressed in monetary values representing the benefits. The cost-benefit analysis is used to determine whether the benefits of a measure outweigh its cost. This analysis helps to compare measures with a different life span and to make a choice between possible combinations of measure sets aiming to improve the level of road safety in the region.

1.1 Objective of the report

This research aims at developing a model for Flanders to assess the effects of measures on road safety at the regional level and help in future decision making. The model enables comparing the costs and benefits of different measure sets so that the best sets can be selected and applied.

This report focuses on the assessment of the effectiveness of measures. In the following sections, the methodology of the computational model is described and a first illustration shown to indicate the value of the model. In addition, the advantages and challenges encountered during the development of the model are discussed and aspects for further improvement of the model highlighted.

1.2 Organization of the report

In Section 2 the data are described and the methodology is explained in Section 3. Results from applying the methodology to a set of highway segments in Flanders are presented in Section 4 while the Conclusion and further research are the subjects of Sections 5.

2. DATA

In this section, the data required for the computational model are described. For each data category, an overview of the required data is first given after which the actual data used to illustrate the model are described. First, data describing the current situation of the road network, road safety and traffic performance are presented, followed by data reflecting changes in traffic performance and autonomous risk over time. Thirdly, scientific results on the effectiveness of measures found in literature are given. Finally, data required to carry out a cost-benefit analysis described.

2.1 The current situation: the road network, road safety and traffic performance

The road network is categorized into various categories of road segments and intersections. The road segment categories include highways, primary roads, secondary roads and residential roads. These are further classified into rural and urban roads. The intersection categories comprise three-arm, four-arm, signalized and unsignalized intersections which are also grouped into rural and urban intersections. The road segments or intersections in each category consist of specific characteristics. Examples of characteristics of road segments include: speed limit, curve radius, shoulder width, lane width, number of lanes, median, etc. Among the characteristics of intersections are sight distance from stop line, intersection angle, number of approach roads, approach speed, number of lanes, lane width and traffic control for pedestrians and cyclists (Vogt and Bared, 1998b). For the moment, the model focuses on one road category (highways). In the future, other road categories as well as different intersection categories will be integrated in the model.

The road safety data describe the road safety situation in terms of the number of injury accidents, slight casualties, serious casualties and fatalities per road segment and intersection in the reference year. It should be noted that the number of accidents and casualties is in reality higher than shown in official statistics because not all accidents are reported and registered by the authorities (Elvik and Vaa, 2004). To better reflect reality, underreporting factors of the various levels of severity are used. These are factors by which a registered road safety quantity is multiplied in order to obtain a better approximation of the road safety quantities. Hence, data on underreporting factors are required for the number of injury accidents, slight casualties, serious casualties and fatalities per road segment and intersection category. Underreporting factors are available in literature but not broken down to road and intersection category. Hence, 1.75, 1.90, 1.30 and 1.05 (Elvik and Mysen, 1999) for injury accidents, slight casualties, serious casualties and fatalities respectively are utilized.

The methodology is illustrated using 2002 data of 99 highway segments in Flanders. The traffic performance or the number of kilometres driven in the entire region on highways is obtained by summing up the number of kilometres on all road segments. The number of kilometres on a road segment is calculated by multiplying the length of a segment and the number of vehicles passing by that segment (between 6:00am and 10:00pm) and the total on all segments serves as the regional traffic performance. The number of kilometres and vehicles are expressed in thousands. Table 1 shows an example of traffic performance on four road segments (H1, H11, H12 and H13). The figures in the last column would describe the traffic performance in the entire region if all the 99 segments were presented instead of the four.

Table 1: Traffic performance on H1, H11, H12 and H13 in 2002

Traffic performance (TP)	Road H1	Road H11	Road H12	Road H13	Total of four segments
Length km (L)	3.2000	13.0000	4.6000	1.9000	
L1 (in 1000s) = L/1000	0.0032	0.0130	0.0046	0.0019	
Number of vehicles (V)	14,700	81,600	86,200	97,400	
V1 (in 1000s) = V/1000	14.7000	81.6000	86.2	97.4000	
TP (in 1000s km) = L1*V1	**0.0470**	**1.0608**	**0.3965**	**0.1851**	**1.6894**

2.2 Changes in the future: traffic performance and autonomous risk

These are two aspects which change over time and affect the level of road safety; they are taken into account in the model. The data used to compute the growth in traffic performance on highways in Flanders relate to the period 1985–2006 and are obtained from the FOD MV (2008) and the Federal Plan Bureau (Federaal Planbureau, 2008). The autonomous risk refers to results from measures taken in the past but still having an impact on the current road safety situation. Further, COST329, 2004, explains the autonomous risk as the collective learning process caused by the growing knowledge of the traffic safety problem, the constant improvement of the safety performance of the road transport system, better equipped motor vehicles and roads, improvement of traffic safety education and, increasing legislation and enforcement. The effect of the autonomous risk will be quantified using time series data of the total number of casualties.

2.3 Effectiveness of road safety measures from literature

To calculate the impact of a set of measures on road safety, the effectiveness is required with respect to injury accidents, slight casualties, serious casualties and fatalities. Below, some measures tested in Flanders and at the international level are listed. In brackets are the severity levels on which the impact of the measure has been assessed for Flanders. However, there are severity levels for which the effectiveness of measures are not investigated in literature and therefore need to be approximated.

2.3.1 Measures in Flanders

- Roundabouts (IA, SLC & SCs) - De Brabander et al., (2005)
- Invisible and visible speed controls on roads with speed limits from 80–120 km/h (IA) - Van Geirt (2006)
- Speed limit of 30 km/hr in school zones (IA) – Dreesen and Princen (2005)
- Fully protected left turn signals (IA & FATs) – Dreesen and Nuyts (2006)
- Partly protected left turn signals (FATs) - Dreesen and Nuyts (2006)
- Protected left turn on an intersection with a permissive left turn (IA) - Dreesen, (2005)
- Automatic speed cameras (FATs) - Nuyts, (2004)

IAs=Injury accidents, SLC=Slight casualties, SCs=Serious casualties, FATs=Fatalities

2.3.2 Measures at the international level

At the international level, the handbook of road safety measures, (Elvik and Vaa, 2004) provides useful information. Below is a list of categories of measures described in the handbook and the number of measures belonging to the categories.

- Road design and road furniture (19 measures)
- Traffic control (17 measures)
- Driver training and regulation of professional drivers (19 measures)
- Vehicle design and protective devices (14 measures)
- Road maintenance (4 measures)
- Police enforcement and sanctions (9 measures)
- Public education and information (3 measures)

In this report, three relevant measures for highways are studied: speed reduction (130 to 110, 130 to 120 and 120 to 110km/hr) on highways, automatic warning of queues with variable signs and stationary speed enforcement. The effectiveness of these measures as given in Elvik and Vaa (2004) is used in the model. Speed reduction and automatic warning of queues with variable signs reduce the number of injury accidents by -0.14 (-0.20,-0.07) and -0.14 (-0.22,-0.08) respectively. Stationary speed enforcement reduces the number of injury accidents by -0.06 (-0.09,-0.04). The effectiveness of these measures on the other severity levels is not provided in literature and an approximation is made.

2.4 Costs and benefits

In order to calculate the total annual cost of measures, the cost of the applied measures must be known. These costs include the cost per measure per kilometre per year for road segments and the cost per measure per piece per year for intersections. The cost information will be obtained by consulting experts. In addition, the value in euros of an injury accident, a slight casualty, a serious casualty and a fatality are required to calculate the annual benefits of the applied measures in terms of the casualties prevented. Except for slight casualties, 20,943, 725,512 and 2,004,799 euros are the values of an injury accident, a serious casualty and a fatality respectively (De Brabander and Vereeck, 2007). The value of a slight casualty is to be estimated from other international sources. Finally, a discount rate is required to express the costs and benefits in terms of the nominal value of the reference year and a discount rate of 4% (Transumo, 2008) will be utilized. The cost-benefit analysis is not illustrated in this report since the aim of the first analysis concerns assessing the effectiveness of measures in terms of the number of casualties saved.

3. METHODOLOGY

This section describes the structure of the model and how it calculates the effects of measures on road safety and cost-benefit ratios. The formulae used are obtained from Reurings and Wijnen, (2008). Figure 1 presents the various stages of the model after which each stage is explained in detail. Section 3.1 elaborates on the reference year. Section 3.2 discusses the baseline prognosis focussing on the change in traffic performance and autonomous risk. Next, sections 3.3 and 3.4 respectively present the measure prognosis and the savings. Finally, section 3.5 gives an overview of the cost-benefit analysis**.**

