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Evidence-based and data-driven road safety management

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ABSTRACT

Over the past decades, road safety in highly-motorised countries has made significant progress. Although we have a fair understanding of the reasons for this progress, we don't have conclusive evidence for this. A new generation of road safety management approaches has entered road safety, starting when countries decided to guide themselves by setting quantitative targets (e.g. 50% less casualties in ten years' time). Setting realistic targets, designing strategies and action plans to achieve these targets and monitoring progress have resulted in more scientific research to support decision-making on these topics. Three subjects are key in this new approach of evidence-based and data-driven road safety management: ex-post and ex-ante evaluation of both individual interventions and intervention packages in road safety strategies, and transferability (external validity) of the research results. In this article, we explore these subjects based on recent experiences in four jurisdictions (Western Australia, the Netherlands, Sweden and Switzerland). All four apply similar approaches and tools; differences are considered marginal. It is concluded that policy-making and political decisions were influenced to a great extent by the results of analysis and research. Nevertheless, to compensate for a relatively weak theoretical basis and to improve the power of this new approach, a number of issues will need further research. This includes ex-post and ex-ante evaluation, a better understanding of extrapolation of historical trends and the transferability of research results. This new approach cannot be realized without high-quality road safety data. Good data and knowledge are indispensable for this new and very promising approach.

Contents

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1. Introduction

Over the past decades, road safety has continued to improve in many highly-motorised countries if measured by the number of road fatalities or road crash mortality rates (fatalities per 100,000 inhabitants), see Fig. 1.

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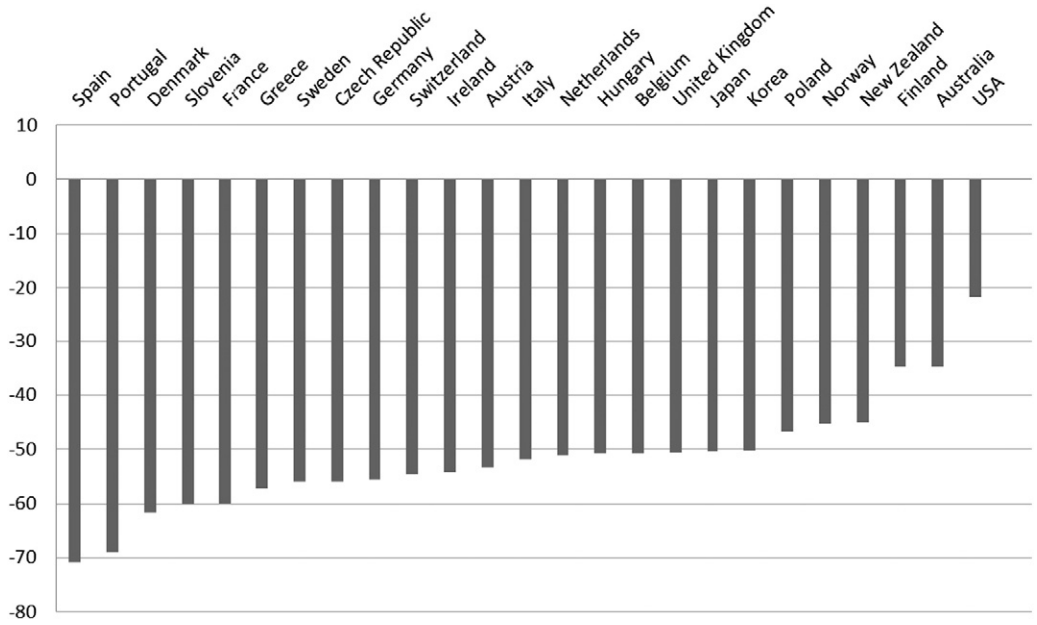

Fig. 1. Changes in number of fatalities 2000–2013 [1].

Johnston [2] argues that the critical success factors in nations with the lowest mortality rates or the largest progress are data-driven problem identification and the development of evidence-driven countermeasure packages formalised in a strategy for effective implementation, combined with ambitious, quantitative targets and transparent lines of institutional accountability. Road safety management captures all these components. However, although Johnston's view seems plausible, the question is whether enough scientific evidence can be found to support it.

