A COMPUTATIONAL MODEL TO ASSESS THE IMPACT OF A SET OF POLICY MEASURES ON ROAD SAFETY AT THE REGIONAL LEVEL

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ABSTRACT

Policy measures in road safety are frequently taken at a locational level (e.g. at a particular risky intersection). This approach does not facilitate assessing the effects of policy measures in a broader perspective. To achieve this, a method estimating road safety effects at a regional level is a valuable tool. Moreover, several policy measures are often implemented simultaneously in the real world. To model the effect of a set of measures on road safety, methods for estimating the combined effect of policy measures are required. In most cases, the accident modification factors are multiplied. The term “modification factor” refers to the accidents that remain after a measure has taken place. In that case, a measure effect is assumed to be independent of the effects of any other measure and to remain unchanged when introducing other measures. However, this assumption is likely to be incorrect in a lot of cases. One would expect dependence among measure effects applied around the same time. Therefore, the dominant common residuals method will be illustrated in this paper. The basic idea underlying this method is that the most effective measure in a set dominates the others to some extent, by partly or fully influencing the same group of accidents or the same risk factors.

A model assisting regions to assess the road safety effects of a set of measures on a broader area and aiding in selecting measures resulting in the most efficient cost-benefit ratios is discussed. The regional road safety explorer (RRSE) model developed by SWOV (Reurings and Wijnen, 2008) is used as a starting point for the region of Flanders in Belgium. The model consists of five stages: the reference situation, the baseline prognosis, the measure prognosis, the number of saved injury accidents and the cost-benefit analysis. The reference situation describes the current traffic performance (exposure) and the current road safety situation in the region. The model considers a long time perspective and therefore, the main future evolutions in exposure and autonomous risk are taken into account in the baseline prognosis. 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 injury accidents (and/or casualties) and the cost-benefit ratios of the measures taken. By expressing the saved injury accidents in monetary values, the cost-benefit analysis determines whether the applied measures are cost-effective. Through this analysis, policy makers are assisted in selecting policies that make the most efficient use of resources.

1 INTRODUCTION

Road safety is an important issue that can be tackled by means of measures. In practice, different road safety measures are often taken simultaneously, causing potential dependences between them. It is thus useful to consider the dependence of measure effects in a computational model for road safety. So far, the most common way of dealing with more than one measure is to multiply the accident modification factors to estimate the combined effect of road safety measures. This method has been proposed by Smeed (1949). This method assumes that the effectiveness of one road safety measure is independent of the effectiveness of any other measure and remains unchanged when other road safety measures are introduced. In reality, effects will not be entirely independent. Measures are likely to influence some of the risk factors that are the targets of other measures, thus reducing their likely effects (Elvik, 2008; Elvik, 2009). For instance, pedestrian reflective devices will be less effective on well lit roads than on unlit roads; seat belt ignition interlocks will render any other measure designed to increase seat belt wearing less effective (Elvik, 2009). Further, Nilsson (2004) has shown that those who drink and drive are more likely than those who do not, to also speed and not wear seatbelts. If seatbelt ignition interlocks were mandatory, the risk associated with drinking and driving would possibly be reduced as well, and any measure designed to curb it would be less effective. In a study assessing the combined effects of road safety measures, Elvik (2009) demonstrates that the effect of each of six road safety measures (concerning alcohol sales, unemployment, speed cameras, publicity campaigns, drink-driving enforcement and black spot treatment) are considerably weakened when they are combined. Such dependences are not taken into account by most current models, and only the individual effects of the measures are considered. The hypothesis is that measures affect road safety independently. To address this research gap, dependence between measure effects will be taken into account in the model presented here. It should be noted that some measure effects reinforce each other. For example, Vaa et al. (2009) found that a combination of road safety campaigns and increased enforcement with respect to seatbelt usage is associated with more reduced accident counts. However, cases of reinforcing measures are outside the scope of the current paper.

The objective of this paper is to present a computational model assessing the impact of a set of policy measures on road safety at the regional level. The combined effect of road safety measures introduced at the same time is evaluated using the dominant common residuals method.

The remaining of this paper is structured as follows: in Section 2 the essential theoretical concepts of the model are discussed. Next, the effect of measures is assessed taking dependence between measure effects into account. Road safety data on highways in Flanders are used. The outcomes in terms of the number of injury accidents saved and cost-benefit ratios are discussed (Section 3). Finally, uncertainty analysis is performed to examine the robustness of the model output (Section 4) and this paper ends with the discussion, conclusions and topics for future research in Section 5.