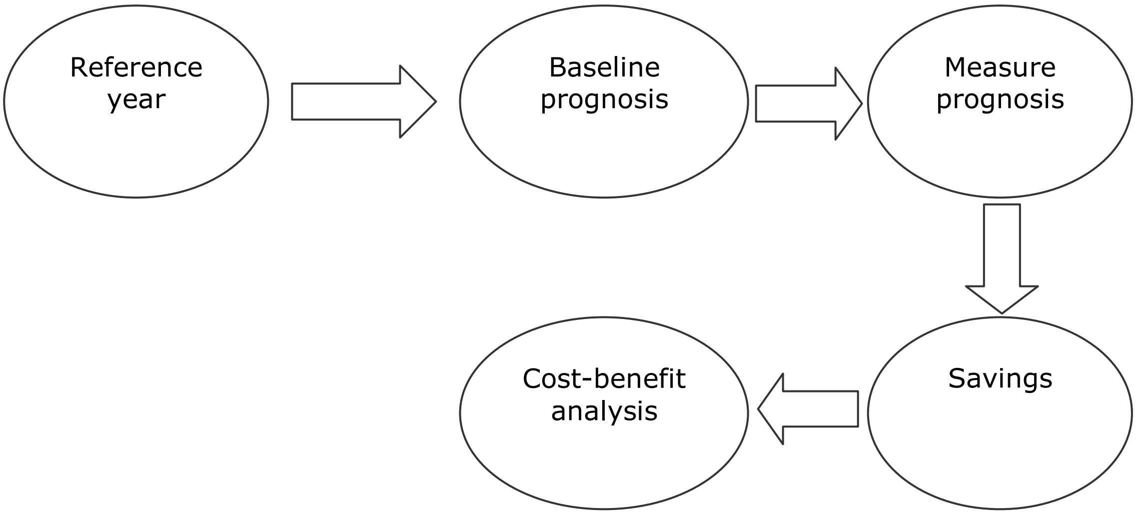

Figure 1: Stages of the model

3.1 The reference year

The first stage describes the traffic and road safety situation in the reference year. The traffic situation consists of traffic performance i.e. the annual number of kilometres travelled by motorized vehicles per road category and the annual number of motorized vehicles through an intersection category. The road safety situation comprises the number of injury accidents, slight casualties, serious casualties and fatalities per road segment and intersection category. Underreporting of road safety quantities is taken into account by multiplying the registered quantities by an underreporting factor per severity level. Underreporting is lower for some severity levels (Reurings et al., 2007). Moreover, different categories of road segments and intersections might have different underreporting levels. In this report, it is assumed that all road segments and intersections have the same underreporting factor as the road or intersection category to which they belong. The computation is illustrated for injury accidents (IA_s).

$IAs_c = IAs_{c,registered} * f_{c,accident}$ with

IAs_c = incremented number of injury accidents on category c

$IAs_{c,registered}$ = registered number of injury accidents on category c

$fc,_{accident}$ = underreporting factor for the number of injury accidents on category c

The other severity levels are incremented in a similar manner.

Apart from the number of injury accidents, slight casualties, serious casualties and fatalities, the road safety situation in the reference year is reflected by various indicators.

The most important ones are: the accident risk (r_c), the number of casualties per injury accident $(N_{0,c})$, the number of slight casualties per total casualties $(N_{1,c})$, the number of serious casualties per total casualties $(N_{2,c})$ and the number of fatalities per 100 casualties $(N_{3,c})$ per road segment or intersection category. The accident indicators are computed as follows:

$r_c = \frac{IAs_c}{TP_c}$, $N_{0,c} = \frac{C_c}{IAs_c}$, $N_{1,c} = \frac{SLC_c}{C_c}$, $N_{2,c} = \frac{SCs_c}{C_c}$ and $N_{3,c} = \frac{FATs_c}{C_c} * 100$ with

IAs_c = incremented number of injury accidents on all infrastructures belonging to road segment or intersection category c in the reference year

TP_c = traffic performance on all infrastructures belonging to road segment or intersection category c in the reference year

C_c = number of casualties on all infrastructures belonging to road segment or intersection category c in the reference year

SLC_c = number of slight casualties on all infrastructures belonging to road segment or intersection category c in the reference year

SCs_c = number of serious casualties on all infrastructures belonging to road segment or intersection category c in the reference year

$FATs_c$ = number of fatalities on all infrastructures belonging to road segment or intersection category c in the reference year

3.2 Baseline prognosis

Having described the reference situation, the baseline prognoses can be calculated. The baseline prognosis contains the number of injury accidents, slight casualties, serious casualties and fatalities before the impact of measures is taken into account. To determine the baseline prognosis, two developments on which the user of the model has no influence are taken into account. They include the change in traffic performance and in autonomous risk. At this stage, the baseline prognosis concerning traffic performance and road safety quantities is calculated. We distinguish between baseline prognoses at the regional level and at the locational level.

3.2.1 Baseline prognosis for traffic performance at the regional level

Traffic performance increases each year and this results into uncertainity about the future. Thus, different scenarios representing specific growth rates in traffic performance are considered. Every growth scenario consists of a set of traffic performance growth factors relating to a particular year and infrastructure category. The baseline traffic performance for infrastructure category c in year t due to growth scenario A ($TP_{A, c, t}$) is given by:

$$TP_{A,c,t} = g_{A,c,1} * g_{A,c,2} * ... * g_{A,c,t} * TP_c$$ with

$g_{A,c,t}$ = growth factor for traffic performance in year t on road segment or intersection category c due to growth scenario A

TP_c = traffic performance on road segment or intersection category c in the reference year

Flemish data from 1985-2006 (FOD MV, 2008), are used to predict the yearly growth in vehicle kilometres for the period 2007-2030. A long period is selected because the model is developed with a long time frame to predict future values until 2030. The non-linear logistic growth curve model proposed by Oppe (1989) is utilized for the prediction. This curve is characterized by a slow growth at the start, rapid growth with time and limiting growth after some time. The selected model is of the form below as estimated by CurveExpert 1.3 software (Daniel Hyams).

$$y_i = \frac{\beta_0}{\left(1 + \beta_1 * \exp\left(-\beta_2 * year_i\right)\right)} + \varepsilon_i$$ with

y_i = predicted number of vehicle kilometres driven in year i

β_0 = limiting value of vehicle kilometres driven

β_1 = number of times the initial number of driven vehicle kilometres (year i=0) must grow to reach the limiting value

β_2 = rate of growth in the number of driven vehicle kilometres as the curve approaches the limiting value

ε_i = error term

The correlation coefficient and the standard error estimate are used to assess the goodness of fit of the model. The model with the largest magnitude of the correlation coefficient and the smallest standard error estimate is considered best. In this case the magnitude of the correlation coefficient and the standard error estimate of the selected model are 0.9525 and 686.7576 respectively. The model is then fitted in SAS 9.1 and Table 2 contains the results obtained from the non-linear logistic growth curve model. The parameter estimates obtained are used to predict the number of vehicle kilometres for the period 1985-2030 (Table 3).

Table 2: Parameter estimates (standard errors) and Confidence intervals

Parameter	Estimate (standard errors)	Confidence intervals
β_0	23487 (960.4900)	(21495, 25479)
β_1	1.4676 (0.0753)	(1.3115, 1.6238)
β_2	0.1123 (0.0117)	(0.0881, 0.1366)
$Var(\varepsilon_i)$	441.1100 (66.4987)	(303.2000, 579.0200)

The comparison of the observed and the predicted data is presented in Figure 2. It can be seen that the evolution in the predicted and the observed kilometres is close. In other words, most of the variability in the data is captured by the prediction although there appears little alteration at some points.

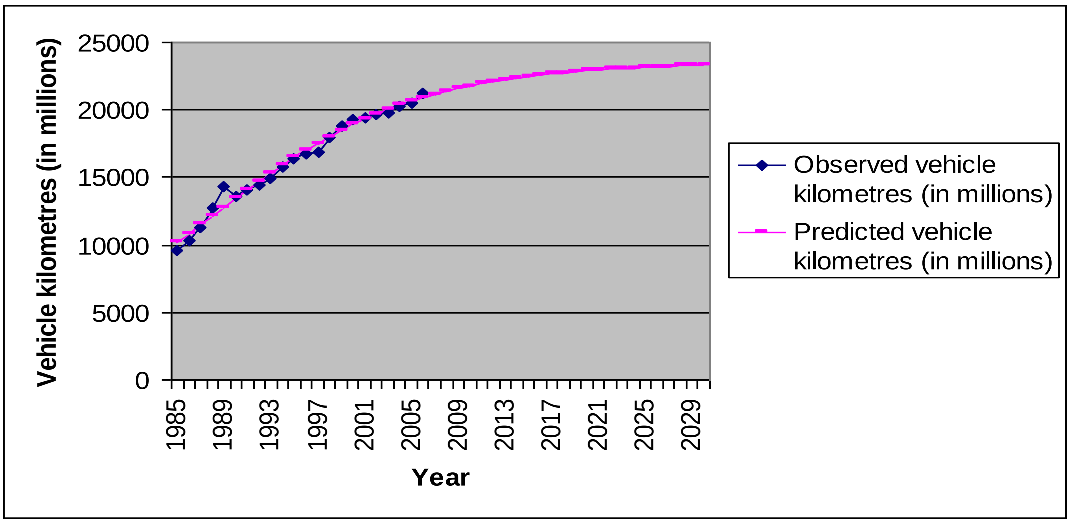

Figure 2: Comparison of observed and predicted traffic performance data

Here, we consider two options for predicting the growth in the number of vehicle kilometres. The first option is to use the parameter estimates in Table 2 to capture the growth in percentage per year. These growth factors represent the first growth scenario (GS1) (Table 3). The second option starts from the predicted growth in the number of vehicle kilometres in Belgium between 2005 and 2030 as determined by the Federal Plan Bureau (FPB) (Federaal Planbureau). Yearly growth factors for the second growth scenario (GS2) are computed by spreading the predicted growth in vehicle kilometres between 2005 and 2030 by the FPB over different years using the same rate as determined by the logistic growth model rather than a more unrealistic constant rate. The formula used to compute the second set of growth factors is given below.

$$\frac{\text{Growth rate in predicted km in year } i}{\text{Overall growth in predicted km (2005-2030)}} * \text{Overall growth in predicted km FPB (2005-2030)}$$

with i = 2005, 2006, …, 2030

The overall growth in predicted km (2005-2030) is 12.93% obtained as the percentage difference between the predicted kilometres for the period 2005–2030 (Table 3) while the overall growth in predicted km FPB (2005-2030) is 22%. Table 3 contains the two sets of growth factors representing GS1 and GS2.