The question how exactly the implementation of (a multitude of) road safety interventions has influenced the positive road safety developments in many countries, is not easy to answer. In a Special Issue of Safety Science on *Scientific Research on Road Safety Management* [3], a variety of approaches from different countries were presented. Subjects discussed included how to support decision-making for designing individual safety interventions, how to design strategies with multiple interventions in which interventions (could) interact, and how to evaluate implementations of individual interventions and of implemented strategies. The Editorial to this Special Issue [4] observed that the design and evaluation of road safety programmes appear not to be very popular topics amongst researchers, considering the limited amount of peer-reviews on the subject. Bax et al. [5] concluded that designers of road safety strategies make hardly any or no use at all of the results of these studies. However, we see a growing interest from both the research and the policy-making domains in this area. One of the reasons for this might be that more and more countries and jurisdictions are setting quantitative road safety targets (for example 50% less road fatalities in ten years). Data and knowledge are essential to set realistic targets. As those who set the targets are held accountable for reaching those targets, more and more attention is paid to monitoring progress over time and using the results to improve their performance further (Wegman & Hagenzieker, 2010).

This article explores three different subjects relevant for road safety management:

- Ex-post evaluation of individual interventions and of road safety strategies
- Ex-ante evaluation of individual interventions and of road safety strategies
- Transferability of research results (external validity).

For the exploration of these three subjects, we use the so-called SUNflower approach. This approach presents a conceptual framework to find out what exactly causes road safety to improve in countries [6]. Koornstra et al. [7] started with a comparison between Sweden, the United Kingdom and the Netherlands. The comparison was later expanded by Wegman et al. [8] including six other European countries (Greece, Portugal, Spain, the Czech Republic, Hungary and Poland). The methodological approach is based on a road safety target hierarchy as shown in Fig2 and was adapted from a consultation document on the Road Safety Strategy 2010 of New Zealand [9]. This approach demands a fundamental understanding of traffic safety processes at different levels in the hierarchy of causes and consequences that lead to casualties (number of people killed or injured in a road crash) and of changes in them over time.

The vertical dimension is formed by the different levels in the pyramid. We have the final outcome of the system on top: i.e. the number of people killed and injured and the related social-economic costs. The level of safety measures and programmes reflects policy performance. Policy performance deals with the quality of a road safety strategy and the quality of its implementation. So, it is a combination of how well a strategy has been designed ('evidence-based and data-driven') and how well action plans based on a strategy have been implemented. Implementation of effective measures should lead to a higher safety quality of the road traffic system, which is reflected by a better design of system components and better operational traffic conditions. The indicators at this level are intermediate outcomes between policy output and the number of casualties (final outcomes) (Fig. 3).

Ex-post and ex-ante evaluations deal with the relation between policy output of interventions (safety measures and programmes) and final outcomes in terms of number of people killed or seriously injured and the associated social costs. Of course, this relationship should be a causal one: it should be possible to attribute changes in outcome indicator values solely to implemented interventions. It is advisable to distinguish between evaluation of individual interventions and packages of interventions, as is common practice when designing and implementing a road safety strategy. In case of ex-ante evaluations, we have to rely on research results from elsewhere, collected in different settings and at different times. The question is whether these results can be generalized. In other words: are the research results transferable and do we consider their so-called external validity to be sufficient? Sometimes we are able to collect specific data on the three subjects (ex-post evaluation, ex-ante evaluation and transferability of results),

Fig. 2. A target hierarchy for road safety (Koornstra et al., 2002, and LTSA, 2000).

but most of the time we are dependent on existing data collections and (official) statistics.

In so-called ex-post policy evaluations, one looks backward, and attempts to estimate the safety effects of implemented interventions by comparing the observed road safety situation after implementing certain policies with the (hypothetical) situation where no policies have been implemented. Unfortunately, double blind, randomized controlled trials are not a realistic option for road safety research. This gold standard of evaluation research, as recommended for example in the Cochrane Reviews for health research (www.cochranelibrary.org), is practically never a viable option for road safety research. In road safety, we have to work most of the time with quasi-experimental research designs, as we lack full control of assignment of a treatment or intervention to a target group and our control groups are not fully comparable to the treatment groups. Two procedures are used in road safety to reduce the risk of drawing the wrong conclusions: application of a method called meta-analysis and the use of safety performance indicators when building up evidence for a causal chain between policy output and safety effects.