2 THEORETICAL CONCEPTS OF THE MODEL

This section describes the structure of the model. The model consists of five stages: the reference situation, the baseline prognosis, the measure prognosis, the number of saved injury accidents and the cost-benefit analysis. The results are computed based on the formulae presented in Reurings and Wijnen (2008). Section 2.1 elaborates on the reference year. Section 2.2 discusses the baseline prognosis. Next, Section 2.3 presents the measure prognosis. Finally, Section 3 gives an overview of the injury accidents saved and the results from the cost-benefit analysis.

2.1 The reference year

The reference year considered is 2002. The reference year describes the traffic performance (exposure) and road safety situation of a region in the starting year of the analysis. Due to data scarcity, only highways in Flanders are considered. Traffic performance in this paper is defined as the number of motorized vehicle kilometres on highways. This number is calculated by multiplying the length of the highway segment and the number of vehicles passing by that segment and the total on all highway segments serves as the regional traffic performance. The regional traffic performance is expressed in thousands as 43.8km (1000s).

For now, the road safety situation is only reflected in terms of the number of injury accidents. It should be noted that the number of injury accidents 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 injury accidents are used. These are factors by which a registered road safety quantity is multiplied in order to obtain a better approximation of the actual road safety quantities. Different highway segments have different underreporting levels (Reurings et al., 2007). Hence, data on underreporting factors are required per highway segment, yet not available. In this paper, it is assumed that all highway segments have the same underreporting factor. In particular, 1.75 (Elvik and Mysen, 1999) is utilized as a factor with which the registered number of injury accidents on all highways is multiplied. Adjusting for underreporting results into 8,954 injury accidents at the regional level in the reference year. In addition to injury accidents, the road safety situation in the reference year can be reflected by the accident risk. By dividing the adjusted injury accidents by the traffic performance in the region, the accident risk is computed as 205. This indicates that in 2002 approximately 205 injury accidents occurred per 1000 kilometres driven on highways.

Subsequent to the reference year is the baseline prognosis in which changes in traffic performance and autonomous risk are taken into account.

2.2 Baseline prognosis

In this section, baseline prognoses are discussed. First, with respect to the baseline risk for injury accidents, followed by the baseline for traffic performance and lastly the baseline for injury accidents. In this paper, interest is in evaluating road safety measures upto 2010. Therefore, eight baseline years are considered (2003-2010).

2.2.1 Baseline risk for injury accidents

The baseline risk for injury accidents, br_t on highways in year t is determined by the injury accident risk in the reference year, r_c, and the autonomous risk change in that year, f_t as: $br_t = f_1 * f_2 ... f_t * r_c$. The autonomous risk refers to 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, improvement of road safety education and, increasing legislation and enforcement (COST329, 2004). The change in autonomous risk is quantified as 0.9551 using time series data of the number of casualties (1970-2006) in Belgium (FOD Economie, 2008). This decrease is assumed constant during the years following the reference year. In other words, the baseline risk for injury accidents is expected to decrease by 0.0449 (1-0.9551) each year due to the collective learning process. Starting from 2003 to 2010, the baseline risk for injury accidents is obtained as 196, 187, 178, 170, 163, 155, 148 and 142 respectively. Note that the baseline risk for injury accidents decreases with time due to the declining rate of the autonomous risk.

2.2.2 Baseline for traffic performance

Traffic performance changes over time. This change is incorporated into the model assuming that all highway segments have the same growth rate in traffic performance each year. The data used to compute the growth factor in traffic performance on highways (1.0176) relate to the period 1985–2006 (FOD MV, 2008). In other words, traffic performance on highways is expected to grow by 1.76% each year. The traffic performance, TP_t in year t is given by: $TP_t = g_1 * g_2 * ... * g_t * TP$ with TP and g_t being the regional traffic performance on highways in the reference year and the growth factor in traffic performance in year t. The traffic performance is respectively calculated as 44.5, 45.3, 46.1, 46.9, 47.7, 48.6, 49.4 and 50.3 (1000s km) for the period 2003, 2004…2010.

