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Does empirical evidence support the effectiveness of the Safe System approach to road safety management?

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Highlights

- Norway has adopted the Safe System approach to road safety management.
- This is associated with a larger decline in killed or seriously injured road users.
- The use of effective road safety measures has increased.
- Causal relationship cannot be established.
- Replication of the study in a different country is encouraged.

Abstract

The objective of this paper is to evaluate the effectiveness of the Safe System approach to road safety management, as implemented in Norway. The paper proposes simple operational definitions of key elements of the Safe System approach to road safety management. The relationship between these elements and changes over time in the number of killed or seriously injured road users in Norway is studied by means of negative binomial regression models. These models do not support a causal interpretation of the findings, but predict systematic patterns in findings that, if replicated in other data sets, at least make a causal interpretation plausible, although not incontestable. The findings reported in this paper are broadly consistent with theoretical predictions and therefore support the effectiveness of the Safe System approach. It is highly likely that the adoption of the Safe System approach to road safety management in Norway has contributed to a larger improvement in road safety than would otherwise have occurred.

Previous Next

Keywords

Safe system approach; Vision Zero; Road safety management; Negative binomial regression; Safety performance

1. Background and research problem

Progress in improving road safety continues to be elusive in many parts of the world. A key question is how it can be speeded up by creating more effective systems for road safety management. The UN General Assembly has proclaimed the period 2021–2030 as the Decade of Action for Road Safety and established a target of reducing the number of road traffic deaths and injuries by at least 50% by 2030. The Safe System approach forms the basis for UN's new Global Plan for the Decade of Action on Road Safety 2021–2030. The Safe System approach has become the state-of-the-art in road safety management, and it is recommended to countries worldwide (ITF, 2022).

The Safe System approach aims to eliminate fatal and serious injuries to all groups of road users through a holistic view of the road system that accepts the fact that humans make mistakes and aims to limit impact energy on the human body to tolerable levels. The Safe System approach is based on the experiences of top performers in road safety, as well as road safety research and research on occupational safety. The approach emerged in the 1990s in Sweden, under the name Vision Zero, and in the Netherlands under the name Sustainable Safety. The Safe System approach involves a change in thinking about how best to prevent traffic injury in the sense that the "blame the victim" approach is replaced by "blaming the traffic system", which highlights the responsibility of system designers (highway authorities, car manufacturers, enforcement agencies) for the safety of the system (Green et al. 2022). The systematic management approach in Safe System is described through six pillars: 1) Road safety management, 2) Safe roads and infrastructure, 3) Safe vehicles, 4) Safe Road users, 5) Safe speeds and 6) Post crash care.

To make these pillars and the Safe System approach operational, it is important to develop concrete and research-based descriptions of what they mean in practice. The Organisation for Economic Cooperation and Development (OECD) and the International Transport Forum (ITF) have called for countries to adopt the Safe System approach to road safety in reports published in 2008, 2016 and 2022. The elements of this approach have been described in increasing detail in these three reports, but even the most recent report (ITF, 2022) recognises that the approach continues to develop and that not all elements of it are sufficiently developed in depth and detail.

Although the Safe System approach is recommended to countries worldwide as the state-of-the-art way of managing road safety, there are few studies that systematically and empirically describe the importance of the concrete road safety management practices in the Safe System approach. In addition, there might be a lack of clarity or disagreement with respect to what the best practices within each of the pillars of the Safe System are.

Thus, there seems to be a clear need for an empirical evaluation of the Safe System approach, to assess the importance of the various road safety management elements and principles and identify the most important. This knowledge is crucial for other countries and actors aiming to implement the Safe System approach.

The aim of this study is to evaluate empirical evidence relevant to the first pillar of the Safe System approach: road safety management. The evaluation is based on data from Norway. During the period 2015–2022 Norway had the lowest number of traffic fatalities per million inhabitants of any highly motorised country (ETSC, 2023). From 2000 to 2021, the number of fatalities declined by 77%, although traffic volume increased by 35%. The question is whether the adoption of the Safe System approach to road safety management contributed to this decline, and in case it did, how large the contribution was. It is almost impossible to give a scientifically rigorous answer to this question (Elvik, 2016, Elvik and Høye, 2022). Nevertheless, this paper attempts to perform an evaluation. The paper will focus on the following questions:

1. What are the characteristics of a Safe System approach to road safety management? Can the concept be operationalised?
2. To what extent can it be determined empirically whether these characteristics are present or not?
3. Does a Safe System approach to road safety management improve road safety performance?

2. Previous research

Several elements of road safety management have been examined in previous studies. The effects of quantified road safety targets have been evaluated in a few studies, the most recent of which are Allsop et al. (2011) and Sze et al. (2014). Allsop et al. (2011) found that a quantified target was associated with a net reduction of road accident fatalities of 10 %. However, this varied between the countries studied from a 22 % reduction to a 6 % increase. The reasons for this variation were not studied. Sze et al. (2014) found that targets referring to a period of 10 years or more were more likely to be achieved than targets referring to shorter periods. They also found that more ambitious targets (aiming for at least 4.5 % annual reduction of fatalities) were less likely to be achieved than less ambitious targets.

Elvik (2012) studied the association between the use of formal tools for road safety management, like road safety audits, network screening and road protection scoring and road safety performance in 17 European countries. The findings were ambiguous and did not clearly show that a more extensive use of safety management tools was associated with a more favourable road safety performance.

Papadimitriou and Yannis (2013) developed three indicators of road safety management: (1) the systematic measurement of road user attitudes and behaviour; (2) the presence of a dedicated budget for road safety, regular evaluation and reporting on programmes and measures; (3) a vision for road safety and a national strategy. These indicators were not found to be statistically associated with road safety performance.

Alfonsi et al. (2016) studied road safety research in different countries. Countries were plotted in a diagram with number of scientific papers per inhabitant on one axis and number of citations per paper on the other. The number of citations was interpreted as an indicator of study quality. Interestingly, the highest number of scientific papers per inhabitant were published by Norway and Sweden. The mean number of citations per paper was highest for papers published by Swiss researchers. There was a tendency for the amount and quality of road safety research to be highest in the countries with the best road safety performance. The data, however, were cross-sectional and did not show trends over time.

The results of these studies do not support the hypothesis that a more professional approach to road safety management is associated with a better road safety performance. Some of the papers, notably Elvik (2012) and Papadimitriou and Yannis (2013), note that it is difficult to evaluate the effects of road safety management.

3. Operational definition of Safe System road safety management

In its most recent report, the International Transport Forum included an appendix providing an operational framework for the Safe System approach. Table 1 lists the characteristics of mature Safe System road safety management.

Table 1. Components of the Safe System approach to road safety management as described by the International Transport Forum.

Key component	Description of road safety management at the mature stage of implementation
Institutional governance	Road safety governance is well-defined, featuring a large-scale institutional structure to prevent system defects.
	This structure includes large-scale and institutionalised funding of road-safety strategies; detailed data collection; and regulation and enforcement aligned with the safe system approach.
	A well-established interdepartmental and multisectoral partnership administers plans, strategies and responsibilities.
	It works with a solid evidence base that is tuned to the insight that professionals can prevent system defects.
	Its role is to support safe behaviour by road users and ensure that crashes will not result in fatalities or severe injuries.
	The partnership operates under well-established principles of good governance to ensure transparency, engagement and accountability.
Share responsibility	Road safety management operates through a partnership model that is adaptive and accountable.
	Objectives, targets, and performance indicators are reviewed and reset based on a shared analysis of outcomes and areas for improvement.
	Road safety management is also closely aligned with related and complementary public policy goals for health and sustainable transport.
Strengthen all pillars	The positive interaction of interventions related to infrastructure, vehicle technology, speed management, and behaviour modification drive progress towards a fail-safe system in which crash forces are always within the physical tolerances the human body can withstand.
Prevent exposure to large forces	The road-safety manager's system-wide programmatic approach contains the most effective standards to deal with vulnerability problems in the system.
	The road-safety manager achieves a high level of compliance with standards for all physical elements of the system and has an integral programmatic approach to rehabilitation.
Support safe road user behaviour	The management of the road-safety system is organised through an institutionalised process of planning, efficiency control and evaluation, and an elaborate mechanism for allocating funding.