A meta-analysis may be performed to achieve a higher statistical power and to weigh results from different studies based on sample size and quality of individual studies. So, meta-analysis combines results from different studies to identify a weighted effect size. A wide range of individual evaluation studies for single road safety interventions in specific situations is available [10].

Another approach is the use of safety performance indicators (SPIs) as an intermediate step to establish road safety effects [11,12]. Safety performance indicators are the measures (indicators) reflecting those operational conditions of the road traffic system which influence the system's safety performance. The purposes of SPIs are 1) to reflect the current safety conditions of a road traffic system (i.e. they are not necessarily considered in the context of a specific safety measure, but in the context of specific safety problems or safety gaps), 2) to measure the influence of various safety interventions and 3) to compare different road traffic systems (e.g. countries, regions, etc.).

This approach starts by establishing if policies have been implemented, how they changed SPIs and how these changes can be isolated from other influences (confounding factors). Next, it has to be determined how an SPI is causally related to outcome indicators such as number of people killed or seriously injured.

This approach can be illustrated, for instance, by considering the safety effects of increased seat belt wearing. If we measure a change in the extent of seatbelt wearing in a population of car drivers as a result of an enforcement and mass media campaigns (Arrow 1: changing wearing rates), knowing the effectiveness of seat belts (Arrow 2) in preventing fatalities [13] and the number of people killed in car crashes before the intervention started, it is possible to estimate the number of people saved due to increased wearing rates.

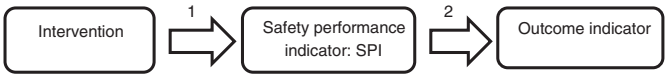

Fig. 3. Relationship between intervention, and intermediate (SPIs) and outcome indicators.

Ex-ante evaluation is carried out to support decision-making on certain interventions that are, for instance, considered for inclusion in a road safety strategy. It uses results from ex-post evaluations, that may be collected in a meta-analysis. Ex-ante research in the field of road safety does not have a very mature theoretical basis and approaches used are similar in structure but greatly differ in assumptions and details. Ex-ante research only delivers good quality results if good quality road safety data are available. Ex-ante evaluation of multiple interventions has to deal with a potential interaction and overlap between interventions [14].

Transferability of research results from one setting to another (also called external validity) deals with generalisation of the findings. When performing ex-ante evaluations, external validity has to be assumed; otherwise this research would be meaningless. OECD/ITF [15] identifies two methods to assess external validity: a deductive and an inductive approach. The deductive approach is based on a theoretical interpretation of the findings. Sometimes, such an approach is possible (impact of speed changes on risks/injuries), at other times it is not, especially in cases where behavioural adaptations to interventions cannot be excluded [16]. The inductive approach is based on the stability of research results when replicating the same intervention under different settings in space (countries) and time. A large variability of reported effects of interventions should generate cautiousness. Variation in results may have different reasons: a random variation (for example, related to a small sample size), or a systematic variation (related to differences in interventions or the context of an intervention, but also to poor research design if it does not control well for confounding factors).

In Section 2, the three issues are discussed in four case studies from four different jurisdictions: the State of Western Australia in Australia, the Netherlands, Sweden and Switzerland. Section 3 goes into how (good) data systems and knowledge (from research) are essential to support road safety management.

2. Road safety management: cases from Western Australia, the Netherlands, Sweden and Switzerland

The issues raised in Section 1 are dealt with in many road safety strategies and a group of four jurisdictions was selected for further elaboration. This selection was based on the information presented in a Special Issue of Safety Science [3] on *Scientific Research on Road Safety Management* (www.sciencedirect.com). These four jurisdictions are relatively safe (with mortality rates in 2013 of 7.6 in Western Australia, 3.4

in the Netherlands, 2.7 in Sweden and 3.3 in Switzerland; 5.6 in the European Union) and are at the forefront of road safety management using 'evidence-based and data-driven' policies. It is interesting to compare road safety management in these four jurisdictions in order to learn how they deal with the issues raised in Section 1. Since we did not select the four cases randomly, we don't claim any generalisation of the results presented. However, other countries could certainly learn from these experiences.