Table 3: Predicted growth in vehicle kilometres 1985-2030

Year	Observed km (in millions)	Growth factors in the observed km	Predicted km (in millions)	Growth in predicted km (in millions)	Growth factors GS1	Growth factors GS2
1985	9,630		10,160.0300			
1986	10,320	1.0717	10,811.6879	651.6579	1.0641	
1987	11,240	1.0891	11,469.1724	657.4845	1.0608	
1988	12,690	1.1290	12,128.3821	659.2097	1.0575	
1989	14,260	1.1237	12,785.1725	656.7905	1.0542	
1990	13,600	0.9537	13,435.4598	650.2872	1.0509	
1991	14,100	1.0368	14,075.3208	639.8611	1.0476	
1992	14,480	1.0270	14,701.0859	625.7650	1.0445	
1993	14,950	1.0325	15,309.4175	608.3316	1.0414	

1994	15,790	1.0562	15,897.3738	587.9563	1.0384	
1995	16,380	1.0374	16,462.4535	565.0797	1.0355	
1996	16,750	1.0226	17,002.6216	540.1681	1.0328	
1997	16,860	1.0066	17,516.3173	513.6957	1.0302	
1998	17,930	1.0635	18,002.4449	486.1276	1.0278	
1999	18,850	1.0513	18,460.3506	457.9058	1.0254	
2000	19,290	1.0233	18,889.7886	429.4380	1.0233	
2001	19,360	1.0036	19,290.8780	401.0894	1.0212	
2002	19,680	1.0165	19,664.0560	373.1779	1.0193	
2003	19,800	1.0061	20,010.0275	345.9715	1.0176	
2004	20,270	1.0237	20,329.7163	319.6887	1.0160	
2005	20,460	1.0094	20,624.2166	294.5004	1.0145	1.0246
2006	21,210	1.0367	20,894.7497	270.5331	1.0131	1.0223
2007			21,142.6235	247.8738	1.0119	1.0202
2008			21,369.1976	226.5741	1.0107	1.0182
2009			21,575.8537	206.6561	1.0097	1.0165
2010			21,763.9702	188.1165	1.0087	1.0148
2011			21,934.9021	170.9320	1.0079	1.0134
2012			22,089.9654	155.0633	1.0071	1.0120
2013			22,230.4244	140.4590	1.0064	1.0108
2014			22,357.4837	127.0593	1.0057	1.0097
2015			22,472.2817	114.7980	1.0051	1.0087
2016			22,575.8877	103.6060	1.0046	1.0078
2017			22,669.3002	93.4124	1.0041	1.0070
2018			22,753.4467	84.1465	1.0037	1.0063
2019			22,829.1852	75.7385	1.0033	1.0057
2020			22,897.3065	68.1213	1.0030	1.0051
2021			22,958.5366	61.2302	1.0027	1.0045
2022			23,013.5405	55.0039	1.0024	1.0041
2023			23,062.9251	49.3847	1.0021	1.0037
2024			23,107.2437	44.3185	1.0019	1.0033
2025			23,146.9989	39.7552	1.0017	1.0029
2026			23,182.6472	35.6482	1.0015	1.0026
2027			23,214.6018	31.9546	1.0014	1.0023

2028	23,243.2367	28.6349	1.0012	1.0021
2029	23,268.8897	25.6530	1.0011	1.0019
2030	23,291.8657	22.9760	1.0010	1.0017

3.2.2 Baseline prognosis for road safety quantities at the regional level

This section presents formulae for the baseline prognoses of the road safety quantities at the regional level. The computations for injury accidents are given first, followed by those for total casualties, fatalities, serious casualties and lastly slight casualties.

3.2.2.1 Baseline prognosis for the number of injury accidents

The baseline prognosis for the number of injury accidents is obtained by multiplying a category's traffic performance and its baseline risk. The baseline risk is determined by the risk in the reference year and the autonomous risk change. The baseline risk $br_{c,\,t}$ on category c in year t after the reference year is given by:

$br_{c,t}$ = $f_{c,1} * f_{c,2} ... f_{c,t} * r_c$ with

$f_{c,t}$ = modification factor for the autonomous risk on category c in year t

r_c = accident risk for category c in the reference year

The baseline prognosis for the number of injury accidents, $b\_IAs_{A,c,t}$ in year t on category c due to growth scenario A is given by:

$b\_IAs_{A,c,t}$ = $br_{c,t} * TP_{A,c,t}$ with

$br_{c,t}$ = baseline risk in year t for category c

$TP_{A,c,t}$ = traffic performance in year t on category c due to growth scenario A (section 3.2.1)

The modification factor for the autonomous risk is estimated using the extensive time series data available on casualties in Belgium (1970-2006). The exponential function recommended in literature (Van den Bossche et al., 2005; COST329, 2004; Oppe, 1989) is fitted to the data. The exponentially decreasing trend over time can be explained in terms of a collective learning process (COST329, 2004), caused by the ever-increasing knowledge of the traffic safety problem and the constant improvement of the safety performance of the road transport system. For example, cars and roads become better equipped, traffic safety education improves and legislation and enforcement efforts have also increased over time. All these measures result in a decreased risk over time and the exponential function has been proposed to describe this trend. The equation for the exponential function is $y = ae^{bx}$ (Ahlfors, 1953). Here, x is the value of the independent variable (years), while y is the value of the dependent variable (road safety risk). The number *e* (approximately 2.7182) is the base of natural logarithm.

Figure 3 shows a decreasing rate of -0.0449. The same rate is assumed for each year. Therefore, 0.9551 is used as the yearly modification factor for the autonomous risk in the model.

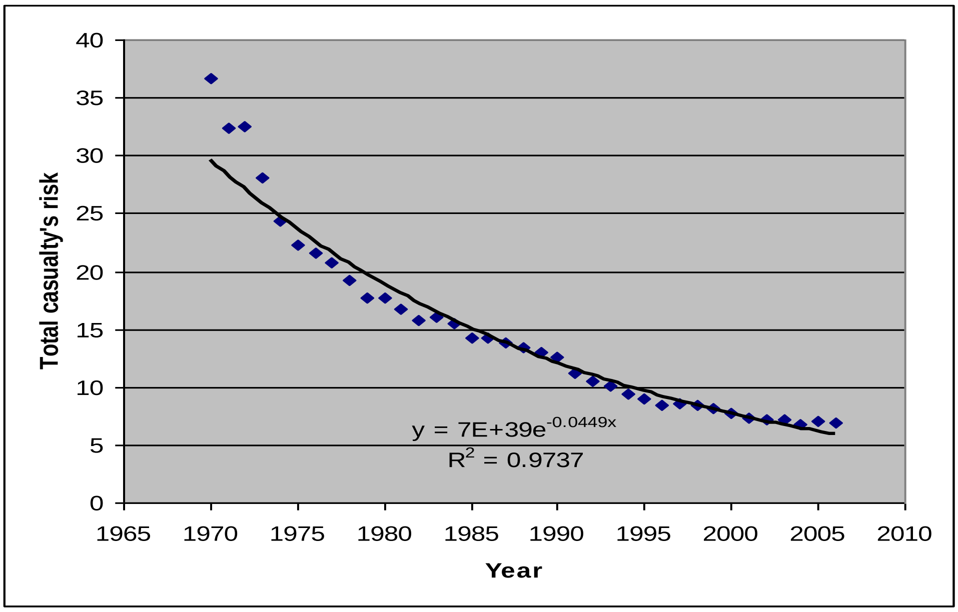

Figure 3: Total casualty's risk in Belgium: 1970-2006

3.2.2.2 Baseline prognosis for the number of casualties

The baseline prognosis for the number of casualties, $b\_C_{A,c,t}$ in year t on category c due to growth scenario A is given by:

$b\_C_{A,c,t} = b\_IAs_{A,c,t} * N_{0,c}$ with

$b\_IAs_{A,c,t}$ = baseline prognosis for the number of injury accidents in year t on category c due to growth scenario A

$N_{0,c}$ = number of casualties per injury accident on category c in the reference year (section 3.1)

3.2.2.3 Baseline prognosis for the number of fatalities

The baseline prognosis for the number of fatalities, $b\_FATs_{A,c,t}$ in year t on category c due to growth scenario A is given by:

$b\_FATs_{A,c,t} = \frac{N_{3,c}}{100} * b\_C_{A,c,t}$ with

$b\_C_{A,c,t}$ = baseline prognosis for the number of casualties in year t on category c due to growth scenario A

$N_{3,c}$ = number of fatalities per 100 casualties on category c in the reference year (section 3.1)

3.2.2.4 Baseline prognosis for the number of serious casualties, $b\_SCs_{A,c,t}$

The baseline prognosis for the number of serious casualties, $b\_SCs_{A,c,t}$ in year t on category c due to growth scenario A is given by:

$b\_SCs_{A,c,t} = N_{2,c} * b\_C_{A,c,t}$ with

$b\_C_{A,c,t}$ = baseline prognosis for the number of casualties in year t on category c due to growth scenario A

$N_{2,c}$ = number of serious casualties per total casualties on category c in the reference year (Section 3.1)