Use of the word "operational" suggests that it is possible to determine empirically whether the characteristics listed are present or not, and, possibly, the degree to which they are present. However, almost all the characteristics listed in Table 1 require further elaboration and interpretation to become operational. Varhelyi (2016) developed a check list of 12 points for road safety management. Based partly on his paper, a mature Safe System approach to road safety management consists of at least the following elements:

1. Vision Zero (or a similar idea) is the ultimate objective for road safety. Norway adopted Vision Zero as the long-term objective for transport safety (all modes of transport) in 2001.

2. Road safety policy is developed by a forum in which all key stakeholders are represented. Such a forum was created in Norway in 2002 and its membership has expanded over time.

3. A quantified target has been set for reducing the number of killed or seriously injured road users. Such a target was set in 2010 in Norway and revised in 2014. The revised target is more ambitious than the original target.

4. A road safety action plan has been developed and its implementation monitored. The first such plan in Norway was published in 2002. The current plan is the sixth of these plans and applies to the 2022–2025 term (Statens vegvesen et al, 2002, Statens vegvesen et al, 2006, Statens vegvesen et al, 2010, Statens vegvesen et al, 2014, Statens vegvesen et al, 2018, Statens vegvesen et al, 2022). A report published at the end of each four-year planning term describes the implementation of the plan.

5. The use of road safety measures is evidence-based, i.e. only measures that are known to reduce the number of killed or injured road users are implemented. The use of road safety measures in Norway is partly evidenced-based. The road safety action plan contains both measures that are known to be effective and measures whose effects are not known.

6. A set of safety performance indicators has been developed and are monitored regularly. Norway currently has 14 road safety performance indicators and annual progress is monitored and reported. The number of indicators has expanded over time.

It is seen that the implementation of a mature Safe System approach has taken time in Norway. Vision Zero was adopted in 2001. The first road safety action plan was developed in 2002. The first quantified road safety target was set in 2010. This target was revised and became more ambitious in 2014. The number of road safety performance indicators has increased over time. The use of road safety measures is still only partly evidence based. It is nevertheless correct to say that road safety management in Norway is consistent with the Safe System approach. Thus, referring to Table 1, it is reasonable to say, for example, that the system for road safety management in Norway is based on “a well-established interdepartmental and multisectoral partnership” (the policy making forum), that “transparency, engagement and accountability” is satisfied by the regular publication of reports describing the implementation of road safety plans, and that Norway has adopted “objectives, targets and performance indicators”, which are reviewed regularly.

Several hypotheses that can be tested empirically can be formulated on the basis of the key elements of the Safe System approach to road safety management as outlined above. These hypotheses, and their empirical implications, are outlined in Table 2.

Table 2. Hypotheses about the effects of the Safe System approach to road safety management.

Element of road safety policy	Hypothesis about effectiveness	Expected observations if element is effective
1 Adoption of a long-term ideal (e.g. Vision Zero)	Makes policy more effective	Larger rate of decline in fatalities or injuries than before ideal was adopted
2 Setting a quantified target	Makes policy more effective	Larger rate of decline in fatalities or injuries than before target was set
3 Increasing ambition of quantified target	Makes policy more effective	Larger rate of decline in fatalities or injuries associated with a more ambitious target
4 Increasing time-horizon of quantified target	Ambiguous; one the one hand, it gives more time to implement measures; on the other hand, it reduces the urgency to do so (“we have plenty of time”)	As the hypothesis is ambiguous, no specific pattern of observations is expected
5 Setting sub-targets in addition to main target	Ambiguous; a good idea if targeted measures exist; otherwise it may be little more than wishful thinking	As the hypothesis is ambiguous, no specific pattern of observations is expected
6 Implementation of effective road safety measures	Makes policy more effective	Larger rate of decline in fatalities or injuries than if effective measures are not implemented
7 Increasing the use of effective road safety measures	Makes policy more effective	Larger rate of decline in fatalities or injuries the more extensive the use effective measures is
8 Spatial variation in use of effective road safety measures	More effective policy in some areas than others	Larger decline of fatalities and injuries in areas favoured by effective road safety measures

The first hypothesis is that adoption of a long-term ideal, like Vision Zero, makes road safety policy more effective, which in turn implies that the rate of decline in the number of killed or injured road users should increase. The rate of decline can be measured as the mean annual percentage change in the number of killed or seriously injured road users during a specific period.

The second hypothesis is that setting a quantified target for reducing the number of killed or seriously injured road users makes road safety policy more effective. This hypothesis has the same implications as the first hypothesis, but if, as was the case in Norway, Vision Zero and a quantified target were introduced at different times, the two hypotheses can be tested independently. One would then expect the introduction of a quantified target to generate an additional impact on top of that generated by the adoption of Vision Zero.

The third hypothesis concerns the level of ambition of a quantified target. It proposes that a more ambitious target, e.g. one aiming for an annual reduction of 6 % on the number of killed or injured road users, will be associated with a larger decline in the number of killed or injured road users than a target aiming for, e.g. 3 % annual reduction in the number of killed or injured road users.

The fourth hypothesis refers to the length of the period a quantified target applies to. This hypothesis is equivocal. On the one hand, a longer period gives more time to implement road safety measures, on the other hand it reduces the urgency to do so. No predictions have been developed on the basis of this hypothesis and it is not tested.

The fifth hypothesis, about sub-targets in addition to the main target is also equivocal. Setting a sub-target for a specific group of road users or a specific type of accident can make policy more effective if effective road safety measures influencing the target group exist and are more likely to be implemented than if the sub-target had not been set. Sub-targets often refer to high-risk groups, like inexperienced drivers or motorcyclists. The high risk of these groups is caused by factors that are difficult to influence (Elvik 2010). The hypothesis about sub-targets will therefore not be tested empirically.

The sixth and seventh hypotheses refers to the implementation of effective road safety measures. It is expected that if Vision Zero and a quantified target are adopted, the use of effective road safety measures will increase. This will, in turn, increase the rate of decline in the number of killed or seriously injured road users.

Finally, if there is geographical variation in the use of effective road safety measures, one would expect to observe a larger decline in areas with a more extensive use of effective road safety measures than in areas with a less extensive use of effective road safety measures (hypothesis 8).

4. Method

4.1. The causal pathway

To evaluate the effectiveness of the Safe System approach to road safety management as implemented in Norway, the causal pathway by which it exerts its effects was first modelled. This model is shown in Fig. 1.

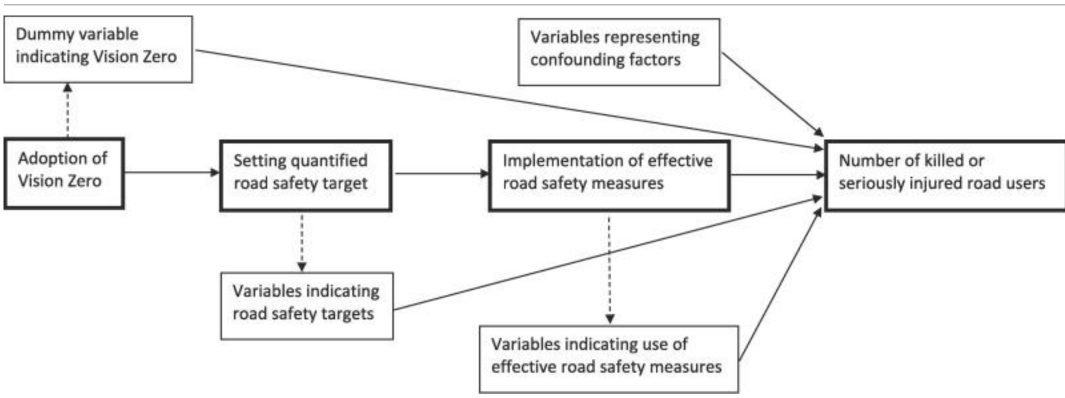

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Fig. 1. Causal model for effects of Safe System approach to road safety management.