2.1. Western Australia

The State of Western Australia (WA) developed a road safety strategy for the period 2008–2020 using the WA Safe System Matrix [17,18]. The starting point of this matrix, inspired by the Swedes and the Dutch, is the Safe System approach, and potential interventions are classified using two axes: one axis includes safe roads/roadsides, safe speeds, safe vehicles and safe road use, the other axis shows regional breakdowns: all of WA, Metropolitan Perth (the capital city), Regional WA and Remote WA. Western Australia invited Monash University Accident Research Centre (MUARC) researchers to develop an optimal safety strategy for Western Australia based on a model earlier applied for Australia [19]. The modelling work includes evidence-based estimates of the effectiveness of individual road safety initiatives as a combination of initiatives to forecast savings in serious casualties for a 12-year period from 2008–2020. Individual countermeasures are combined to strategy 'packages' and the individual effectiveness is multiplied, if they act upon the same pool of serious casualties in order to avoid double-counting of savings.

These savings are estimated relative to the level of serious casualties that could be expected to occur in the absence of a significant road safety strategy. Two influences were taken into account, as a continuous point of reference, to predict future developments: future growth in serious casualties as a result of increasing exposure (2.6% per annum), based on measured growth between 2001 and 2005. Secondly, it was assumed that serious casualty rates (serious casualty per vehicle kilometre travelled) will drop by an estimated 1.6% per annum based on trends from 1990–1996.

Results of these exercises in terms of serious casualty savings over the 12-year life of the strategy were grouped into safer infrastructure, enhanced enforcement, speed limit reduction, vehicle safety measures and aggregate behaviour change programme. If implemented in isolation, the contribution on savings is almost similar in all five groups. If these interventions were made in combination, a reduction of about 50% in serious casualties was to be expected in 2020.

Parallel to this modelling work, an extensive community consultation programme took place. The community was in strong support of initiatives aimed at maximising compliance with the road rules amongst road users, improving the road network and enhancing the safety of vehicles. The community was more divided on reducing speed limits in regional, urban and shopping areas.

The Road Safety Council in Western Australia (the legislated peak advisory group to Government) concluded from the work of MUARC and the results of the community consultation that it could support all proposed measures except for a system-based speed limit reduction and the effectiveness of certain proposed infrastructure investments. Using these decisions, MUARC published a 'refinement' of their initial report [20]. The Road Safety Council recommended to the Government a new *Strategy Towards Zero 2008–2020* [17]. This strategy was endorsed by the Government and presented to the Parliament. The implementation of interventions and the progress made in bringing down the number of people killed and seriously injured, are closely monitored and a set of key safety performance indicators has been developed. Western Australia has adopted a 'Management by Results' approach on an annual basis similar to the Swedish 'Management by Objectives' approach. This involves annual reviews of progress against the baseline figures (i.e. 2005–2007). The aim of this review is to determine whether or not Western Australia is on track in reaching its 2020 target (i.e. 40% reduction over the 12-year period of the Strategy). Based on this review priorities are established and budget allocations are made. Although annual reviews describe the progress made, they do not report on formal evaluation studies that have been carried out 'explaining' the effectiveness of interventions and used in this mid-term review. However, ex-post evaluation studies are carried out on subjects such as speed limit reductions, speed enforcement strategies, novice drivers, alcohol and drugs.

2.2. The Netherlands

Road safety forecasting and ex-ante evaluation play an important role in decision-making on Dutch road safety policies. This is of relevance because the Netherlands have been working with quantitative targets for several decades and design road safety strategies regularly. The Netherlands follow a bottom-up approach, meaning that ambitious but realistic targets are defined and updated on the basis of expected trends in casualties.

The prevailing policy plan (Road Safety Strategic Plan 2008–2020, *From, for and by everyone*) [21] has separate targets for fatalities and serious injuries (MAIS2+). Every four years, it is checked whether the targets for fatalities and serious injuries are still achievable and whether the current policy strategy should be adjusted. This process starts with forecasts for the numbers of fatalities and serious injuries, based on a two-step approach [22]. First, extrapolation of past casualty rate trends for different road user categories are combined with forecasts on distances travelled (using a lowest and highest scenario). Secondly, the extrapolation is corrected for changes in road safety policies based on the assumption that known changes in policies don't allow for extrapolation of past trends. This approach is similar to the approach proposed by Broughton and Knowles [23].