3.2.2.5 Baseline prognosis for the number of slight casualties, $b\_SLC_{A,c,t}$

The baseline prognosis for the number of slight casualties, $b\_SLC_{A,c,t}$ in year t on category c due to growth scenario A is given by:

$$b\_SLC_{A,c,t} = b\_C_{A,c,t} - b\_FATs_{A,c,t} - b\_SCs_{A,c,t}$$ with

$b\_C_{A,c,t}$ = baseline prognosis for the number of casualties in year t on category c due to growth scenario A

$b\_FATs_{A,c,t}$ = baseline prognosis for the number of fatalities in year t on category c due to growth scenario A

$b\_SCs_{A,c,t}$ = baseline prognosis for the number of serious casualties in year t on category c due to growth scenario A

3.2.3 Baseline prognosis for traffic performance at the locational level

To assess the effectiveness of locational measures on a location belonging to category c in year t, the number of injury accidents and casualties that would occur at that location before applying the locational measures is required. These road safety quantities are the baseline prognosis at the location and are determined by the total injury accidents and casualties on the category to which the location belongs and the traffic performance at the location. To compute the traffic performance at the location, it is assumed that locations have the same growth factor for traffic performance as the road or intersection category to which they belong. The traffic performance of a location, $TP_{A,loc,t}$, in year t due to growth scenario A, is calculated as follows.

$$TP_{A,loc,t} = g_{A,c,1} * \ldots * g_{A,c,t} * TP_{loc}$$ with

TP_{loc} = traffic performance of location, loc in the reference year

$g_{A,c,t}$ = growth factor for the traffic performance in year t on category c due to growth scenario A (Table 3)

3.2.4 Baseline prognosis for road safety quantities at the locational level

These are the number of injury accidents, slight casualties, serious casualties and fatalities at a particular location before a measure is applied. They are determined by the total number of road safety quantities on the category to which the location belongs and the traffic performance at the location. This is illustrated for injury accidents (the other severity levels are computed analogously). The number of injury accidents in year t at location, loc, belonging to category c due to growth scenario A before applying a measure is given by:

$$IAs_{A,loc,t} = \frac{IAs_{A,c,t}}{TP_{A,c,t}} * TP_{A,loc,t}$$ with

$TP_{A,c,t}$ = traffic performance in year t on category c due to growth scenario A

$IAs_{A,c,t}$ = number of injury accidents in year t on category c due to growth scenario A

$TP_{A,loc,t}$ = traffic performance at location, loc, in year t due to growth scenario A.

By replacing the number of injury accidents with slight casualties, serious casualties and fatalities, the baseline prognosis for other severity levels are computed.

3.3 Measure prognosis

In this phase of the model, the impact of measures is calculated on the number of injury accidents, slight casualties, serious casualties and fatalities. The final selection of measures incorporated in the model will be decided on in consultation with policy makers. Here, the method used to calculate the impact of one or several measures on road safety is described. For each measure, the modification factor per severity level is required. The modification factor is the expected proportion of the traffic safety quantities remaining after the measure is applied.

3.3.1 Computing effectiveness of measures

Two types of measures need to be distinguished with respect to this regional: regional and locational measures. First, the regional measures are described after which the locational ones are explained.

3.3.1.1 Regional measures

Regional measures have an impact on road safety in the entire region. From the baseline prognosis, $b\_IAs_{A,c,t}$, b_SLC, $b\_SCs_{A,c,t}$ and $b\_FATs_{A,c,t}$ denote the number of injury accidents, slight casualties, serious casualties and fatalities respectively. Assume P regional measures are applied in year t on category c with modification factors given by $V_{IAs,p}$, $V_{SLC,P,}$ $V_{SCs,p}$ and $V_{FATs,p}$. The remaining road safety quantities in year t on category c due to growth scenario A after applying P measures are obtained by multiplying the modification factors and the road safety quantities in the baseline. This is illustrated by the following equations:

$$IAs_{A,c,t} = b\_IAs_{A,c,t} * V_{IAs,1} * ... * V_{IAs,P}$$

$$SLC_{A,c,t} = b\_SLC_{A,c,t} * V_{SLC,1} * ... * V_{SLC,P}$$

$$SCs_{A,c,t} = b\_SCs_{A,c,t} * V_{SCs,1} * ... * V_{SCs,P}$$

$$FATs_{A,c,t} = b\_FATs_{A.ct} * V_{FATs,1} * ... * V_{FATs,P}$$

3.3.1.2 Locational measures

One of the objectives of the model is to assess the effectiveness of locational measures on safety. However, not all measures can be applied on all road or intersection categories, for example a roundabout on a highway. Further, certain measures can only be implemented at locations as it may be very expensive to apply them in the entire region. Such measures are termed locational measures and only have effectiveness at the location they are applied. The effectiveness of locational measures on road safety is obtained as follows. Suppose K locational measures are applied at a particular location, loc, with modification factors given by $V_{IAs,K}$, $V_{SLC,K}$, $V_{SCs,K}$ and $V_{FATs,K}$ for injury accidents, slight casualties, serious casualties and fatalities respectively. The remaining number of injury accidents ($IAs_{A,loc,t}$), slight casualties ($SLC_{A,loc,t}$), serious casualties ($SCs_{A,loc,t}$) and fatalities ($FATs_{A,loc,t}$) at a location, loc, in year t due to growth scenario A after applying K locational measures is given by the following equations:

$$IAs_{A,loc,t} = IAs_{A,loc,t} * V_{IAs,1} * ... * V_{IAs,K}$$

$$SLC_{A,loc,t} = SLC_{A,loc,t} * V_{SLC,1} * ... * V_{SLC,K}$$

$$SCs_{A,loc,t} = SCs_{A,loc,t} * V_{SCs,1} * ... * V_{SCs,K}$$

$$FATs_{A,loc,t} = FATs_{A.loc,t} * V_{FATs,1} * ... * V_{FATs,K}$$

The methodology utilized to compute the effectiveness of measures (section 3.3.1) is based on the assumption that the effect of each measure on road safety is independent of other measures. Nevertheless, this assumption is likely to be incorrect in some cases. One would expect dependence (interactions) between some combinations of measures, for example, the combination of alcohol and drugs on road safety (Van Vlierden and Lammar, 2007). Such interactions are not taken into account by this methodology and in the following section we describe the various forms of interactions to be investigated in future.

3.3.2 Dependence among measures

Though not performed in this first analysis, there are possible interaction effects between measures when implemented simultaneously. For example, the combination of humps and rumble strips reduce the number of injury accidents by 0.27(-0.30,-0.24) (Elvik and Vaa, 2004). These interactions are rarely modelled and only the individual effect of the measures is assumed. The hypothesis is that measures affect road safety independently. To better reflect reality, interactions will be taken into account in a future version of this model. In particular, attention will be paid to: synergism, (the total effect exceeding the sum of the individual effects), substitution (the total effect being less than the sum of the individual effects) and additivity (the total effect equal to the sum of the individual effects).

3.4 Savings

When the effectiveness of the regional and locational measures is calculated, the number of saved IAs, SLC, SCs and FATs can be determined. The number of saved quantities results from the difference between the baseline and the measure prognoses. For example, the saved number of IAs on category c in a specific year t due to growth scenario A equals the difference between the number of IAs according to the baseline prognosis and the measure prognosis in that year. If BP-$IAs_{A,c,t}$ and MP-$IAs_{A,c,t}$ denote the number of IAs in the baseline prognosis and measure prognosis respectively, then the corresponding number of saved IAs, S-$IAs_{A,c,t}$ is obtained as follows:

$$S-IAs_{A,c,t} = BP\_IAs_{A,c,t} - MP\_IAs_{A,c,t}$$

The saved number of slight casualties, serious casualties and fatalities is calculated using the same procedure.

3.5 Cost-benefit analysis

In order to determine the benefits of the applied regional and locational measures, the value of an injury accident, a slight casualty, a serious casualty and a fatality must be expressed in euros. A cost-benefit analysis is one of the tools used to assess the possible measures by comparing their profitability. This analysis allows the comparison of measures with a different life span and justifies the choice between possible combinations of measures. Here, we focus on two criteria namely: net cash value (NCV) and cost-benefit ratio (CBR). The NCV is the difference between the cash value of benefits and costs. A set of measures is profitable when the NCV is positive. However, When the NCV is used; large measure sets (with large costs and benefits) are given preference as they have higher NCV than smaller measure sets. The cost-benefit ratio is the ratio between the cash value of costs and benefits. It is possible to have negative benefits in a cost-benefit analysis. The negative benefits should not be added to the costs but should be deducted from the positive benefits. Adding negative benefits to the costs would wrongfully lead to a lower CBR. This is one of the disadvantages of the CBR, (Janssen, 2005). Another limitation of the CBR is that all effects need to be expressed in monetary terms. On the other hand, a cost-benefit analysis has the advantage of taking into account both the intended effects such as the construction costs and side effects for example noise nuisance (Vlakveld et al., 2005). Further, the CBR is useful for comparing the profitability of measures with varying costs (Janssen, 2005). The NPV and the BCR rank projects according to their net benefit. Thus, it remains a practical tool for the comparison of several possible measures (Ampe et al., 2008).

3.5.1 Benefits

The benefits $B_{c,t}$ in year t on category c, are the products of the number of saved quantities and the values in euros corresponding to a particular road safety quantity. Let W_{IAs}, W_{SLC}, W_{SCs} and W_{FATs} denote the monetary value of an injury accident, a slight casualty, a serious casualty and a fatality respectively. Then, $B_{c,t}$ is given by:

$$B_{c,t} = S-IAs_{A,c,t} * W_{IAs} + S-SLC_{A,c,t} * W_{SLC} + S-SCs_{A,c,t} * W_{SCs} + S-FATs_{A,c,t} * W_{FATs}$$

The total sum of benefits over all categories, C, in year t is obtained by summing the benefits on all categories in that year i.e. $B_{C,t} = \sum_{C=1}^{C} B_{c,t}$.