The causal pathway is indicated by the boxes with thick lines. It is assumed that the adoption of Vision Zero leads to the setting of a quantified road safety target for the reduction of the number of killed or seriously injured road users. The setting of a quantified road safety target in turns leads to an increased use of effective road safety measures. This leads to a larger reduction in the number of killed or seriously injured road users.

To test this causal pathway empirically, each of the stages must be defined operationally. The boxes with thin lines in Fig. 1 show operational definitions of variables constituting the causal chain. The next section explains how and why the operational definitions were chosen.

4.2. Describing road safety policy

To test the hypotheses about the effects of the Safe System approach to road safety management, data were collected on long-term changes in the number of killed or seriously injured road users and on factors influencing the number of killed or seriously injured road users. Data on road safety measures were of particular interest, in order to determine whether the implementation of road safety measures has changed over time. The study covers the period from 1980 to 2021. This period can be divided into a period before the adoption of Vision Zero (1980–2000) and a period after the adoption of Vision Zero (2001–2021). Data describing the measures that are part of road safety policy are needed for this period. A survey of the availability of such data was made (Tran, 1999, Bjørk, 2017a, Bjørk, 2017b, Elvik and Høye, 2021). The results are shown in Appendix 1. This lists the data that were found for the following road safety measures:

1. New motorways, indicated by total length in kilometres each year
2. New 2+1 roads with a median barrier, length in kilometres each year
3. Number of roundabouts
4. Share (%) of vehicle kilometres performed by cars with frontal air bags
5. Share (%) of vehicle kilometres performed by cars with electronic stability control
6. Share (%) of vehicle kilometres performed by cars scoring 5 stars in the European New Car Assessment program (EuroNCAP)
7. Car driver seat belt wearing in urban areas (%)
8. Car driver seat belt wearing in rural areas (%)
9. Bicycle helmet wearing (%)
10. Citations for traffic offences per million vehicle kilometres
11. Number of speed cameras in operation
12. Kilometres of road with section control (two or more speed cameras measuring speed along a section of road)

It is seen that the completeness of the data varies. Some of the road safety measures have only been used after 2001 (section control) or were used to a very limited extent before 2001 (2+1 roads, cars with 5 EuroNCAP stars). Data for the whole period is needed in order to find out whether road safety policy has become more effective after the adoption of Vision Zero than it was before. Only two of the variables listed in Appendix 1 have complete data for the whole period from 1980 to 2021: length of motorways and citations per million vehicle kilometres. For the length of motorways, data are available from 1962. A motorway, usually referred to as a freeway in the United States, is a highway with at least two lanes in each direction of travel, divided by a median, with no accesses to adjacent properties and only grade separated interchanges. Pedestrians and cyclists are not allowed to travel on motorways. For citations for traffic law violations, data are available from 1972.

The length of motorways has grown over time; more rapidly after 2000 than before. The number of citations per million vehicle kilometres shows a cyclical pattern, with periods of growth alternating with periods of decline. The length of motorways is very highly correlated with many of the other road safety measures listed in Appendix 1. It correlates 0.972 with the length of 2+1 roads with a median barrier (2000–2021); 0.952 with share of vehicle kilometres performed by cars with frontal air bags (1989–2021); 0.948 with the share of vehicle kilometres performed by cars with electronic stability control (1994–2021); 0.986 with share of vehicle kilometres driven by cars with 5 EuroNCAP stars (2000–2021); 0.928 with car driver seat belt wearing in rural areas (1998–2019); 0.970 with car driver seat belt wearing in urban areas (1998–2019); and 0.968 with bicycle helmet wearing (2006–2019). These high correlations suggest that the length of motorways can be interpreted as a general indicator of the use of road safety measures. The coefficient estimated for growth of motorways in a statistical model will no doubt have an omitted variable bias, i.e. the coefficient will reflect not only the growth of motorways, but also the parallel growth of roads with median barriers, share of cars having electronic stability control, increased seat belt wearing, and so on. However, this bias is regarded as harmless as long as the motorway variable is interpreted as a general indicator for the use of all road safety measures.

It is not likely that the increase in motorway construction in Norway after 2000 is mainly the result of adopting Vision Zero and the Safe System approach to road safety management. Although motorways do improve safety (Elvik et al. 2017), they are not primarily a safety measure. In this paper, length of motorways is used as an indicator only, since detailed data on annual use is missing for all other road safety measures. The use of motorway length as an indicator of road safety policy is by no means intended to suggest that building motorways should be an important element of a Safe System approach to road safety. It is a pragmatic choice made only because there is a complete time-series of data and because the length of motorways correlates very highly with other road safety measures and so is likely to at least partly capture their effects in a statistical analysis.

Vision Zero is defined operationally by a dummy variable, taking on the value of 1 from the year 2001 onwards, when Vision Zero was adopted in Norway. The setting of a quantified road safety target is likewise indicated by a dummy variable, taking on the value of 1 from year 2010 onwards. The level of ambition of a quantified target is indicated by the annual percentage reduction in the number of killed or seriously injured road users the target aims for. This is stated as a positive number, e.g. an annual targeted reduction of 5.5 % is stated as 5.5.

In addition to these variables, data on vehicle kilometres of travel have been included. All data used in the study are shown in Appendix 2.

4.3. Choice of statistical model

There are at least three types of statistical models that can be used to analyse the development of road safety over time: (1) Time-series models; (2) Structural equation models; (3) Generalised Poisson models (e.g. negative binomial).

Structural time-series models can include several independent variables, but experience (Commandeur et al. 2013) shows that it is easy to develop overfitted models. Quddus (2008) illustrates the use of integer-valued autoregressive Poisson (INAR) models, but this type of model has so far not found a wide application in accident research. In the examples given by Quddus, the estimated coefficients were close in value to those estimated by means of a negative binomial regression model which included a time trend.

Structural equation models can be used to estimate the coefficients for each stage of a causal path, such as the one shown in Fig. 1. However, like time-series models, structural equation models have not been developed for count data, and the primary objective of this study is to estimate the relationship between the independent variables and changes in the count of killed or seriously injured road users, not the intervening stages of the causal path leading to these changes.

In view of these considerations, negative binomial regression models have been applied. The variables that were included, and the correlations between these variables, are shown in Table 3. The correlations between the independent variables are highlighted in bold italics.

Table 3. Correlation matrix for variables included in the study.

	Year count	Killed	Killed or seriously injured	Vehicle km	Motorway km	Sanctions per vehicle km	Dummy for Vision Zero	Dummy for quantified target
Killed	−0.9633							
Killed or seriously injured	−0.9274	0.9214						
Vehicle km	0.9923	−0.9401	−0.9257					
Motorway km	0.9141	−0.9076	−0.7523	***0.8821***				
Sanctions per vehicle km	0.1643	−0.1999	−0.2963	***0.1835***	***−0.0029***			
Vision Zero (dummy)	0.8550	−0.8065	−0.7210	***0.8657***	***0.8454***	***0.1698***		
Quantified target (dummy)	0.7399	−0.7704	−0.5773	***0.7037***	***0.8953***	***−0.1584***	***0.6604***	
Level of target (%)	0.7411	−0.7735	−0.5757	***0.7043***	***0.8966***	***−0.1804***	***0.6568***	***0.9946***

The models included the following independent variables: vehicle kilometres of travel (million), motorway kilometres, citations per million vehicle kilometres, dummy for Vision Zero, dummy for quantified target, and ambition of quantified target. Vehicle kilometres of travel is almost perfectly correlated with year (0.9923), and therefore captures the long-term trend. The only correlation between the independent variables that is worryingly high, is the correlation between the dummy for a quantified target and the ambition of the quantified target (0.9946).