2.2.3 Baseline for injury accidents

Based on the baseline risk for injury accidents and traffic performance obtained in Sections 2.2.1 and 2.2.2 respectively, the model predicts the baseline for injury accidents in various baseline years at the regional level. These represent the amount of injury accidents if no regional or locational measures are taken. The baseline for the number of injury accidents, b_IAs_t in year t is given by: $b\_IAs_t = br_t * TP_t$. This results in 8,702; 8,458; 8,220; 7,990; 7,766; 7,549; 7,337 and 7,132 in the period 2003, 2004…2010 respectively. Based on the predicted baseline injury accidents, it is deduced that if no regional or locational measures are applied, the baseline injury accidents decrease at an approximate rate of 2.81% per year. These results depend on the growth in traffic performance on the one hand and the autonomous risk change on the other hand. If the growth in traffic performance outweighs the decline in the autonomous risk per year, an increase in injury accidents is realized and vice versa. In this case, the decline in autonomous risk (-4.49%) is higher than the growth in traffic performance (1.76%) per year for the period 2003–2010 causing a decreasing trend in injury accidents. Apart from the regional figure, the baseline for the number of injury accident in year t on a specific highway segment can be obtained by multiplying the regional baseline risk for injury accidents and the traffic performance on that highway segment in that year.

2.3 Measure prognosis

In this phase of the model, the effectiveness of measures on the number of injury accidents is assessed. Two types of measures are distinguished in the model: regional and locational measures. Regional measures have an effect on road safety in the entire region. However, certain measures can only be implemented at locations as it may be very expensive or unnecessary to be applied in the entire region. Such measures are termed locational measures and only have an effect at the location(s) they are applied. The procedure used to calculate the effectiveness of measures on injury accidents is described in the next section.

2.3.1 Computing the effectiveness of measures

To determine the effectiveness of a measure(s), its modification factor for injury accidents is required. The modification factor is the expected proportion of the injury accidents remaining after the measure is applied. The methods used to estimate the effectiveness of one or several measures are illustrated. First, the computation for the effectiveness of a single measure is described (Section 2.3.1.1) after which the procedure for estimating the combined effect is explained. Two methods are described for estimating the combined effect of road safety measures: the accident modification factor method (Section 2.3.1.2) and the dominant common residuals method (Section 2.3.1.3). The term “residuals” refers to the accidents that remain after a measure has taken effect (so this is the same as the modification factor). The methods are illustrated using regional measures. The effectiveness of locational measures is obtained by replacing the regional quantities with locational ones.

2.3.1.1 Effectiveness of a single measure

Let E_{IAs} denote the effectiveness of a regional measure applied on injury accidents. This implies a modification factor of $1\text{-}E_{IAs}$. Starting from the number of injury accidents computed in the baseline, the remaining injury accidents, IAs_t in year t after applying a regional measure are obtained as: $IAs_t = b\_IAs_t * (1 - E_{IAs})$. The number of injury accidents saved is obtained as: $b\_IAs_t - IAs_t$.

2.3.1.2 The accident modification factor method

This method assumes that the first order effect of a measure is independent of the first order effect of any other measure and remains unchanged on introducing other measures. The first order effect is the effect each measure has when it is the only measure having an effect and everything else is unchanged. This is an often used method. With this method, the remaining injury accidents, IAs_t after applying P regional measures in year t are obtained as: $IAs_t = b\_IAs_t * (1 - E_{IAs,1}) * \dots * (1 - E_{IAs,P})$.

In practice, measure effects will not be entirely independent in a lot of cases. One measure could influence some of the risk factors that are the targets of another measure, thus reducing the expected effects. For example, this is likely to apply to measures that influence speed, since speed is a risk factor for many accidents (Elvik, 2008). To account for this, another method, termed the dominant common residuals method, is presented.

2.3.1.3 The dominant common residuals method

This method assumes that the most effective measure in a set has a dominant effect that weakens the effects of the measures it is combined with. In this case, $IAs_t = b\_IAs_t * \left[(1 - E_{IAs,1}) * \dots * (1 - E_{IAs,P})\right]^{(1 - E_{IAs,P})}$ with P being the most effective measure in the set. Compared to the accident modification factor method, the combined effect of measures estimated using the dominant common residuals is smaller, thereby reflecting the substitution effect of measures. In this paper, the dominant common residuals method is applied in 2006 regarding the combination of signs showing recommended speed in curves and new guardrails along embankments. However, the methods can be extended to other and as many measures as possible.