3.5.2 Costs

The total cost per year is determined by summing the cost of regional and locational measures. Measure costs on road categories are calculated per kilometre while those of intersection categories are estimated per piece. Information with respect to costs of measures will be obtained from authorities in Flanders. In the following sections an explanation of how the costs of regional and locational measures are calculated is given. The calculations for regional costs are presented first and those of locational costs will follow.

3.5.2.1 Costs of a regional measures

Suppose a set m contains j regional measures i.e. m=1, 2,…, j and the cost of measure j in year t denoted by $R_{j,t}$. If these measures are applied in year t, on category c, the total cost $R_{c,t}$ of the applied regional measure set on category c in year t equals the total cost of all measures as follows:

Error! Objects cannot be created from editing field codes. $= \sum_{j=1}^{j} R_{j,t}$

The total cost, R_t, of all regional measures applied in year t on all categories C equals:

$$R_t = \sum_{c=1}^{C} R_{c,t} \ .$$

3.5.2.2 Costs of a locational measures

Let a set m contain n locational measures i.e. m=1, 2,…, n that are introduced at locations belonging to category c in year t. Let $L_{,n,t}$ be the cost of locational measure n applied in year t. The total cost $L_{c,t}$ of the applied locational measures on category c in year t then equals:

$L_{c,t} = \sum_{1}^{n} L_{n,t} * l_m$ with

l_m = length of the road segment if the measure is applied on a road segment

l_m = 1 if the measure is applied on an intersection

The total cost, L_t, of all locational measures applied in year t on all categories C equals:

$L_t = \sum_{c=1}^{C} L_{c,t}$ .The overall cost in year t is determined by summing the cost of regional and locational measures (R_t+L_t).

The cash value of costs (CVC)

The CVC is obtained by expressing the total costs in year t of all the applied measures in terms of the nominal value of the reference year using a discount rate R as below:

$$CVC = \sum_{t=1}^{t} \frac{R_t + L_t}{(1+R)^t}$$ with

R = discount rate for the entire calculation period

L_t = cost of locational measures in year t

R_t = cost of regional measures in year t

t = last year of the calculation period

The cash value of benefits (CVB)

The CVB is calculated by expressing the total benefits over all categories C in year t in terms of the nominal value of the reference year using a discount rate R as follows.

$$CVB = \sum_{C=1,t=1}^{C,t} \frac{B_{C,t}}{(1+R)^t}$$

The net cash value (NCV)

The NCV is the difference between the cash value of costs (*CVC)* and the cash value of benefits (*CVB)* and is computed by the following expression.

$$NCV = CVB - CVC$$

The cost-benefit ratio (CBR)

This indicates how much higher the costs are compared to the benefits and it is computed as:

$$CBR = CVC / CVB$$

Apart from the cost-benefit analysis, there are other evaluation tools. These are briefly described with their advantages and disadvantages. The first method used for measure assessment is the cost-effectiveness analysis (CEA). This method is often used to determine the effectiveness of measures. This is done using a ratio of saved victims versus the cost attached to the measure. This method only includes the intended effects (safety effects in this case) and the costs incurred to attain these effects. However, in order to make policy decisions it is required to have insight into all relevant social effects and not only the intended ones (Vlakveld et al., 2005).

Another tool is the cost utility analysis (CUA). This is comparable to the CEA. The only difference is that the CUA uses quality adjusted life years as a basic concept. While in the CEA counting is done in amount of life years, the CUA uses a weighting for the life years in terms of quality of life. This tool takes into account the severity of an injury and the disability going with the injury. One barrier to this tool is that the kind of medical data required is not always available (Ampe et al., 2008).

Incase of multiple decisions, methods that handle several criteria are required. One of the options is the multi-criteria analysis or multi-criteria decision analysis (MCDA). A

MCDA groups several methods and techniques, structures the decision problem and supports decision making (Ampe et al., 2008).

The preceding section discussed the theoretical concepts of the computational model. In the next section, we illustrate the concepts of the model using real data on the reference situation, baseline prognosis, measure prognosis and savings. The concepts of the cost-benefit analysis are not demonstrated as the effectiveness of measures is the concern of this report.

4. RESULTS

This section illustrates the computation of the effectiveness of measure sets, the effect of the growth scenario (GS1 and GS2) and one case study. Although the model is able to consider both road and intersection categories, only results on highways are presented for illustration purposes. The same approach can be utilized to obtain results on the other road and intersection categories. The reference year considered here is 2002 (section 4.1). First, the effectiveness of a set of measures carried out in one particular year (2003) is shown, the impact of the growth scenarios is tested for the period 2005-2030 while the case study relates to four consecutive years (2003–2006). The measure set involves a regional and a locational measure applied simultaneously (R and L), a regional measure first and then a locational one (R+L) and a locational measure first and then a regional one (L+R). The regional measure is speed reduction (130 to 110, 130 to 120 and 120 to 110km/hr) and the locational one is automatic warning of queues with variable signs. The locational measure is applied on highway segment H1 in 2003. Second, the impact of changes outside the control of the user of the model is studied for the period 2005-2030. The autonomous risk change and the growth in traffic performance are accounted for in these years. The total remaining casualties with respect to two growth scenarios are compared for statistical differences. Third, in the case study, a regional and a locational measure are simultaneously applied in 2003, followed by the implementation of another locational measure (stationary speed enforcement) in 2005 at three locations (highway segments H11, H12 and H13). The results of the reference year, the baseline prognosis and the measure prognosis are presented in the succeeding section. The results of the cost-benefit analysis are not discussed as this is outside the scope of this report.

4.1 The reference year

For each of the 99 highway segments in Flanders, traffic performance figures are obtained relating to 2002. This serves as the reference year in this report. The traffic performance for the 99 highway segments is summed to obtain the traffic performance in the entire region. The road safety quantities per severity level on each segment are available as well. One pitfall of using registered road safety quantities is underreporting. As a remedy, underreporting factors greater than 1 are used to increase road safety quantities in order to better approximate reality. The underreporting factors utilized in this report are obtained from literature (Elvik and Mysen, 1999). It is assumed for now that the general figures apply to highways and are the same for each highway segment. The road safety (Table 4) as well as traffic performance situations and the road safety indicators[3] (Table 5) in the reference year are described.

[3] Road safety indicators: injury accident risk (IAs risk), the number of casualties per injury accident (C per IAs), the number of slight casualties per total casualties (SLC per C), the number of serious casualties per total casualties (SCs per total C) and the number of fatalities per 100 casualties (FATs per 100C) per road or intersection category

Table 4: Road safety situation in 2002

Infrastructure	Severity level	Registered quantity per severity level	Under-reporting factor	Incremented quantity
Highways	IAs	5,268.00	1.75	9,219.00
	SLC	6,868.00	1.90	13,049.20
	SCs	1,008.00	1.30	1,310.40
	FATs	159.00	1.05	167.00
Road H1	IAs	4.00	1.75	7.00
	SLC	4.00	1.90	7.60
	SCs	1.00	1.30	1.30
	FATs	0.00	1.05	0.00
Road H11	IAs	114.00	1.75	199.50
	SLC	167.00	1.90	317.30
	SCs	33.00	1.30	42.90
	FATs	1.00	1.05	1.10
Road H12	IAs	34.00	1.75	59.50
	SLC	44.00	1.90	83.60
	SCs	5.00	1.30	6.50
	FATs	0.00	1.05	0.00
Road H13	IAs	17.00	1.75	29.80
	SLC	22.00	1.90	41.80
	SCs	8.00	1.30	10.40
	FATs	0.00	1.05	0.00

IAs=Injury accidents, SLC=Slight casualties, SCs=Serious casualties, FATs=Fatalities

Table 5: Traffic performance and road safety indicators in 2002

Infrastructure	TP (in 1000s)	IAs risk	C per IAs	SLC per C	SCs per C	FATs per 100 C
Highways	42.7536	215.6311	1.5757	0.8983	0.0902	1.1493
Road H1	0.0470	148.8095	1.2714	0.8539	0.1461	0.0000
Road H11	1.0608	188.0656	1.8107	0.8783	0.1188	0.2906
Road H12	0.3965	150.0555	1.5143	0.9279	0.0721	0.0000
Road H13	0.1851	160.7587	1.7546	0.8008	0.1992	0.0000

IAs=Injury accidents, SLC=Slight casualties, SCs=Serious casualties, FATs=Fatalities, TP=Traffic performance, C = FATs + SCs + SLC

The results in Table 5 show that in 2002 approximately 215 injury accidents occurred on highways per 1000 driven kilometres. On average, there were 1.6 casualties per injury accident. In total, there were 167 fatalities and 1,310 seriously injured persons (Table 4). The results of roads H1, H11, H12 and H13 show the road safety situation on a particular segment in 2002.

Having described the reference situation, the baseline prognosis in which changes in traffic performance and autonomous risk are accounted for is determined. The baseline prognosis for traffic performance, the baseline risk and the various road safety quantities are computed.

4.2 Baseline prognosis

In this section, baseline prognoses for highways in Flanders are discussed. First, with respect to the years following the reference years (2003–2006) for which actual total values is observed. Second, for a longer time period (2005-2030) in which the input of the related growth scenario is assessed.