4.4. Variable redundancy and mediation

Some of the five variables describing aspects of road safety policy and the use of road safety measures may to some extent be redundant. In particular variables indicating the first stages of the causal chain in Fig. 1 may turn out to be superfluous if there is complete mediation. By complete mediation is meant that these variables exert their influence on the dependent variable – the number of killed or injured road users – exclusively through the other variables constituting the causal chain. Thus, if the "only" effect of Vision Zero is to induce an increased use of effective road safety measures, and it does not influence the number of killed or injured road users in any other way, the coefficient for Vision Zero using the number of killed or seriously injured road users as dependent variable should be zero.

If, on the other hand, there is incomplete mediation, the variables at the initial stages of the causal chain will have an influence which is not transmitted by the causal chain, but through a different path. Vision Zero may, for example, influence road user behaviour independently of police enforcement, and thus generate an effect outside the causal chain. The estimated coefficients will indicate whether there is complete or partial mediation. It should be remembered that a coefficient value of zero for the Vision Zero variable, for example, does not necessarily mean that Vision Zero has been ineffective. Quite the opposite, its effect may have been to induce an increased use of road safety measures whose effect is completely captured by the coefficient for the indicator for the use of road safety measures (motorway length).

5. Results

5.1. Estimated models

Table 4 shows estimated regression coefficients in the model for killed road users and the model for killed or seriously injured road users. Both models are based on data for 1972–2021.

Table 4. Coefficients of negative binomial regression models based on data for 1972–2021.

	Model for killed road users			Model for killed or seriously injured road users		
Terms	**Estimate**	**Standard error**	**P-value**	**Estimate**	**Standard error**	**P-value**
Constant term	6.741665	0.1302522	0.000	9.148283	0.1234226	0.000
Million vehicle kilometres	−0.0000128	0.0000035	0.000	−0.0000417	0.0000032	0.000
Motorway kilometres	−0.0023055	0.0004394	0.000	−0.0007819	0.0003692	0.034
Citations per million vehicle kilometres	−0.0606518	0.0249802	0.015	−0.0663924	0.0234353	0.005
Dummy for Vision Zero	0.1739038	0.0686786	0.011	0.1647309	0.0633811	0.009
Dummy for quantified target	0.785396	0.3982454	0.049	−0.0482673	0.3309425	0.884
Ambition of quantified target (%)	−0.175702	0.0811919	0.030	−0.0012739	0.0666962	0.985
Overdispersion parameter	0.0073589	0.0022703		0.0089816	0.0018902	
Autocorrelation of residuals (lag 1)	0.3510			0.7610		
Autocorrelation of residuals 1980–2021 (lag 1)	0.3388			0.6884		
Elvik index of goodness of fit	0.9355			0.9356		

All the policy variables (motorway length, citations, Vision Zero, quantified target, ambition of target) were expected to have negative coefficients. In the model for killed road users, only three of them had negative coefficients. All estimated coefficients in the model for killed road users were statistically significant at the 5 % level. In the model for killed or seriously injured road users, four of the five policy variables had a negative coefficient but only three of them were statistically significant at the 5 % level. It is not known why not all coefficients had the expected sign, but as noted above, some of the variables were highly correlated.

Fig. 2 shows the recorded and model-predicted number of traffic fatalities (killed road users) in Norway from 1972 to 2021. In general, the model tracks the recorded numbers quite well, but it fails to capture a few years which had an abnormally high or low number of fatalities. As seen from Table 4, there was a moderate autocorrelation of the residual terms.

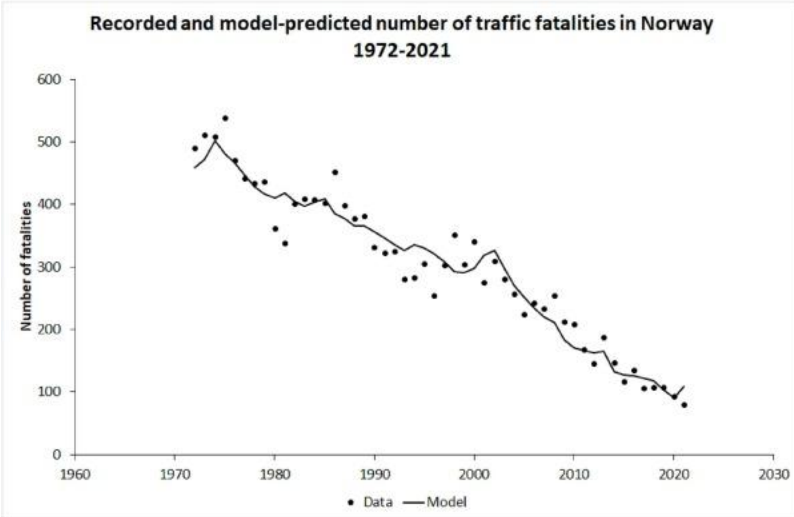

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Fig. 2. Recorded and model-predicted number of traffic fatalities in Norway 1972–2021.

Fig. 3 shows the recorded and model-predicted number of killed or seriously injured road users. The model does not fit the data very well for the first years of the period, until about 1985. There was a sharp decline in the number of killed or seriously injured road users from 1972 to 1980, following by a much slower decline afterwards. Besides, there was a quite high autocorrelation of the residual terms in the model for killed or seriously injured road users.

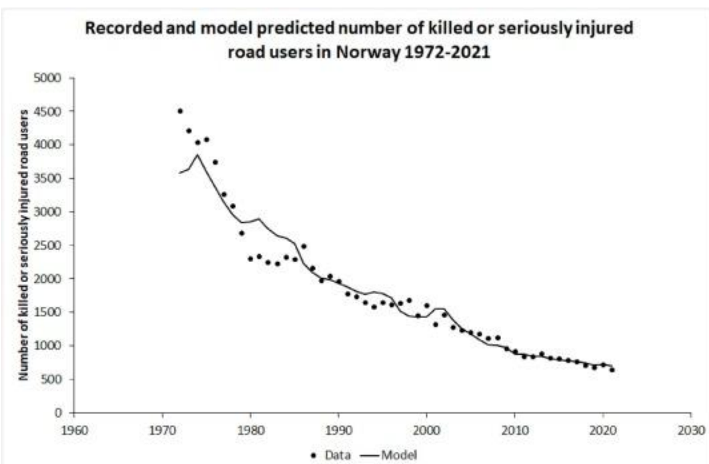

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Fig. 3. Recorded and model-predicted number of killed or seriously injured road users in Norway 1972–2021.

The data suggest that a model for killed or seriously injured road users starting with the year 1980 might fit the data better. Models based on data for the years from 1980 to 2021 were fitted both for killed road users and for killed or seriously injured road users. The estimated coefficients and goodness-of-fit statistics are shown in Table 5.

Table 5. Coefficients of negative binomial regression models based on data for 1980–2021.

	Model for killed road users			Model for killed or seriously injured road users		
Terms	**Estimate**	**Standard error**	**P-value**	**Estimate**	**Standard error**	**P-value**
Constant term	6.445832	0.3346031	0.000	8.527421	0.1034712	0.000
Million vehicle kilometres	−0.00000397	0.00000508	0.435	−0.0000223	0.0000027	0.000

Terms	Model for killed road users			Model for killed or seriously injured road users		
	Estimate	Standard error	P-value	Estimate	Standard error	P-value
Motorway kilometres	−0.0025286	0.0004555	0.000	−0.0011761	0.0002301	0.000
Citations per million vehicle kilometres	−0.0493427	0.0287871	0.087	−0.0489119	0.0155757	0.002
Dummy for Vision Zero	0.1036345	0.0762377	0.174	−0.0006659	0.0414335	0.987
Dummy for quantified target	0.7868588	0.4073294	0.053	−0.0023808	0.2062604	0.991
Ambition of quantified target (%)	−0.1750787	0.0832479	0.035	−0.0124339	0.0416767	0.765
Overdispersion parameter	0.0078558	0.0026286		0.0026985	0.0007271	
Autocorrelation of residuals (lag 1)	0.4129			0.4449		
Elvik index of goodness of fit	0.9198			0.9777		

The model for killed road users is not better than the model based on data for 1972–2021. It has a higher value for autocorrelation of the residuals, a lower value for the Elvik-index of goodness-of-fit and in general higher P-values for the coefficients for each of the variables. The model for killed or seriously injured road users, on the other hand, is better than the model based on data for 1972–2021. It has a better fit to the data and lower autocorrelation of the residuals. All coefficients are negative, as expected, but the coefficients for the Vision Zero variables (Vision Zero, quantified target, ambition of target) are not statistically significant. In the following analyses, the models fitted for 1980–2021 will be applied.