2.3.2 The assessed measures

In this paper, eight measures obtained from international and regional sources (Elvik and Vaa, 2004; Ministerie van de Vlaamse Gemeenschap, 2007) are examined for the period 2003-2010. They comprise one regional measure and seven locational ones. The regional measure is alcohol or drugs checks applied in 2003 and the locational ones include automatic warnings of queues with variable signs taken at nine highway segments in 2004, congestion warning signals implemented at eight highway segments in 2005, a combination of signs showing recommended speed in curves and new guardrails along embankments taken at 21 highway segments in 2006, fog warning signals applied in 2007 at eight highway segments, more stringent road works warnings on two-lane roads in 2008 at 11 highway segments and scent signals to frighten game in 2009 at 10 highway segments. A measure is applied on the proportion of injury accidents related to it. For example, alcohol or drug checks are applied on injury accidents related to alcohol or drugs. Table 1 lists the measures with the respective years of implementation and the effectiveness in terms of a specific category of accidents (average and confidence interval). In 2010, only the effect of the growth in traffic performance and the change in autonomous risk are taken into account.

Table 1: Measures and effectiveness

Measure; Year of implementation	Effectiveness (Confidence interval %)
Alcohol or drug checks; 2003	Reduce IAs related to alcohol or drugs by 25% (-32,-18)
Automatic warnings of queues with variable signs; 2004	Reduces IAs involving rear-end collisions by 22% (-29,-13)
Congestion warning signals; 2005	Reduce IAs involving rear-end collisions by 16% (-23,-11)
Signs showing recommended speed in curves and new guardrails along embankments; 2006	Signs reduce IAs in curves by 13% (-22,-2) New guard rails reduce IAs in the event of running off the road by 47% (-52,-41)
Fog warning signals; 2007	Reduce IAs related to fog by 84% (-93,-63)
More stringent road works warnings on two-lane roads; 2008	Reduce IAs at road works by 40% (-65,-5)
Scent signals to frighten game; 2009	Reduce IAs involving game by 70% (-90,-5)

IAs = Injury accidents

3 NUMBER OF INJURY ACCIDENTS SAVED AND COST-BENEFIT ANALYSIS

This section demonstrates the evaluation of the measures. Only results of alcohol or drug checks in 2003, automatic warnings of queues with variable signs in 2004 and the dominant common residuals method in 2006 are illustrated. The same procedures apply to the other measures. Table 2 summarizes the results. The total number of injury accidents saved by 2010 results from the sum of injury accidents saved in the previous years (2003-2010).

3.1 Alcohol or drug checks – 2003

Before implementing measures in 2003, the effect of the change in autonomous risk and growth in traffic performance on the number of injury accidents in the region is taken into account. The total number of injury accidents in the region in the reference year is 8,954 (Section 2.1). The change in the autonomous risk and growth in traffic performance in 2003 are applied on 8,954 and the injury accidents in the region reduce to 8,702 (Section 2.2.3). The injury accidents saved due to the change in autonomous risk and growth in traffic performance is calculated as; 252 = 8,954-8,702. Alcohol or drug checks which reduce injury accidents related to alcohol or drugs by 25% (Table 1) are then evaluated at the regional level in 2003. The proportion of injury accidents related to alcohol or drugs is obtained from literature as 7.69% (National Highway Traffic Safety Administration, 2005). The number of injury accidents related to alcohol or drugs in 2003 is 669=7.69%*8,702. The number 502 (669*0.75) represents the remaining injury accidents after applying alcohol or drug checks (Section 2.3.1.1). The saved injury accidents related to alcohol or drug checks after applying the measure is 167 (669-502). 419 (252+167) is the total number of injury accidents saved due to the change in autonomous risk, growth in traffic performance and the regional measure. 419 is deducted from the total number of injury accidents in the region in the reference year to obtain the remaining injury accidents in the region in 2003 i.e. 8,535 = 8,954–419. This is used as a starting point for the year 2004 in which automatic warnings of queues with variable signs are implemented.