4.2.1 Baseline prognosis for traffic performance

Traffic performance changes from year to year. This information is incorporated into the model. First, it is assumed that all road segments belonging to a particular road category have the same growth rate in traffic performance as that category. Thus, the same growth rate is assumed for highways. In this case all highway segments (including H1, H11, H12 and H13) have the same growth rate in traffic performance. Table 6 provides the traffic performance in 2003, 2004, 2005 and 2006. The results are obtained by multiplying the traffic performance in the reference year and the growth factor in traffic performance in the baseline year (sections 3.2.1 and 3.2.3). For example, 43.0144 in 2003 (Table 6) is computed by multiplying 42.7536 (Table 5) and 1.0061 (Table 6) i.e 42.7536*1.0061=43.0144 and 44.0338 in 2004=42.7536*1.0061*1.0237.

Table 6: Growth factors and traffic performance in 2003, 2004, 2005 and 2006

Year	Growth factors (%)	TP (in 1000s)				
		Highways	Road H1	Road H11	Road H12	Road H13
2003	1.0061	43.0144	0.0473	1.0673	0.3989	0.1862
2004	1.0237	44.0338	0.0484	1.0926	0.4084	0.1906
2005	1.0094	44.4477	0.0489	1.1028	0.4122	0.1924
2006	1.0367	46.0790	0.0507	1.1433	0.4273	0.1995

TP = Traffic performance

4.2.2 Baseline risk for injury accidents

The baseline risk for injury accidents in year t on category c, $br_{c,t}$, is the product of the accident risk in the reference year and the modification factor for the autonomous risk on road category, c, in year, t ($f_{c,t}$) (section 3.2.2.1). The accident risk in the reference year is obtained as 215.6311 (Table 5) for highways and the overall modification factor for the autonomous risk as 0.9551 (section 3.2.2). It is assumed that this applies to highways and is the same each year. Table 7 presents the baseline risk on highways for the period 2003–2006.

Table 7: Baseline risk in 2003, 2004, 2005 and 2006

Year	$f_{c,t}$	$br_{c,t}$
2003	0.9551	205.9493
2004	0.9551	196.7022
2005	0.9551	187.9702
2006	0.9551	179.4349

The baseline risk for injury accidents decreases from year to year due to the declining rate of the modification factor for the autonomous risk.

4.2.3 Baseline prognosis for road safety quantities

The traffic performance and the baseline risk for injury accidents obtained in Table 6 and Table 7 respectively are used to compute the baseline prognosis for the various road safety quantities. The procedure has been described in sections 3.2.2 and 3.2.4 of the methodology. The baseline prognosis for road safety per severity level in 2003–2006 is provided in Table 8.

Table 8: Road safety situation in 2003, 2004, 2005 and 2006

Highways	**IAs**	**SLC**	**SCs**	**FATs**	**C**
2003	8,858.7778	12,539.3170	1,259.1976	160.4266	13,958.9412
2004	8,661.5448	12,260.1400	1,231.1626	156.8549	13,648.1575
2005	8,350.4043	11,819.7305	1,186.9367	151.2203	13,157.8876
2006	8,268.1709	11,703.3318	1,175.2480	149.7311	13,028.3109
Road H1	**IAs**	**SLC**	**SCs**	**FATs**	**C**
2003	9.7470	13.7965	1.3854	0.1765	15.3585
2004	9.5299	13.4893	1.3546	0.1726	15.0165
2005	9.1876	13.0048	1.3059	0.1664	14.4771
2006	9.0971	12.8767	1.2931	0.1647	14.3345
Road H11	**IAs**	**SLC**	**SCs**	**FATs**	**C**
2003	219.8037	311.1251	31.2432	3.9805	346.3488
2004	214.9100	304.1982	30.5476	3.8919	338.6376
2005	207.1899	293.2707	29.4502	3.7521	326.4731
2006	205.1496	290.3827	29.1602	3.7151	323.2580
Road H12	**IAs**	**SLC**	**SCs**	**FATs**	**C**
2003	82.1612	116.2965	11.6785	1.4879	129.4629
2004	80.3319	113.7073	11.4185	1.4548	126.5805
2005	77.4462	109.6227	11.0083	1.4025	122.0335
2006	76.6835	108.5431	10.8999	1.3887	120.8317
Road H13	**IAs**	**SLC**	**SCs**	**FATs**	**C**
2003	38.3455	54.2768	5.4505	0.6944	60.4217
2004	37.4917	53.0684	5.3291	0.6790	59.0764
2005	36.1450	51.1620	5.1377	0.6546	56.9543
2006	35.7890	50.6582	5.0871	0.6481	56.3934

IAs=Injury accidents, SLC=Slight casualties, SCs=Serious casualties, FATs=Fatalities,

C = FATs + SCs + SLC

From Table 8, a decrease in road safety quantities is observed from year to year. These results depend on the growth in traffic performance and the autonomous risk change. If the growth in traffic performance outweighs the decline in the autonomous risk per year, an increase in road safety quantities is realized and vice versa. In this case, the decline in autonomous risk (-0.0449) is higher than the growth in traffic performance (0.0176) per year for the period 2003–2006 causing a decreasing trend in the road safety quantities.

Secondly, the effect of the selected growth scenario (GS1 or GS2) on road safety is studied for the period 2005-2030. This is done by a comparison of road safety quantities from the two growth scenarios (section 4.2.4).

4.2.4 Growth scenarios GS1 and GS2 (2005 – 2030)

The impact of two different growth scenarios in traffic performance GS1 and GS2 on the injury accidents and casualties is studied for 26 years (2005-2030). During this period only the autonomous risk change and the growth in traffic performance are accounted for. The total growth in traffic performance from 2005-2030 in GS1 and GS2 are obtained as 12.93% (Table 3) and 22% respectively. From 2005 onwards, the growth factor differs between the two scenarios. Consequently, 2004 is now the reference year instead of 2002. The total remaining casualties per year from 2005-2030 from the two growth scenarios are compared for statistical differences. That way, it can be checked whether results from the two growth scenarios differ significantly and can be deduced from each other.

Since the effect of the growth scenarios is studied for 26 years, each with a different growth factor per year, it implies that each severity level has a result per year per growth scenario making a total of 26 results. The total casualties per growth scenario are investigated for statistical differences. More specifically, the 26 results (C1) obtained using GS1 are compared to the 26 results (C2) obtained using GS2 (Table 9). Due to the small sample size per growth scenario (n=26), the Wilcoxon Mann-Whitney test for independent samples is utilized to assess the presence of statistical differences (Lehmann, 1975). Based on the Wilcoxon Mann Whitney test, it can be concluded that there is no evidence that the total remaining casualties from GS1 and GS2 significantly differ (P-value=0.440). provides the remaining number of injury accidents and casualties per severity level and the total number of remaining casualties per year using GS1 and GS2. The road safety quantities in Table 9 are computed using the formulae in section 3.2.2 For example, for IAs in 2004 with GS1, 8,661.5448 is obtained by multiplying the baseline risk for IAs in 2004 (Table 7) and the traffic performance in 2004 (Table 6) i.e 44.0338*196.7022=8,661.5453. The road safety quantities in Table 8 and Table 9 for the period 2005-2006 differ because the growth factors used to compute the former are based on real data while for the latter, growth factors are derived using predicted data.

Table 9: Remaining casualties from GS1 and GS2

Year (GS1)	IAs	SLC	SCs	FATs	C1
2004	*8,661.5448*	*12,260.1400*	*1,231.1626*	*156.8549*	*13,648.1575*
2005	8,392.5948	11,879.4498	1,192.9337	151.9843	13,224.3679
2006	8,120.7738	11,494.6959	1,154.2968	147.0618	12,796.0545
2007	7,848.4493	11,109.2292	1,115.5882	142.1302	12,366.9477
2008	7,576.2617	10,723.9564	1,076.8992	137.2011	11,938.0566
2009	7,306.2776	10,341.8025	1,038.5233	132.3119	11,512.6376
2010	7,038.9363	9,963.3894	1,000.5231	127.4705	11,091.3830
2011	6,775.9988	9,591.2099	963.1488	122.7089	10,677.0676
2012	6,517.7060	9,225.6046	926.4347	118.0313	10,270.0707
2013	6,264.9014	8,867.7677	890.5008	113.4532	9,871.7218
2014	6,017.7139	8,517.8817	855.3652	108.9768	9,482.2238
2015	5,776.8308	8,176.9195	821.1258	104.6146	9,102.6600
2016	5,542.8314	7,845.7008	787.8649	100.3770	8,733.9427
2017	5,315.6635	7,524.1519	755.5750	96.2632	8,375.9900
2018	5,095.7751	7,212.9069	724.3197	92.2811	8,029.5077
2019	4,883.0358	6,911.7812	694.0807	88.4286	7,694.2905
2020	4,677.7789	6,621.2465	664.9052	84.7115	7,370.8633
2021	4,479.8095	6,341.0272	636.7656	81.1264	7,058.9193
2022	4,288.9349	6,070.8503	609.6345	77.6698	6,758.1545
2023	4,104.9640	5,810.4455	583.4846	74.3382	6,468.2683
2024	3,928.1004	5,560.1006	558.3450	71.1353	6,189.5809
2025	3,758.1066	5,319.4799	534.1819	68.0568	5,921.7186
2026	3,594.7517	5,088.2562	510.9624	65.0986	5,664.3172
2027	3,438.1540	4,866.5972	488.7034	62.2627	5,417.5633
2028	3,287.7214	4,653.6647	467.3208	59.5385	5,180.5239
2029	3,143.5569	4,449.6043	446.8290	56.9277	4,953.3611
2030	3,005.4136	4,254.0669	427.1932	54.4261	4,735.6861