5.2. Hypothetical counterfactuals

A road safety measure, or a policy consisting of a set of measures, has an effect on road safety if it produces changes in the number of killed or seriously injured road users that would not otherwise have occurred. To say what would otherwise have happened, i.e. without the road safety measures or policy, one may use a comparison group. However, in a study of long-term changes in a single country, no meaningful comparison group can be defined. History does not produce counterfactual changes in addition to actual changes.

However, it is possible to generate what might be termed "hypothetical counterfactuals" by relying on the models fitted. This can be done in two ways:

1. A hypothetical number of killed or injured road users is estimated by omitting a specific variable but keeping all other variables in the model. As an example, by omitting motorway kilometres, one estimates what the number of killed or injured road users would have been if no new motorways had been built, while keeping constant the associations between all other variables and the number of killed or seriously injured road users.

2. One may estimate new models, omitting one variable at a time, to see what the model-predicted number of killed or seriously injured road users is when a variable is omitted.

In this paper, the first option has been chosen. The reason for doing so, is that the objective is to estimate a counterfactual (i.e. not observed) number of killed or seriously injured road users. If, for example, the coefficient for motorway kilometres is omitted from any of the models, while retaining the coefficients for all other variables, a higher number of killed or injured road users will be estimated, reflecting what this number could have been if the contribution from motorways was absent.

If, on the other hand, the second option is chosen, the values of all coefficients for the variables included in the model are likely to change compared to the estimates in the full model (i.e. the model including all variables). The reason is that the statistical software will then try to fit a model predicting the actual number of killed or seriously injured road users as accurately as possible, and not try to predict a counterfactual number which is higher or lower than the actual number. Since fewer variables are included, the variables still included in the model will have larger omitted variable bias than in the full model. There is, as noted above, omitted variable bias even in the full model, but this is viewed as harmless as long as the motorway variable is interpreted as a general indicator for the use of road safety measures.

5.3. Assessing potential causality of regression coefficients

The procedure outlined above for establishing a counterfactual (albeit a hypothetical one) presumes that regression coefficients can be interpreted as showing causal relationships. Such an interpretation is controversial, but Hauer (2010) offers the following guideline for assessing causality in regression coefficients:

"Suppose … that two regressions that differ in some variables yield roughly the same θ for a treatment. The interpretation of such a consistency depends on the 'state of nature'. If θ depends only weakly on all variables included in one regression but not the other, then the consistency could be viewed as genuine. However, if θ depends strongly on the not-in-common variables, then the noted consistency should carry little causal weight."

To assess whether a certain regression coefficient depends strongly or weakly on variables that are included in one regression model but not the other, one can fit models omitting one variable at a time as indicated above. Comparisons can then be made between six models: one full model including all variables, and five other models in each of which one of the policy variables (motorways, citations, Vision Zero, quantified target, ambition of target) has been omitted. The full model was compared to each of the other five models. The constant term and vehicle kilometres of travel were included in all models. The other variables were omitted one at a time. The values of the coefficients were then compared.

To give an example, in the model for killed or seriously injured road users based on data for 1980–2021 (confer Table 5), the coefficient for motorway kilometres was −0.0011761 in the full model. In the other models it was −0.0011878 (omitting citations), −0.0011774 (omitting Vision Zero), −0.0011762 (omitting quantified target) and −0.0011891 (omitting ambition of target). These values are remarkably close. No matter which variable is omitted, the value of the coefficient is almost the same. It does not depend on variables included in one model but not the other.

The similarity of the coefficients can be tested formally by computing standardised differences. A standardised difference is defined as follows:

$$\text{Standardised difference} = \frac{C_A - C_B}{\sqrt{SE_A^2 + SE_B^2}}$$

C_A and C_B are two estimates of a coefficient referring to the same variable. SE_A and SE_B are the standard errors of the two estimates (produced by the software used to estimate the coefficients). Standardised differences were computed for the differences between the full model and the reduced models, based both on data for 1972–2021 and on data for 1980–2021. The standardised difference indicates a statistically significant difference between two coefficient estimates if its value is greater than 1.96 or smaller than −1.96.

In total 120 standardised differences were computed. Four of these were statistically significant. This is not more than one would expect by chance. In general coefficient estimates were very similar across different models and lent strong support to the assumption that "all else remains equal" when one estimates a counterfactual number of killed or seriously injured road users by omitting a variable and retaining the others with coefficients identical to the full model. Details can be found in Appendix 3.

5.4. Estimation of counterfactual numbers of killed or seriously injured road users

To illustrate how the hypothetical counterfactual was estimated, consider the full model for killed or seriously injured road users based on data for 1980–2021 (Table 5, right half). The full model estimates a total of 62,436 killed or seriously injured road users during 1980–2021. The recorded number was 61117.

The period covered by this model can be divided into the years before the adoption of Vision Zero (1980–2000) and after the adoption of Vision Zero (2001–2021). There was a downward trend in the number of killed or seriously injured road users in both periods. If an exponential trend line is fitted to the model-predicted number of killed or seriously injured road users in the before period, it indicates an annual decline of 2.23 percent. The trend line fits the predicted numbers very well (R-squared 0.9761). A similar trend line for the after period (using the year 2000 as baseline, since 2001 was the first year Vision Zero could have an effect) shows an annual decline of 4.00 percent (R-squared 0.9686).

The motorway variable was then omitted from the model, while the other variables were retained with identical coefficients to the full model. The total predicted number of killed or injured road users was then 76858. In other words, if no motorways had been built, the number of killed or seriously injured road users would have been higher than it actually was.

Trends were then estimated for the before- and after-periods based on the counterfactual number of killed or seriously injured road users. For 1980–2000, the annual decline was 1.81 percent (R-squared 0.9483). For 2001–2021 it was 1.56 percent (R-squared 0.8132). The interpretation of these results is as follows: If no motorways had been built during 1980–2000, there would still have been a declining trend in the number of killed or seriously injured road users (1.81 percent per year), but it would have been weaker than the actual trend (2.23 percent per year). The difference in trend shows the contribution that building motorways during 1980–2000 made to the trend in this period.

5.5. Identifying the contribution of road safety policy

The contribution that road safety policy has made to the decline in the number of killed or seriously injured road users before and after the adoption of Vision Zero can now be identified. The difference between the trend including the policy variables and the counterfactual trend omitting them show their contribution to the declining trend. Table 6 summarises the estimates.

Table 6. Estimated contribution of road safety policy to decline in killed or seriously injured broad users.

Injury severity	Period	Annual trend (%)	Total decline (%)	Counterfactual decline (%)	Contribution of policy to decline (%)
Killed road users (#)	1980–2000	−1.89	31.72	18.78	40.8
	2001–2021	−6.03	71.17	21.93	69.2
Killed or seriously injured road users	1980–2000	−2.23	36.30	30.34	16.4
	2001–2021	−4.00	57.57	22.61	60.7

(#) Estimates are based on model for 1972–2021, applied to a before-period from 1980 to 2000.

For killed road users, the annual decline increased from 1.89 % before the adoption of Vision Zero to 6.03 % after. Road safety policy contributed to 40.8 % of the decline in the before-period and 69.2 % of the decline in the after-period. For killed or seriously injured road users, the annual decline was 2.23 % in the before-period and 4.00 % in the after-period. Road safety policy contributed to 16.4 % of the decline in the before-period and 60.7 % of the decline in the after-period. Fig. 4 shows a graphic presentation of the results for the after-period for killed or seriously injured road users.