3.2 Automatic warnings of queues with variable signs – 2004

This measure is applied at nine highway segments in 2004 and reduces injury accidents involving rear-end collisions by 22% (Table 1). Of the total injury accidents, 19.81% are related to rear-end collisions (Wang et al., 1999). Before implementing the measure, the change in autonomous risk and growth in traffic performance in 2004 are taken into account. These two factors are applied on 8,535 to yield 8,295 (Table 2). The number of injury accidents saved due to the change in autonomous risk and the growth in traffic performance is 240 (8,535-8,295). The number of injury accidents that occur as a result of rear-end collisions (1,643) in the region in 2004 is then obtained as 1,643 (8,295*19.81%). Automatic warnings of queues with variable signs are then applied at the highway segments i.e. the number of baseline injury accidents on each of the highway segments are multiplied by 0.78 and the rear-end injury accidents reduce from 1,643 to 1,598. The number of rear-end injury accidents saved after applying automatic warnings of queues with variable signs is obtained as 1,643-1,598 = 45. The total injury accidents saved in 2004 is 240+45 = 285. The total number of remaining injury accidents in the region in 2004 after applying the autonomous risk change, the growth in traffic performance and automatic warnings of queues with variable signs is 8,535-285 = 8,250. This serves as the starting point of year 2005.

3.3 The dominant common residuals method – 2006

The dominant common residuals method is applied in 2006 for the combination of signs showing recommended speed in curves and new guardrails along embankments. Signs showing recommended speed in curves reduce injury accidents in curves by 13% and new guardrails along embankments reduce injury accidents in the event of running off the road by 47% (Table 1). The product of the modification factors of both measures is raised to the power of the modification factor of the most effective measure. This results into a combined effect of 0.34 ($1-[0.87*0.53]^{0.53}$) and a modification factor of 0.66 (1-0.34) (see Section 2.3.1.3). In other words, when taken simultaneously, these measures reduce injury accidents by 34%. The proportion of injury accidents related to the measures is obtained from literature as 21.75% (Elvik and Vaa, 2004; Comte and Hamson, 2000). These are the injury accidents on which the measures are applied in 2006. The procedure utilized for automatic warnings of queues with variable signs (Section 3.2) is repeated here to obtain the number of injury accidents saved. Table 2 summarizes the number of saved injury accidents with respect to the autonomous risk change, the growth in traffic performance and the measures.

3.4 Overview of injury accidents saved

On the whole, 2,167 (24.20%) injury accidents are saved by 2010. Of these, the measures contributed to 400 (4.47%) accidents while 1,767 (19.73%) saved accidents were attributed to the change in autonomous risk and the growth in traffic performance.

In the next section, the results of the cost-benefit analysis are presented. All measures with a cost-benefit ratio greater than 1 yield more benefits than they cost. A ratio below 1 indicates negative cost effectiveness.

Table 2: Summary of injury accidents saved 2003-2010

Measure; Year of implementation	Regional IAs in previous year	Regional IAs after AR, GTP	Regional savings (%) after AR, GTP	Number of IAs related to measure	Remaining IAs after applying measures	Savings (%)		Remaining IAs in region after AR,GTP, measures
						Measure	Total	
Alcohol or drugs checks; 2003	8,954	8,702	252 (2.81)	669	502	167	419	8,535
Automatic warnings of queues with variable signs; 2004	8,535	8,295	240 (2.81)	1,643	1,598	45	285	8,250
Congestion warning signals; 2005	8,250	8,019	231 (2.81)	1,588	1,558	30	261	7,989
Signs showing recommended speed in curves and new guardrails along embankments; 2006	7,989	7,765	224 (2.81)	1,689	1,565	124	348	7,641
Fog warning signals; 2007	7,641	7,427	214 (2.81)	41	36	5	219	7,422
More stringent road works warnings on two-lane roads; 2008	7,422	7,213	209 (2.81)	172	164	9	217	7,205
Scent signals to frighten game; 2009	7,205	7,002	202 (2.81)	350	330	20	222	6,983
AR,GTP; 2010	6,983	6,787	195 (2.81)	NA	NA	NA	195	6,787
Savings by 2010			1,767 (19.73)			400 (4.47)	2,167 (24.20)	

IAs = Injury accidents AR = Autonomous risk change GTP = Growth in traffic performance NA = Not applicable

3.5 Cost-benefit analysis

This analysis is designed to identify best policy options for which benefits are much greater than costs. This is realized using cost-benefit ratios being the ratio between the cash value of benefits and costs. To determine the benefits of the applied measures, the value of an avoided injury accident expressed in euros is required. The utilized value in this paper is 10,000 euros (European road safety observatory, 2009). In addition, the cost of the applied measures per kilometre must be known to compute the total cost of the applied measures. The measure costs (euros) are obtained from literature (Verstraete, 2000; Elvik and Vaa, 2004). 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% is used for this (SWOV, ECORYS, TNO and MNP, 2008; Elvik et al., 2009).