Forecasts in 2011 showed that the target for serious road injuries in 2020 was not very likely to be met without additional measures. As a result, the Minister of Infrastructure and the Environment decided to update the Strategic Plan. This process in which also other stakeholders such as provinces, municipalities, police and interest groups were involved, resulted in a proposal for additional policy (Policy Impulse for Road Safety). An ex-ante evaluation of the proposed policy was carried out [22], following a similar approach as the one proposed by Siegrist [24]. The ex-ante evaluation showed that also with the Policy Impulse, the target for seriously injured was still not likely to be achieved in 2020. The forecasts and ex-ante evaluation of the Policy Impulse was carried out impartially, i.e. without any of the stakeholders responsible for designing the Policy Impulse being involved.

From the ex-ante evaluation of the Policy Impulse, it could be concluded that the current target for serious injuries was not achievable anymore. However, there appeared to be no political support for reduction of the ambition. Therefore, the Minister of Infrastructure and the Environment decided to postpone the decision on the possible adjustment of the serious injury target. The decision will be based on updated forecasts. In the meanwhile, a broad political and societal discussion on additional, more expensive and far-reaching measures will take place.

Ex-post evaluations of Dutch policy interventions are incidental, and not mandatory or customary in Dutch road safety policy-making. There are some exceptions, however. In the past, some individual measures like the construction of roundabouts, separate bicycle tracks and enforcement on seat belt use were evaluated. Moreover, an evaluation of the effectiveness of a trial on accompanied driving is foreseen in 2015/2016. On a more aggregate policy level, the evaluation of ten years of implementation of Sustainable Safety measures is relevant [25]. This study concluded that all measures together prevented 300–400 fatalities in 2007 and had a benefit–cost ratio of 3.6: 1.

It is evident from the description of the evaluation work that a substantial amount of assumptions needs to be made in the process.

Key assumptions relate to extrapolation of past trends, of penetration levels and of the effectiveness of new policy measures. A complicating factor with regard to new policy measures is that policy plans often discuss broad actions rather than specific measures. As a result, assumptions have to be made concerning detailing policy into specific measures. Finally, also the mobility forecasts are based on certain assumptions, e.g. demographic and economic developments.

2.3. Sweden

Vision Zero was introduced by the Swedish Parliament in 1997 [26]. The Vision, which intends to be holistic and systemic, has formed the basis for road safety work over the past decades. Vision Zero differs fundamentally from earlier approaches to improve road safety and is seen as one of the 'Safe System' approaches in the world [27]. Safe System is expressed most formally in the road safety policies of the Netherlands and Sweden known as Sustainable Safety and Vision Zero respectively. This approach is common in other transport systems and has determined safety programmes in aviation, rail and shipping for several decades. The long-term goal of Vision Zero is that no-one is killed or seriously injured as a result of road crashes and consequently implies a transport system free of health losses. This goal was based on the idea that it is ethically unacceptable to formulate any other goal. However, it triggered a discussion in Sweden on acceptable levels of safety (more than zero) and the price the Swedish society is willing to pay for eliminating risks versus an acceptable risk level.

Today, Vision Zero is a politically adopted public road safety policy with broad political support [28]. One important component of Vision Zero is the shared responsibility between the 'system designers' e.g. national agencies, local authorities etc. and the 'system users', e.g. different road users. One key principle in this chain of responsibility is that the amenability to prevent injuries both starts and ends with the system designers. Today, Vision Zero forms the basis for policy developments. With such a target, an ex-ante evaluation is not required, nor is a cost–benefit analysis. Since 2009, Vision Zero has been linked to an interim target for 2020: the number of fatalities should be no more than half of the average number in the period 2006–2008, and seriously injured a quarter less.