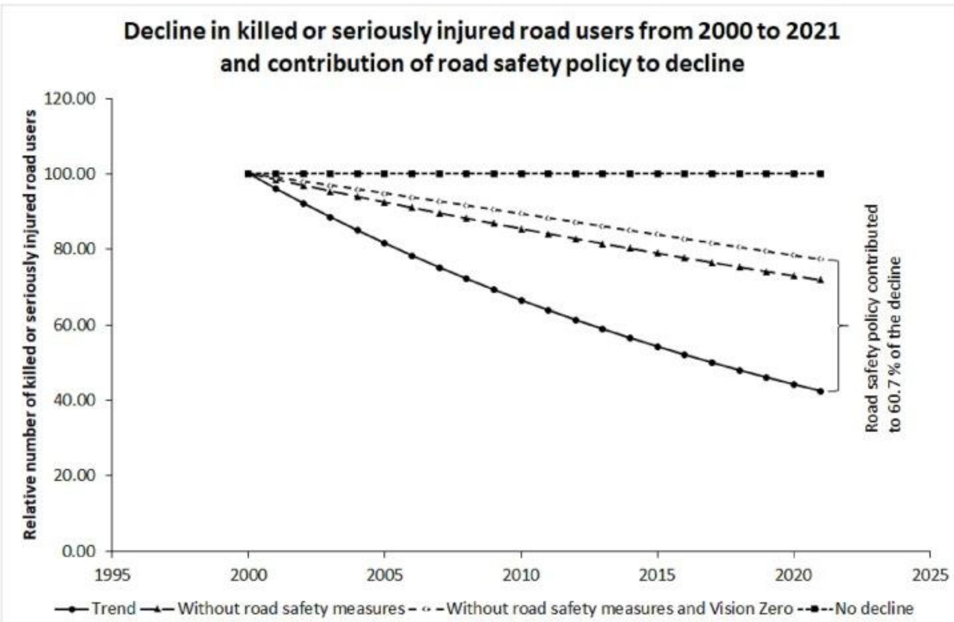

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Fig. 4. Decline in killed or seriously injured road users in Norway from 2000 to 2021 and contribution of road safety policy to the decline.

The lower curve shows the trend. The other curves show what the trend would have been without the motorway variable and without both the motorway variable and the Vision Zero variables. The horizontal curve on the top shows what the numbers would have been without any decline. The initial values of all curves were set to 100, to enable them to be interpreted as percentage changes.

5.6. The effects of enforcement

As noted above, the amount of police enforcement, as indicated by the number of citations for traffic law violations per million vehicle kilometres, has varied over time in a cyclical pattern. To determine if there is a relationship between these cyclical changes and changes in the number of killed or seriously injured road users, differences-in-differences estimates of effect were developed. These estimates were developed as follows.

To test the similarity of trends over time when the enforcement variable was included to the counterfactual time series not including the enforcement variable, exponential trend lines were fitted to the model-predicted number of killed or seriously injured road users for 1980–2021 for the full model and for a model not including the enforcement variable. The annual trend in the full model was a decline of 3.32 % in the number of killed or seriously injured road users. The annual trend in the model not including the enforcement variable was a decline of 3.33 % in the number of killed or injured road users. These trends are regarded as comparable.

The annual changes in enforcement were converted to relative changes. From 1980 to 1981, citations per million vehicle kilometres declined from 5.37 to 5.05. This is a relative change of 5.05/5.37=0.940, or a decline of 6 %. Numbers lower than 1 show decline, numbers greater than 1 show increase. Similarly, annual changes in the number of killed or injured road users were computed. In the full model, the predicted number was 2408.06 in 1980 and 2438.14 in 1981. There was an increase of 2438.14 – 2408.06=30.08 from 1980 to 1981. Can this increase be attributed to the decline in enforcement? In order to answer this question, the change from 1980 to 1981 that would have occurred if there had been no change in enforcement must be estimated. This change is shown by the counterfactual model, in which the enforcement variable was omitted. This model indicates a decline in the model-predicted number of killed or seriously injured road users of 6.42 from 1980 to 1981. Thus, the differences-in-differences estimate of the change in the number of killed or seriously injured road users from 1980 to 1981 attributable to the decline in enforcement is 30.08 – (-6.42)=36.50. Stated as a percentage of the number of killed or injured road users predicted for 1981 by the full model, this corresponds to an increase of 1.5 %, or a relative number of 1.015.

Similar relative changes in enforcement and the number of killed or seriously injured road users were estimated for each year up to 2021. The relationship shown in Fig. 5 then emerged.

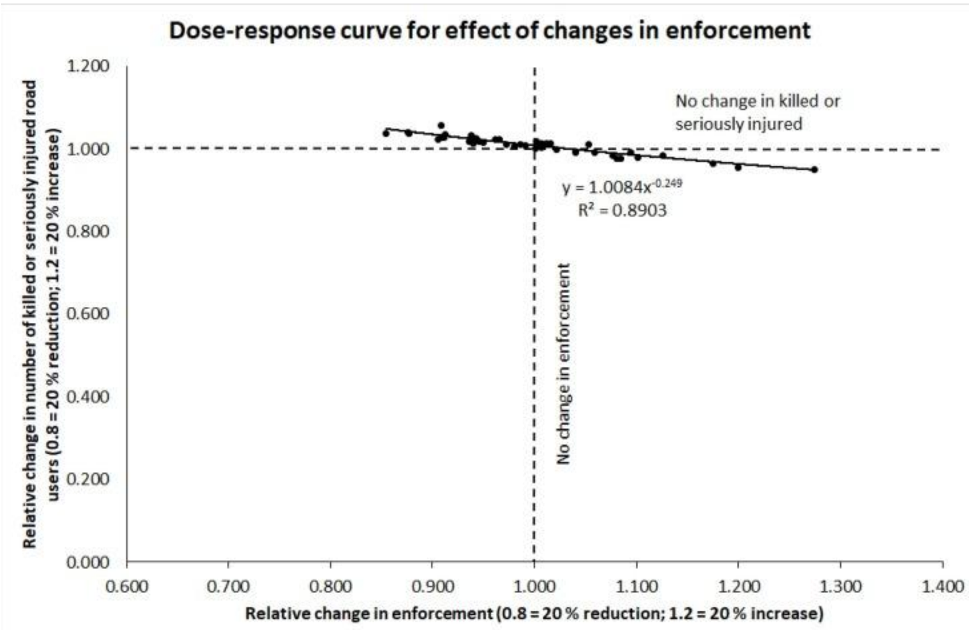

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Fig. 5. Dose-response curve for effects of changes in the amount of enforcement.

It is seen that reductions in enforcement are associated with an increase in the number of killed or seriously injured road users and an increase in enforcement associated with a reduction in the number of killed or seriously injured road users. A power function fits the relationship quite well.

5.7. Changes in the use of road safety measures from before to after 2000

The data presented in Appendix 1 shows that the building of motorways has expanded greatly after 2000. The mean annual growth from 1980 to 2000 was 3.6km. From 2001 to 2021, the mean annual growth was 21.9km. Is there information about the use of other road safety measures before and after Vision Zero was adopted in Norway? Table 7 puts together information contained in Appendix 1.

Table 7. Data on the use of selected road safety measures before and after 2000.