Year (GS2)	IAs	SLC	SCs	FATs	C2
2004	*8,661.5448*	*12,260.1400*	*1,231.1626*	*156.8549*	*13,648.1575*
2005	8,476.1484	11,997.7174	1,204.8102	153.4974	13,356.0250
2006	8,276.1006	11,714.5560	1,176.3751	149.8747	13,040.8058
2007	8,064.1746	11,414.5816	1,146.2517	146.0369	12,706.8702
2008	7,842.2713	11,100.4845	1,114.7101	142.0184	12,357.2129
2009	7,613.7408	10,777.0069	1,082.2265	137.8798	11,997.1132
2010	7,379.5078	10,445.4575	1,048.9323	133.6380	11,628.0278
2011	7,142.6133	10,110.1410	1,015.2598	129.3480	11,254.7488
2012	6,903.7729	9,772.0700	981.3108	125.0228	10,878.4035
2013	6,665.0065	9,434.1037	947.3722	120.6989	10,502.1748
2014	6,427.4954	9,097.9144	913.6121	116.3977	10,127.9242
2015	6,192.3093	8,765.0160	880.1825	112.1386	9,757.3371
2016	5,960.4060	8,436.7642	847.2194	107.9390	9,391.9227
2017	5,732.6332	8,114.3592	814.8435	103.8142	9,033.0169
2018	5,509.7320	7,798.8496	783.1601	99.7776	8,681.7873
2019	5,292.3404	7,491.1388	752.2598	95.8408	8,339.2393
2020	5,080.4934	7,191.2760	722.1476	92.0044	8,005.4280
2021	4,874.2149	6,899.2955	692.8269	88.2688	7,680.3912
2022	4,674.4496	6,616.5341	664.4320	84.6512	7,365.6174
2023	4,481.0858	6,342.8337	636.9470	81.1495	7,060.9303
2024	4,294.0086	6,078.0320	610.3557	77.7617	6,766.1494
2025	4,113.1011	5,821.9633	584.6413	74.4855	6,481.0901
2026	3,938.6368	5,575.0146	559.8427	71.3261	6,206.1834
2027	3,770.4441	5,336.9432	535.9356	68.2803	5,941.1590
2028	3,608.7136	5,108.0188	512.9470	65.3514	5,686.3172
2029	3,453.2311	4,887.9382	490.8465	62.5357	5,441.3205
2030	3,303.7879	4,676.4062	469.6045	59.8294	5,205.8401

IAs=Injury accidents, SLC=Slight casualties, SCs=Serious casualties, FATs=Fatalities

C = FATs + SCs + SLC

It can be seen from Table 9 that all road safety quantities decrease from year to year. This reduction is attributed to a greater decline in the autonomous risk compared to the predicted growth in traffic performance from 2005-2030. Figure 4 shows the evolution in the total casualties from 2005–2030. The steep decrease in the number of casualties seems to indicate that the change in autonomous risk is so effective that no additional road safety measures need to be taken. However, it should be noted that the autonomous risk utilized in this case is approximated using the past evolution in the number of casualties and is no guarantee for a similar change in the future.

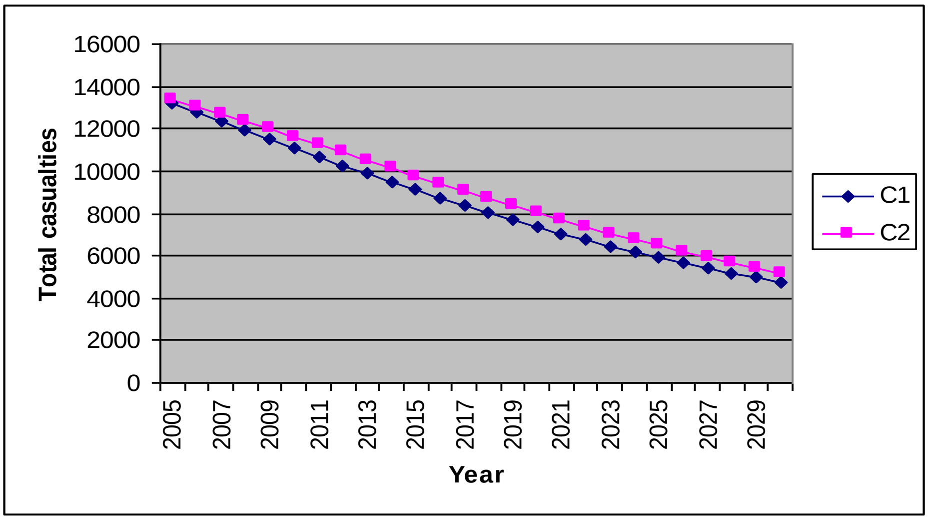

Figure 4: Evolution of the remaining casualties 2005–2030

Once the baseline prognosis representing changes in traffic performance and autonomous risk has been determined, the impact of measures on road safety is assessed. In this report, three options are examined. They comprise applying a regional and a locational measure simultaneously (R and L), applying a regional measure first and then a locational one (R+L) and, applying a locational measure first and then a regional one (L+R). The details on this subject are given in the following section.

4.3 Effectiveness of measures (2003)

This section describes results obtained from applying two measures in three possible ways. All the measures are carried out during 2003. The road safety quantities in 2003 serve as the baseline (Table 8). While the measures have an impact on all road safety quantities, only results on IAs are presented to support the explanations. A measure is regarded as effective if evaluation studies have found that it reduces the number of accidents or the severity of injuries.

4.3.1 Applying a regional and a locational measure simultaneously

The regional measure applies to all highway segments and the locational measure to segment H1. Speed reduction (130 to 110, 130 to 120 and 120 to 110km/hr) on highways and automatic warning of queues with variable signs at segment H1 are simultaneously applied in 2003. The effectiveness of these measures is obtained from literature. In Elvik and Vaa (2004), it is stated that speed reduction reduces the number of IAs by -0.14 (-0.20,-0.07) (modification factor = 0.86) and automatic warning of queues with variable signs lowers IAs by -0.14 (-0.22,-0.08) (modification factor = 0.86). The modification factor is the expected proportion of the remaining IAs after a measure is applied. Multiplying the modification factors and the number of IAs in the baseline prognosis (Table 8), the number of remaining IAs after applying the measures is obtained. The set-up is visually shown in Table 10 and a detailed explanation is given below.

Table 10: Regional and locational measures simultaneously

Infrastructure	BP	R	L	R and L	Savings (%)
Highways	8,858.778 →	7,618.549		7,616.011 →	1,242.767 (14.03)
Road H1	9.747 →		7.209		

BP = Baseline prognosis, R=Regional measure effect, L = Locational measure effect

Applying speed reduction on the baseline figure at highways results into the number of remaining IAs on highways at the regional level (R) i.e 8,858.778*0.86=7,618.549. It should be noted on the other hand that this result incorporates the effectiveness of speed reduction at segment H1. Since road H1 is one of the highway segments in the region, it further implies that speed reduction and automatic warning of queues with variable signs impact simultaneously on IAs at segment H1 i.e 9.747*0.86*0.86=7.209. This provides the number of remaining IAs at segment H1 after applying speed reduction and automatic warning of queues with variable signs simultaneously. The number of IAs at road H1 after applying speed reduction and automatic warning of queues with variable signs simultaneously reduces by 9.747-7.209=2.538. This reduction also occurs to the number of IAs at highways as segment H1 is one of the highway segments in the region i.e 7,618.549-2.538= 7,616.011. This is the number of remaining IAs at highways after applying both speed reduction and automatic warning of queues with variable signs (R and L). The number of saved IAs in the entire region is computed by subtracting R and L from the baseline figure at highways i.e 8,858.778-7,616.011=1,242.767. This approach has a limitation of double counting the effectiveness of speed reduction i.e. at the regional and locational level which calls for more appropriate procedures of assessing the effectiveness of measures as explained in the succeeding sections.

4.3.2 Applying a locational after a regional measure

The same regional and locational measures are used i.e. speed reduction on highways and automatic warning of queues with variable signs on segment H1, but speed reduction is applied first. Applying speed reduction on the IAs in the baseline prognosis yields the number of remaining IAs on highways at the regional level i.e. 7,618.549 (Table 11). This result represents the total number of remaining IAs at all locations in the region. This implies that the number of remaining IAs at segment H1 (8.382) is already incorporated in 7,618.549 (Table 11). Secondly, automatic warning of queues with variable signs is applied on segment H1. However, before implementing the locational measure, the effectiveness of speed reduction is already taken into account at segment H1. The number of remaining IAs at segment H1 after applying automatic warning of queues with variable signs while accounting for speed reduction is 8.382*0.86=7.209. The total number of remaining IAs in the region is 7,617.375 obtained as 7,618.549-(8.382-7.209). Subtracting this from the IAs at highways in the baseline prognosis results into the number of saved IAs in the entire region i.e 8,858.778-7,617.375=1,241.402. An illustration of this set-up is given in Table 11.