When Vision Zero was introduced, a target of 50% reduction of fatalities between 1997 and 2007 was formulated. This goal was not reached. An evaluation showed that a target for the reduction of the number of fatalities ten years ahead does not give enough guidance to the various stakeholders on what they can to do to achieve it. The interim target for 2020 is now complemented by a framework called 'Management by Objectives'. Most of these objectives are formulated in terms of (well-known) SPIs on human behaviour: compliance with speed limits, drinking and driving, seat belt wearing, crash helmets, safe cars, and safe motorcycles (ABS) but also safe national roads, safe municipal streets and better operation and maintenance of bicycle facilities. Progress is measured annually [29,30] and the results of progress reports are discussed every year at a safety conference of stakeholders. In parallel to the first target for years 1997–2007, a methodology was developed called OLA: objective data, list of solutions/actions, and addressed action plans. The OLA methodology was used when statistics showed an important road safety issue (e.g. too many killed moped drivers). The aim of OLA was to have different stakeholders work together and thus solve a road safety issue. The use of this methodology has had an important impact as it committed stakeholders to implementing solutions and not just recognizing a problem. Today, OLA is used as a complement to the Management by Objectives framework. If an SPI or a specific road user group is recognised as problematic, an OLA could be launched to try and find out the best solution to solve the problem.

The 2014 progress report [30] assesses whether recent developments suggest that targets in 2020 are within reach. It also discusses whether external developments might influence this assessment (weather, demography, economy). And finally progress on all road safety performance indicators is discussed. The main conclusion is that "it is reasonable to expect that continued efforts will allow us to achieve the 2020 interim targets both for fatalities and seriously injured but with the reservation that the level of road safety for bicyclists must increase to reach the injury goal". This conclusion comes from comparing the annual fatality reduction in the years 2008–2013 (8%) with a required further reduction (5% annually). It is further concluded that a better connection should be made between the SPI developments and the development in the number of fatalities and injuries. It was also decided that the targets and the mix of SPIs should be evaluated in 2016.

The main focus of Vision Zero is to control the kinetic energy in the road transport system. To this end, several interventions have been implemented in Sweden with the aim of avoiding collisions and lowering speeds. Examples are an increase of roundabouts, the introduction of speed cameras and a new type of so called '2 + 1 lane' rural roads with median cable barriers between opposite directions. According to the ex-postevaluations of these interventions, single vehicle and head-on crashes have been reduced significantly between 2000 and 2010, largely as a result of these median barriers and the installation of Electronic Stability Control in cars [31]. An evaluation of the large-scale use of roundabouts in an urban area [32] showed that the roundabouts reduced the speed considerably at the junctions and on the connecting sections between them. The result indicated an overall decrease in accident risk by 44%. The Swedish speed camera system is one of the largest in the world [33]. A more modern version of automatic traffic safety control (ATSC) was introduced in Sweden in 2006. The primary aim of the Swedish ATSC is to reduce speed on the sections equipped with cameras and thus decrease the number of fatalities and injuries. An evaluation showed a reduction of fatalities by about 30% and the number of fatalities and severely injured by about 25% [34].

2.4. Switzerland

Siegrist [24] identifies three important questions that have to be answered in supporting policy-making on road safety using ex-ante information: what is the estimated effect of a measure in a given situation? What will be the net effect of a set of countermeasures ('a programme') and thirdly, what will be the return on investments for the national economy. According to Siegrist, the effects of a single measure are determined by five factors. It starts with identifying a high-priority accident type (A), that could be implemented (B) and is effective (C), when application is widespread (D) and when compliance is sufficient (E). By multiplying all factors, a number of preventable fatalities can be estimated. The theoretical potential A (total number of casualties to be prevented) for prevention will not be reached because of the B–E factors. These factors are not constant in time. Siegrist reports on a three-step approach for estimating effects of safety programmes, that comprise a multitude of measures. In step 1, a theoretical benefit is estimated. Step 2 deals with potential overlap (different measure targeting the same crash types) and step 3 relates to synergies that can increase the effects of single measures.

The outlined method has been applied on the Swiss road safety programme *Via sicura* [35]. The programme was adopted by the parliament in 2012 [36]. Before taking a decision, the politicians were informed about the results of the study. Implementation of *Via sicura* is expected to result in a reduction of, on average, 70 to 80 fatalities and 850 to 950 serious injuries less, during the first ten years. This represents a reduction of fatalities by a third and of serious injuries by a quarter. The forecasted safety effects correspond with an economical net benefit of 250 million Swiss Francs annually.

The communication towards decision makers focused on the expected number of prevented fatalities and severe injuries (public health perspective). It was the intention for politicians to base their decision mainly on this information. Nevertheless, as a secondary criterion, the effects on national economy were calculated and

communicated (economic perspective). Decision makers were informed on the material net benefit of the whole programme as well as of each single measure. Of course, it is not certain that both criteria lead to same conclusions. In Switzerland, the results of a cost–benefit analysis should always be revealed even if they are contradictory to the main effects on public health. The economic criterion is also important at the single measure level. Politicians should have the possibility to prioritize the measures that have a good cost–benefit ratio.