Road safety measure	Indicator of use of measure	Mean before 2000	Mean after 2000
Building motorways	New kilometres per year	3.6	21.9
Building 2+1 roads with median barrier	New kilometres per year	0.3	16.5
Converting junctions to roundabouts	Number built per year	39.9	59.3
Vehicle kilometres by cars with airbags	Annual growth in percent	2.9	3.1

Road safety measure	Indicator of use of measure	Mean before 2000	Mean after 2000
Vehicle kilometres by cars with electronic stability control	Annual growth in percent	1.6	3.9
Vehicle kilometres by cars scoring 5 stars in EuroNCAP	Annual growth in percent	0.0	2.8
Seat belt wearing by drivers – rural areas	Mean annual percentage point change	−1.2	0.4
Seat belt wearing by drivers – urban areas	Mean annual percentage point change	−1.2	1.2
Bicycle helmet wearing	Mean annual percentage point change	3.6	2.4
Citations er million vehicle kilometres	Mean annual percentage point change	−0.7	0.9
Number of speed cameras in operation	New cameras per year	10.8	3.8
Length of roads with section control - kilometres	Kilometres added per year	0.0	13.6

Very few 2+1 roads with a median barrier were built before 2000; annual growth was only 0.3 km. From 2001, annual growth increased to 16.5 km. According to Elvik and Høye (2021), the number of junctions converted to roundabouts was about 40 per year from 1984 to 1995. Between 2005 and 2015, this increased to 59 junctions per year. The annual percentage growth in vehicle kilometres performed by car with frontal airbags, electronic stability control or a score of 5 stars in EuroNCAP was in all cases stronger after 2000 than before. Seat belt wearing by car drivers tended to decrease during 1980–2000 but has increased after 2000 (Bjørk, 2017a). Bicycle helmet wearing increased more rapidly from 1990 to 1996 (Fosser, 1996) than from 2006 to 2019 (Bjørk, 2017b). The mean annual number of citations per million vehicle kilometres had a weak tendency to decline before 2000 but has increased on the average by 0.9 percentage points each year after 2000. New speed cameras were installed at a higher rate before 2000 than after (Elvik and Christensen 2004).

On the whole, as far as it can be documented, the use of road safety measures has increased after 2000. This supports the causal chain shown in Fig. 1. However, there is no way of knowing whether the use of effective road safety measures would have increased even if Norway had not adopted Vision Zero and quantified road safety targets. It can be shown that the number of killed or seriously injured road users would probably have been greater if use of effective road safety measures had not increased, but this does not explain why the use of effective road safety measures increased.

6. Discussion

To rigorously evaluate the effects of the Safe System approach to road safety management, for example in the form it has been adopted in Norway after 2001, is impossible. Some of the most important obstacles to rigorous evaluation include:

1. It is not possible to perform a well-controlled evaluation. By well-controlled is meant an experimental or quasi-experimental evaluation which by design or analysis controls for as many potentially confounding factors as possible. The basis for an evaluation consists of historical data only and these only represent what actually happened, not, as needed for establishing causality, what would have happened if a Safe System approach had not been adopted.

2. One may try to account for confounding factors by means of statistical analysis. However, controlling statistically for confounding is difficult because: (a) There are no data on all confounding factors, and (b) those for which data can be found tend to be highly correlated. Any statistical analysis is likely to be affected both by omitted variable bias and by collinearity problems.

The analyses reported in this paper cannot be said to have solved these obstacles in a fully satisfactory way. Negative binomial regression models were developed, but these only contained a few variables. Those that were included are likely to be affected by omitted variable bias. The residuals terms had some degree of autocorrelation. If more variables had been included in the models, they would probably have become overfitted, as the models that were developed came very close to explaining all the systematic variation in the number of killed or seriously injured road users.

It is easy to identify weaknesses in the negative binomial regression models but probably not as easy to develop any models that are much better or serve the objectives of this paper more effectively. Ultimately, the models that were developed were instrumental in providing a basis for showing that road safety policy, as indicated by the motorway variable, has become more effective after the adoption of Vision Zero than it was before. As noted, the motorway variable should probably be interpreted as an indicator for road safety policy in general, since its development over time is very highly correlated (correlation coefficients of more than 0.9) with other developments, like seat belt wearing, number of speed cameras in operation, share of cars having electronic stability control, and so on. Results that made sense were obtained although the models serving as the basis for this were not state-of-the-art.

However, the study presented in this paper should be viewed as a case study only. It deals with a single case, Norway, during a specific period. Replication of the study for other countries is essential in order to establish findings of general validity. No country is exactly like Norway or can copy Norwegian road safety policy in all respects. Hence, to develop a basis for advising other countries with respect to the implementation of the Safe System approach, more varied experience in implementing this approach is needed. Countries that have introduced the Safe System approach in addition to Norway include, at least, the Netherlands and Sweden. It would be informative to conduct similar studies for those countries. Preliminary data that have been collected suggest that a replication might be possible. In that case, a possible indicator for road safety policy in the Netherlands would be the number of roundabouts. In Sweden, a policy indicator might be the number of drivers checked by the police.

7. Conclusions

The main findings of the study presented in this paper can be summed up as follows:

1. The annual percentage decline in the number of killed or seriously injured road users in Norway has been considerably greater after Vision Zero was adopted in 2001 than it was before.

2. The greater decline in the number of killed or seriously injured road users can be linked statistically to an increased use of effective road safety measures.

3. These measures were implemented as a part of the Safe System approach to road safety management in Norway.

4. It is not possible to establish causal relationships between the variables, but replication of a similar study in one or more other countries could strengthen the basis for a causal interpretation if the main results of the study are replicated.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

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Appendix

Table 8

Appendix 1. Data on variables describing road safety measures.

	Motorway	**2+1 roads with**	**Number of**	**Vehicle km by cars**	**Vehicle km by cars with**	**Vehicle km by cars**
Year	kilometres	median barrier	roundabouts	with frontal air bags	electronic stability control	with 5 EuroNCAP stars
1980	68.8					
1981	68.8					
1982	70.1					
1983	70.1					
1984	70.1		30			
1985	70.1					
1986	70.1					
1987	70.1					
1988	72.0					
1989	72.0			0.0		
1990	77.5			0.6		
1991	78.6			1.7		
1992	78.6			3.3		
1993	90.1			5.4		
1994	90.1			8.0	0.0	
1995	99.2		469	10.9	0.3	

	Motorway	2+1 roads with	Number of	Vehicle km by cars	Vehicle km by cars with	Vehicle km by cars
1996	113.7			14.3	1.1	
1997	113.7			18.1	2.5	
1998	136.4			22.2	4.5	
1999	140.8			26.7	6.9	
2000	140.8	5.0		31.4	9.8	0.0
2001	170.8	9.0		36.5	13.2	0.3
2002	173.8	13.0		41.8	17.0	0.6
2003	179.8	17.0		47.3	21.2	1.9
2004	192.6	22.4		52.4	25.8	4.5
2005	217.0	49.5	642	57.3	30.7	7.9
2006	225.0	62.0		61.9	35.9	11.4
2007	247.2	84.0		66.2	41.6	15.9
2008	273.3	90.0		70.3	47.1	20.5
2009	349.3	110.0		74.0	52.3	25.2
2010	360.9	140.2		77.5	57.3	29.5
2011	379.9	171.2	1112	80.6	62.0	33.0
2012	389.9	199.7		83.5	66.4	36.4
2013	389.9	220.9		86.0	70.6	40.0
2014	414.7	253.9		88.3	74.4	43.3
2015	434.7	280.9	1235	90.3	77.8	46.3
2016	440.3	314.6		92.0	81.0	49.1
2017	454.9	320.8		93.5	83.8	51.7
2018	466.9	328.9		94.8	86.3	54.0
2019	524.6	328.9		95.8	88.6	56.1
2020	573.6	351.3		96.7	90.5	58.0
2021	583.8	351.3		97.5	92.2	59.7

	Car driver seat belt	**Car driver seat belt**	**Bicycle helmet**	**Citations per**	**Speed**	**Km of section**
Year	wearing -rural	wearing - urban	wearing	mill veh km	cameras	control
1980	89.8	73.7		5.37		
1981	89.8	74.7		5.05		
1982	84.9	66.5		5.35		
1983	87.2	66.7		5.56		
1984	83.3	66.2		5.05		
1985	82.3	63.0		4.43		
1986	83.0	59.4		4.98		
1987	84.3	61.6		5.01		
1988	84.2	65.0		5.39	1	
1989				5.28		
1990	91.1	67.3	16.6	5.49	65	
1991	84.9	67.0	16.9	5.96	80	