The average benefit-cost ratio of all implemented measures is 34. This means that each euro spent to prevent an injury accident implies a saving of 34 euros on average. In addition, the benefit-cost ratios are computed per year as 13, 74, 46, 6, 10, 14 and 72 for 2003, 2004…2009 respectively. According to the theory underlying cost-benefit analysis (Elvik, 2007), it is appropriate to adopt all measures since they yield greater benefits than costs. However, it is sometimes not appropriate to fully base road safety policy on cost-benefit analyses. The objective might be to give priority to those measures that provide the largest reductions in the number of road accidents. In this case, alcohol or drug checks and, the combination of signs showing recommended speed in curves and new guardrails along embankments would be given priority (see Table 2). These measures are not the most cost-effective and policy priorities may depart from the results of cost-benefit analyses (Elvik, 2007). Given that the aim here is to identify the most cost-effective measures, a cost-benefit analysis justifies the choice between measures. In this situation, automatic warnings of queues with variable signs, scent signals to frighten game and congestion warning signals should obtain priority.

So far, the number of injury accidents saved in 2010 is computed taking the effect of autonomous risk change, growth in traffic performance and eight measures into account. However, these results are based on a set of assumptions. Therefore, uncertainty analysis is carried out in the next section to examine the robustness of the output. Through this analysis, possible influences of input factors (such as the constant underreporting factors, growth factors in traffic performance, modification factors for the autonomous risk and the independence versus dependence of measure effects, effectiveness of measures) on the results and conclusions drawn from the model can be investigated.

4 UNCERTAINTY ANALYSIS

Since the number of injury accidents saved can largely be influenced by the decisions taken earlier in the model, their robustness needs to be assessed. In other words, the stability in the output given small changes in the input is tested. This is achieved using uncertainty analysis. Section 4.1 describes some theoretical considerations whereas the results are presented in Section 4.2.

4.1 Theoretical considerations of the uncertainty analysis

Generally, uncertainty analysis estimates the uncertainty in the model output taking into account the uncertainty in the model input factors. Instead of one result, a distribution of values and descriptive statistics such as the mean and standard deviation describe the features of the estimated output (Saltelli et al., 2004). A description of steps to perform for this kind of analysis, independently of the method being used, is given in Saltelli et al. (2004). The following steps are taken to assess the robustness of the model results in this paper.

First, the goal of the analysis and the form of the output function should be established. The output of interest is a single value that provides the top-most solution to the question being investigated. In this case, the output of interest is the number of injury accidents saved by 2010 due to the eight road safety measures and accounting for autonomous risk change and the growth in traffic performance.

Next, the input factors to include in the analysis are decided on. As stated above, the input factors considered here comprise underreporting factors, growth in traffic performance, change in autonomous risk, effectiveness of measures and the (in)dependence of measures.

Subsequently, a distribution function for each of the input factor needs to be chosen. The distributions are based on common knowledge. The truncated normal distribution is chosen. An advantage of this distribution is that the sampling of unwanted values can be avoided.

Afterwards, the input sample is generated. A random sample N of 1000 values is generated for each input factor using a truncated normal distribution. This results in a sample of size N (number of runs) by M (number of input factors). Consequently, the model is assessed on the generated sample and an output produced. Each of the N runs is converted into one output value, that is, a given number of saved injury accidents. In the end, 1000 output values are produced and their average taken. The average number of injury accidents saved by 2010 is the output of interest.

Lastly, the model output is analyzed and conclusions drawn. The distribution of the output indicates the variability in the number of injury accidents saved with respect to the different input factors. The uncertainty analysis results are discussed in the next section.

4.2 Results of the uncertainty analysis

The distribution of the injury accidents saved is displayed by the histogram in Figure 1. The average number of injury accidents saved is 2,200 with a standard deviation of 286, a minimum of 1,319 and a maximum of 3,139. The wide range of the number of injury accidents saved (1,319 to 3,139) implies a high uncertainty caused by a change in the input factors. In the future, the factors causing most uncertainty in the injury accidents saved will be identified. That way, the impact of a change in input factors on the number of injury accidents saved becomes clear as well as the most influential factors for which the best options need to be chosen in order to obtain a robust output.