After the adoption of the national road safety programme *Via sicura* [36], a range of safety measures was progressively implemented, including infrastructural measures: road authorities are now obliged by law to check and improve the road network. Instruments facilitating implementation of infrastructure improvements were developed, local staffs were trained and progress data were collected and published. In addition, a monitoring system was established. A yearly updated study reports on the trends in several road safety indicators [37]. Additionally, in 2013 a multi-level ex-post evaluation – which not only represents a control but also a steering instrument for further policy developments – was planned.

Although the method applied in Switzerland represents an improvement for forecasts in comparison to the uniform use of single evaluation results, some methodological shortcomings limit the validity of the results. The question still remains how the calculated potential of a safety programme can take into account the predicted trend in accident rates. In two Swiss studies [35,38] this trend was determined on the assumption that the intensity of work in the area of road safety would remain constant. As earlier efforts also included the introduction of new safety measures, at least some of the benefits of the programme are already included in the general trend. The method described here offers the possibility to determine the potential of a programme. However, adjustment to allow for the trend (as determined by the suggested methodology) cannot be done accurately, as the size of the overlap is not quantified.

The estimation of the combined effect of safety measures was based on the assumption that the effect of a single measure may be correlated with the effect of another measure. Based on studies that evaluated the effect of multiple road safety interventions introduced at the same 'target group', Elvik [14] showed that indeed a conservative estimation of the whole programme effect is reasonable. This view supports the method applied in Switzerland.

Without any doubt, the presented ex-ante evaluation method was crucial for the development and political acceptance of the Swiss national road safety programme. The study based on this method had a remarkable impact, as it forecast the effectiveness of safety measures, taking into account existing scientific research, an estimate of the degree of implementation that can be expected at a certain point in time, and the interaction between individual measures. Decision makers in Switzerland expressed their interest in getting information about the expected safety impact of interventions and – additionally – whether the expected benefits justify the investments.

2.5. Conclusion after comparing road safety management in four jurisdictions

All four jurisdictions apply similar approaches and tools for supporting road safety policy-making and the observed differences are marginal. It is striking that road safety strategies and the underpinning scientific work are well documented and published, also in peer-reviewed journals. All four jurisdictions have quantified targets (outcome indicators on people killed and injured in a road crash in absolute terms for a specific year, mostly 2020) and ex-ante evaluations (or modelling as the 'Australians' call that work) elucidate how to decide on certain targets. All approaches are based on a combination of extrapolations of historical trends combined with estimates of safety effects of new interventions. The applied methods and their results are widely accepted as a basis for decision-making. Progress monitoring takes place in all four jurisdictions and a growing interest can be observed in using safety performance indicators (SPIs) for that purpose. SPIs are not yet well linked to outcome indicators. Ex-post evaluations are carried out incidentally and not systematically and no clear signals are presented about feedback from ex-post to ex-ante evaluations. The approach adopted in the four jurisdictions is 'data-hungry' but without good road safety data, this approach will be unworkable. International scientific knowledge is applied widely. However, limited attention is paid to transferability to local conditions.

3. Data collection and analysis for evidence-based policymaking

In this chapter, we will see how 'evidence-based and data-driven' road safety management uses two pillars: road safety data and statistics, and scientific knowledge. It is assumed that such an approach will be more effective and more efficient than traditional approaches (Johnston, 2010). However, the four cases (Western Australia, the Netherlands, Sweden and Switzerland) show that fully evidence-based and data-driven road safety management is too complicated at the moment and not a realistic option. The four cases illustrate that we don't have proven methodologies yet, and that sometimes there are not enough good data to claim a solid scientific basis for road safety management.

On the other hand, we see that all four jurisdictions have made progress over the years when it comes to developing methodologies. This learning-by-doing is heavily based on working with quantitative road safety targets, on carrying out systematic ex-post evaluations and on using good research results as much as possible, for example the results of meta-analysis of road safety interventions. It is obvious from the four cases that good quality data systems are required to support road safety management.