Table 11: Locational after regional measure

Infrastructure	BP	R	L after R	R+L	Savings (%)
Highways	8,858.778 →	7,618.549 ↓		7,617.375 →	1,241.402 (14.01)
Road H1	9.747 →	8.382 →	7.209		

BP = Baseline prognosis, R=Regional measure effect, L = Locational measure effect

4.3.3 Applying a regional after a locational measure

Finally, the same regional and locational measures are assessed in this set-up but automatic warning of queues with variable signs is applied before speed reduction. The number of the IAs at segment H1 reduces to 9.747*0.86=8.382. Consequently, the number of IAs in the entire region is reduced by i.e. 8,858.778–1.365=8,857.413 (Table 12). Speed reduction is then applied i.e. 8,857.413*0.86=7,617.375. This is the number of remaining IAs in the region after applying a locational measure first and then a regional one (L+R). The difference between this outcome and the number of IAs in the baseline prognosis is the number of saved IAs in the entire region as a result of L+R i.e. 8,858.778-7,617.375=1,241.402.

Table 12: Regional after locational measure

Infrastructure	BP	L	R after L	L+R	Savings (%)
Road H1	9.747 →	8.382 ↓			
Highways	8,858.778 →	8,857.413 →	7,617.375	7,617.375 →	1,241.402 (14.01)

BP = Baseline prognosis, L = Locational measure, R=Regional measure

4.3.4 Conclusion

Applying one measure after another, results in fewer savings than a simultaneous approach because the effectiveness of the second measure applies on only a smaller proportion of IAs, that is, the second measure only impacts on the remaining IAs after applying the first one. Further more, the simultaneous approach overestimates the effectiveness of the implemented measures and is thus not recommended. The other approaches, R+L and L+R appear to be more appropriate.

4.4 Case study (2003-2006)

This section discusses a case study with respect to four years (2003-2006). In this case study, the change in traffic performance and autonomous risk on highways in Flanders is considered as well as some measures. A regional measure is applied followed by a locational one at segment H1 and in 2005 another locational measure is implemented at three locations (segments H11, H12 and H13). This set-up is given in Figure 5.

2002	2003		2004	2005		2006
Reference	BP(AR, GTP)	MP(R and L)	(AR, GTP)	BP(AR,GTP)	MP(L)	(AR, GTP)
IAs1 →	IAs2 →	IAs3 →	IAs4 →	IAs5B →	IAs5M →	IAs6

BP=Baseline prognosis, MP = Measure prognosis, AR = Autonomous risk change, GTP = Growth in traffic performance, R = Regional measure, L= Locational measure, IAs1, IAs2 and IAs3 are injury accidents in 2002, BP of 2003 and MP of 2003 respectively, IAs4 and IAs6 = Injury accidents in 2004 and 2006 respectively and, IAs5B and IAs5M = Injury accidents in BP and MP of 2005 respectively

Figure 5: Description of the case study

The same regional and locational measures as before are applied in 2003 i.e. speed reduction (130 to 110, 130 to 120 and 120 to 110km/hr) on highways first and then automatic warning of queues with variable signs at segment H1. The procedure of this measure set is explained in section 4.3.2 . The remaining number of IAs in 2003 is used as the starting point for 2004 (Table 11). Since no measure is applied in 2004 (Table 8), the results from 2003 are adjusted for the autonomous risk change (Table 7) and the growth in traffic performance in 2004 (Table 6) to obtain the number of remaining IAs in the entire region in 2004 i.e 0.9551*(7,617.375/43.0144)*44.0338=7,447.781. This yields the starting point for 2005. The autonomous risk change (Table 7) and the growth in traffic performance (Table 6) in 2005 are applied on these results to obtain the number of remaining IAs in the entire region in 2005 (Table 13). Stationary speed enforcement is then implemented at roads H11, H12 and H13 in 2005. Its effectiveness on IAs is obtained from literature (Elvik and Vaa, 2004) as -0.06 (-0.09,-0.04). However, the effectiveness of the regional measure 'speed reduction' in 2003 on segments H11, H12 and H13 is taken into account and the number of IAs at these locations reduced to 189.031, 70.659 and 33.977 respectively (Table 13) in 2003. In addition, the change in autonomous risk and the growth in traffic performance in 2004 are applied at these locations rendering the IAs to decrease to 184.794, 69.075 and 32.328 (Table 13) at H11, H12 and H13 respectively. The effect of autonomous risk and the growth in traffic performance is then taken into account in 2005 and reduces the number of IAs on highways, H11, H12 and H13 to 7,180.242, 178.156, 66.593 and 31.080 respectively. After this, stationary speed enforcement is then implemented at roads H11, H12 and H13 in 2005 and the IAs at the locations reduce to 167.467, 62.598 and 29.215 respectively. The number of remaining IAs in the region in 2005 after stationary speed enforcement is the difference between the IAs in the region in 2005 before applying stationary speed enforcement and the reduction due to stationary speed enforcement at the locations i.e 7,180.242-(10.689+3.995+1.865)=7,163.693 (Table 13). These results serve as the starting point for 2006 in which no measure is applied and the only changes accounted for are those due to the autonomous risk change and the growth in traffic performance in 2006.

The number of saved IAs in 2003 is the difference between the baseline prognosis IAs in 2003 and the remaining IAs in 2003 after applying measures i.e 8,858.778–7,617.375= 1,241.402 (14.01%). The number of saved IAs in 2005 is given by 7,180.242-7,163.693 =16.549 (0.02%). The saved number of IAs only reflects the impact of the applied measures and not all kinds of developments on which the user of the model has no influence. Therefore, the saved number of IAs in 2004 and 2006 are not computed as the decrease in is not due to measures. The results from this case study are presented in Table 13.

Table 13: Case study 2003 - 2006

Infrastructure	2003				2004	2005	2005	2006
	BP AR,GTP	R	L after R	R+L	AR & GTP	AR & GTP	L	AR & GTP
Highways	8,858.778 →	7,618.549		7,617.375 →	7,447.781 →	7,180.242 →	7,163.693 →	7,093.145
Road H1	9.747 →	8.382 →	7.209					
Road H11	219.804 →	189.031 →			184.794 →	178.156 →	167.467	
Road H12	82.161 →	70.659 →			69.075 →	66.593 →	62.598	
Road H13	38.345 →	32.977 →			32.328 →	31.080 →	29.215	

BP = Baseline prognosis, R=Regional measure, L = Locational measure, AR = Autonomous risk change, GTP = Growth in traffic performance

5. CONCLUSION AND FURTHER RESEARCH

The aim of this research is to develop a Flemish computational model to assess the effects of policy measures on road safety at the regional level and compare their costs and benefits so that the most efficient measure sets can be selected. The theoretical concepts as well as a first illustration are presented in this report. More specifically, the main stages of the model – the reference situation, the baseline prognosis, the measure prognosis, the savings and the cost-benefit analysis – have been discussed.

The model developed applies to various road and intersection categories but in this report we only focused on the road category of highways. During the development of the model, several measure sets have been tested. Furthermore, the results from two growth scenarios (GS1 and GS2) have been examined by computing road safety quantities for 26 years (2005-2030) considering only the change in autonomous risk and traffic performance. Lastly, a case study has been carried out for four years. In this case study, the growth in the observed traffic performance for the period 2003-2006 was used and the effect of measures shown.

One of the advantages of the model developed within this research is the aggregation of the results at the regional level. Moreover, the model allows the user to gain insight into the road safety impact of the selection of a particular set of regional and locational measures applied at certain moments in time.

At the same time, some limitations can be mentioned. One weak point is the data used. Detailed, up-to-date data describing the road safety situation, traffic performance and characteristics of road segments and intersections in the whole region of Flanders are scarcely available. The present results are based on road safety and traffic performance data of 2002. 2002 as the reference year does not depict the present road safety picture as in the meantime many developments which affect road safety have taken place. Further, the predictions made based on these data may be misleading. However, these best available data are useful for the purpose of testing the model in this stage. In the future, we aim to incorporate as many Flemish parameters as possible in order to create a realistic and valuable computational model for Flanders. It would be valuable to test a diverse set of Flemish measures (not only related to road safety but also health and environment) as the model is currently illustrated by means of international literature. Other limitations deal with the assumptions considered at this point. For example, the independence of measure effects on road safety, the constant change in autonomous risk and growth in traffic performance and an equal degree of underreporting on all segments. Such assumptions can influence the model results leading to incorrect conclusions.

The next step after presenting the theoretical considerations of the model and a first illustration is to improve the model in various areas (and work on the weaknesses/limitations as described above). The first improvement will be to take the effect of the dependency of measures on road safety into account. It is likely that more than one measure is applied during a particular year. The methodology utilized to compute the effectiveness of simultaneously applied measures in the current model is based on the assumption that the effect of each measure on road safety is independent of other measures. Nevertheless, this assumption is likely to be incorrect in some cases. One would expect dependence (interactions) between some combinations of measures, for example, the combination of road safety campaigns and increased enforcement with respect to seatbelt usage is associated with more reduced accident counts (Vaa et al., 2009). To better reflect reality, interactions will be accounted for in a future version of this model. In particular, attention will be paid to: synergism (the total effect exceeding the sum of the individual effects), substitution (the total effect being less than the sum of the individual effects) and additivity (the total effect being equal to the sum of the individual effects).

A second improvement to the model is to carry out a sensitivity analysis. Given the high number of assumptions and uncertainties in the model, the impact on the end result, for example the number of casualties saved, will be examined.

In addition, a visual component will be added to the model. By linking it to a geographical information system the most unsafe areas in the region can be displayed.

Also the data set will be extended to include intersections and more road categories. Available data with respect to the road safety situation, the traffic performance as well as the characteristics on each intersection and road segment will be used.

Finally, a cost-benefit analysis will be carried out to determine the most cost-effective measures.

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