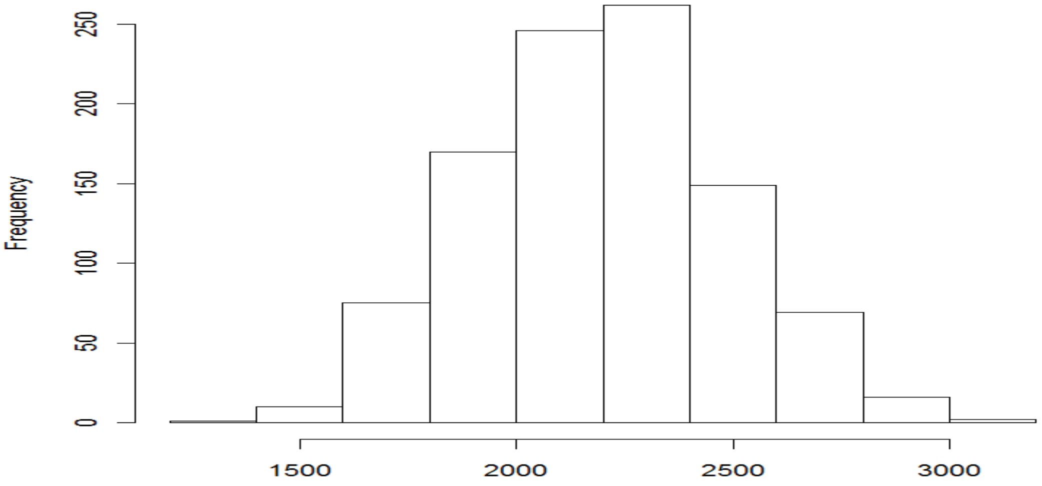

Figure 1: Distribution of injury accidents saved by 2010

5 DISCUSSION, CONCLUSION AND FUTURE RESEARCH

The objective of this paper is to present a model assessing the impact of a set of policy measures on road safety at the regional level. Special attention is devoted to the combined effect of several measures introduced at the same time. Until now, the accident modification factor method is often used. This method assumes that a measure effect is independent of the effects of any other measure it is combined with. However, measure effects are not always independent. Measures can influence some of the risk factors that are the targets of other measures, thus reducing their likely effects. To account for this, the dominant common residuals method is applied. The idea underlying this method is that the most effective measure in a set dominates the others by partly or fully influencing the same group of accidents or the same risk factors. In addition to the combination of measures, effectiveness of single measures is illustrated. The RRSE model developed by SWOV (Reurings and Wijnen, 2008) is used as a starting point. The main outputs of the model are the number of injury accidents saved and the cost-benefit ratios of the measures taken. By 2010, 2,167 injury accidents are saved. Approximately 400 of these are due to the measures taken; the other savings (1,767) can be attributed to the autonomous risk change and the growth in traffic performance. The high number of injury accidents saved due to the change in autonomous risk and the growth in traffic performance seems to indicate that these factors are 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. Cost-benefit analysis indicates that it is appropriate to adopt all measures since they yield greater benefits than costs. Given the assumptions of the model, uncertainty analysis is carried out to examine the robustness of the output. The analysis shows that small changes in the estimates of the input factors cause a large amount of uncertainty in the number of injury accidents saved. Hence, more knowledge concerning the input factors is required to reduce the variability in the output.

The model presented here can assist regions to assess the road safety effects of both regional and locational measures applied in various years. In this respect, the interdependence between measures can be accounted for. Moreover, aggregated results can be obtained and decisions regarding cost-effective measures supported. At the same time, some limitations of the current model can be mentioned. One weak point is the data used. Detailed data describing the road safety and traffic performance in the whole region of Flanders are scarcely available. The present results are based on road safety and traffic performance data of highways in 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. However, these best available data are useful for the purpose of illustrating and fine-tuning the methodology. Other limitations deal with the assumptions considered at this point. For example, the change in autonomous risk and the growth in traffic performance are presumed constant over time and the degree of underreporting equal on all segments. Nevertheless, they have been partly captured through uncertainty analysis. Apart from this quantification of the variability in the number of injury accidents saved, the impact of such model assumptions will be assessed in future research by means of a sensitivity analysis. Through this analysis, the input factors that largely influence the output variance will be identified and their effect quantified. That way, the most influential factors, for which a decision needs to be taken in order to obtain a robust output, can be identified.

In addition to the sensitivity analysis, the following areas will be tackled in future research: the dependency between measures reinforcing each other will be studied, the model will be linked to a geographical information system to display the most unsafe areas in the region, the data set will be extended (including more road and intersection categories) and the effects of environmental and health measures on road safety will be assessed.

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