Road safety management can only be effective if decision makers trust the modelling work from researchers and are willing to accept these results. Of course, a political dimension is always present in these decisions when decision makers have to balance positive safety effects against costs and against side effects. Public acceptance or community support is another relevant aspect to include in final decision-making, as is clear from the Western Australia example on speed reduction.

A key issue when designing a road safety strategy is defining a so-called baseline: what would be the level of fatalities and seriously injured in the absence of significant additional road safety interventions. All four jurisdiction use some form of extrapolation, sometimes based on prediction of crashes and sometimes on underlying developments (like in the Netherlands where predictions of crash rates and mobility is done independently and then combined). Extrapolation accepts the assumption that time trends in the past will continue in the future. But one simply does not know if this assumption is correct. That is the reason why Hauer [39] proposed another approach: predict causes of an evolution and based on that predict a future. From the four cases it is clear that such a procedure is too ambitious at this stage. So, this is considered a key issue in further research.

All jurisdictions suffer from the reality that it is not equally easy for the various road safety interventions to carry out ex-ante and ex-post evaluations. For vehicles mainly dealing with passive safety (design, legislation) and infrastructure design/operations, evaluations are relatively easy. Also interventions dealing with speed management (changing speed limits, police enforcement, physical measures to reduce speed) are well documented. Two major areas have caused problems until now: behavioural adaptation and effects of educational interventions. All four jurisdictions are confronted with this. Furthermore, results of scientific studies on behavioural changes are not easy to transfer to other settings because of cultural differences between countries.

The SUNflower pyramid with its different levels/layers turns out to be an excellent framework for road safety management and its related data collection system. The introduction of the intermediate level (safety performance indicators) is seen as a very welcome addition. Monitoring progress using SPIs provides far better understanding than

monitoring outcome indicators only. The approach in Sweden (Management by Objectives) and Western Australia (Managing by Results) seems to be the way forward especially if it becomes possible to link SPI progress with road safety targets (quantitatively in terms of fewer people killed and injured in road crashes) and with a proper understanding of why progress was made, using results of ex-post evaluations. From an effectiveness perspective, a target should be set in numbers, not in rates nor solely based on cost–benefit rankings.

A key component of a Safe System approach is a concept of shared responsibility, not only between the road users on the one hand and road traffic designers/operators on the other. But also between different designers and operators: municipalities, police forces, road authorities, driver training and testing institutions, and the private sector. If the contributions of different stakeholders are identified (in a road safety strategy, for example), periodic progress monitoring is an excellent means of assessing if one keeps up one's promises.

It is observed that measuring SPIs could be expensive, especially if results are required frequently and at a disaggregated (local) level. It is therefore recommended to develop new methods to measure good quality SPIs more efficiently.

Based on the four cases, socio-economic costs do not seem to play a prominent role when designing a road safety strategy. Perhaps this item is of relevance when it comes to comparing road safety with other threats to public health.

Road safety data and statistics are essential for road safety management as is clearly illustrated in all four cases, and it cannot be overemphasised how relevant good road safety data are. As road safety research and road safety management become more international, it is recommended to pay attention to the harmonization of definitions and data collection procedures. This will allow for better international comparison and, as a consequence, for facilitating the jurisdictions in learning from each other. Three areas deserve special attention:

- estimation of costs: cost estimates are relevant for indicating the socio-economic impact of road crashes (and compare that to other health threats) and to make cost–benefit resp. cost-effectiveness estimates. Until now, countries have not been using a standardized format, which means that reliable comparisons are difficult or even impossible.
- measuring exposure (to risk) is a very relevant component of road safety: it should be clear if changes in numbers of people killed or injured are the result of a lower exposure or a lower risk. Measuring exposure to underpin road safety management decisions deserves more attention. Since the costs of collecting these data could be high, new methodologies and modern technologies (ICT) should be used to make exposure data available, especially when information is requested at a disaggregate level.
- including high-quality data on (serious) injuries, next to estimates on crash fatalities. These data are not necessarily reported by the police; but appear in health sector data, mainly coming from hospitals. A challenge is to make the two systems (health and police) compatible or at least linkable with each other and thus increase the quality of injury data. Both data on fatalities and (serious) injuries should be checked for underreporting regularly and procedures (improvement of data collection systems and linking of data from different sources) should be put into place to correct for underreporting.

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