	Car driver seat belt	Car driver seat belt	Bicycle helmet	Citations per	Speed	Km of section
1992				6.43	93	
1993	85.0	73.7		6.34	106	
1994				5.78	114	
1995	85.4	72.3		5.62	128	
1996			38.0	5.30	139	
1997	92.6	80.0		5.38	156	
1998	91.3	79.1		5.16	158	
1999	91.0	82.0		4.90	173	
2000	91.5	77.5		4.44	215	
2001	94.0	81.6		4.85	252	
2002	91.5	84.3		4.14	220	
2003	94.2	84.2		5.28	231	
2004	91.4	84.3		6.20	245	
2005	91.8	86.8		6.27	266	
2006	93.5	86.6	34.8	6.90	273	
2007	93.7	89.4	40.6	6.92	260	
2008	94.5	89.6	34.8	6.48	254	
2009	93.8	90.5	44.0	5.88	276	12.5
2010	95.3	91.9	48.5	6.19	293	22.1
2011	95.6	94.2	50.8	5.65	314	29.9
2012	95.9	94.6	48.9	5.60	336	67.0
2013	96.9	96.3	53.8	5.23	343	105.2
2014	96.8	94.9	52.3	5.05	311	
2015	97.1	94.9	59.1	4.75	300	
2016	97.7	95.9	57.7	4.75	296	
2017	97.8	96.9	58.8	4.49	292	
2018	97.8	97.8	62.0	4.58	288	161.5
2019	97.8	97.8	65.9	4.61		
2020				5.53		
2021				4.84	295	177.4

Table 9

Appendix 2. Data used in the study.

Year	Yearcount	Killed	Killed or seriously injured	Vehicle km	Motorway km	Sanctions per km	VisionZero	Quantified target	Ambition of target
1972	1	490	4515	13,375	44.6	5.60	0	0	0
1973	2	511	4218	13,999	44.6	4.98	0	0	0
1974	3	509	4046	14,486	46.6	3.78	0	0	0
1975	4	539	4086	15,360	50.0	4.19	0	0	0
1976	5	471	3741	16,486	50.0	4.46	0	0	0

Year	Yearcount	Killed	Killed or seriously injured	Vehicle km	Motorway km	Sanctions per km	VisionZero	Quantified target	Ambition of target
1977	6	442	3264	17,598	53.2	4.80	0	0	0
1978	7	434	3091	18,218	54.7	5.32	0	0	0
1979	8	437	2687	18,895	60.0	5.43	0	0	0
1980	9	362	2310	18,769	68.8	5.37	0	0	0
1981	10	338	2340	18,863	68.8	5.05	0	0	0
1982	11	401	2256	19,642	70.1	5.35	0	0	0
1983	12	409	2226	20,230	70.1	5.56	0	0	0
1984	13	407	2326	21,355	70.1	5.05	0	0	0
1985	14	402	2291	23,210	70.1	4.43	0	0	0
1986	15	452	2496	25,319	70.1	4.98	0	0	0
1987	16	398	2166	26,629	70.1	5.01	0	0	0
1988	17	378	1978	27,060	72.0	5.39	0	0	0
1989	18	381	2042	27,515	72.0	5.28	0	0	0
1990	19	332	1968	27,755	77.5	5.49	0	0	0
1991	20	323	1779	27,673	78.6	5.96	0	0	0
1992	21	325	1732	27,795	78.6	6.43	0	0	0
1993	22	281	1650	28,240	90.1	6.34	0	0	0
1994	23	283	1588	28,772	90.1	5.78	0	0	0
1995	24	305	1652	29,133	99.2	5.62	0	0	0
1996	25	255	1617	30,261	113.7	5.30	0	0	0
1997	26	303	1644	33,016	113.7	5.38	0	0	0
1998	27	351	1680	34,073	136.4	5.16	0	0	0
1999	28	304	1452	34,754	140.8	4.90	0	0	0
2000	29	341	1606	35,345	140.8	4.44	0	0	0
2001	30	275	1318	36,193	170.8	4.85	1	0	0
2002	31	310	1461	37,279	173.8	4.14	1	0	0
2003	32	280	1274	37,950	179.8	5.28	1	0	0
2004	33	257	1237	38,709	192.6	6.20	1	0	0
2005	34	224	1201	39,716	217.0	6.27	1	0	0
2006	35	242	1182	40,391	225.0	6.90	1	0	0
2007	36	233	1112	41,643	247.2	6.92	1	0	0
2008	37	255	1122	42,185	273.3	6.48	1	0	0
2009	38	212	963	42,409	349.3	5.88	1	0	0
2010	39	208	922	42,875	360.9	6.19	1	1	4.6
2011	40	168	847	43,505	379.9	5.65	1	1	4.6
2012	41	145	844	44,227	389.9	5.60	1	1	4.6
2013	42	187	890	44,754	389.9	5.23	1	1	4.6
2014	43	147	821	45,505	414.7	5.05	1	1	5.5
2015	44	117	810	46,406	434.7	4.75	1	1	5.5

Year	Yearcount	Killed	Killed or seriously injured	Vehicle km	Motorway km	Sanctions per km	VisionZero	Quantified target	Ambition of target
2016	45	135	791	46,706	440.3	4.75	1	1	5.5
2017	46	106	771	47,229	454.9	4.49	1	1	5.5
2018	47	108	710	47,316	466.9	4.58	1	1	5.5
2019	48	108	673	47,421	524.6	4.61	1	1	5.5
2020	49	93	720	44,550	573.6	5.53	1	1	5.5
2021	50	80	649	46,413	583.8	4.84	1	1	4.4

Table 10

Appendix 3. Comparisons of models omitting one variable at a time.

	Coefficients of different models. Blank=variable omitted					
Terms	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Killed 72–21						
Constant	6.741665	6.794891	6.472849	6.637069	6.698388	6.682432
Vehkm	−0.0000128	−0.0000233	−0.0000147	−0.0000107	−0.0000132	−0.0000127
Mwykm	−0.0023055		−0.0023184	−0.0017857	−0.0023433	−0.0025383
Sancperkm	−0.0606518	−0.0571782		−0.055403	−0.0500084	−0.0463725
VisionZero	0.1739038	−0.0006691	0.1637803		0.1848795	0.1968071
Quantarg	0.785396	0.8431184	0.582123	0.8496302		−0.0480353
Targlevel	−0.175702	−0.2735159	−0.1247157	−0.2033063	−0.0201181	
KSI 72–21						
Constant	9.148283	9.166578	8.85328	9.037494	9.150938	9.147828
Vehkm	−0.0000417	−0.0000453	−0.0000438	−0.0000393	−0.0000417	−0.0000417
Mwykm	−0.0007819		−0.0007559	−0.0003556	−0.000783	−0.0007833
Sancperkm	−0.0663924	−0.0650693		−0.0599526	−0.0670739	−0.0662777
VisionZero	0.1647309	0.1049248	0.1453237		0.1642768	0.1648687
Quantarg	−0.0482673	−0.0561817	−0.2351668	−0.0037417		−0.0543714
Targlevel	−0.0012739	−0.029326	0.0469562	−0.021721	−0.0106672	
Killed 80–21						
Constant	6.445832	6.636367	6.1944	6.325447	6.39065	6.370986
Vehkm	−0.00000397	−0.0000191	−0.00000428	−0.00000102	−0.00000441	−0.0000039
Mwykm	−0.0025286		−0.0025629	−0.0023083	−0.0025658	−0.0027659
Sancperkm	−0.0493427	−0.0506086		−0.0434924	−0.0361721	−0.031866
VisionZero	0.1036345	−0.0472803	0.0860501		0.1139439	0.1250987
Quantarg	0.7868588	0.850541	0.6276033	0.8184236		−0.0417695
Targlevel	−0.1750787	−0.2789138	−0.1351416	−0.1887196	−0.018816	
KSI 80–21						
Constant	8.527421	8.613242	8.279694	8.528219	8.527567	8.522519
Vehkm	−0.0000223	−0.0000293	−0.0000227	−0.0000223	−0.0000223	−0.0000223