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Research article

Factors contributing to the decline in the number of heavy goods vehicles involved in injury accidents in Norway from 2007 to 2020

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Abstract: There has been a large decline in the number of police reported injury accidents on public roads in Norway after 2007. The decline has been particularly large for accidents involving heavy goods vehicles. From 2007 to 2020, the number of heavy goods vehicles involved in injury accidents declined by 68%. The total number of injury accidents declined by 56%. The study presented in this paper aimed to identify factors explaining the decline from 2007 to 2020 in the number of heavy goods vehicles involved in injury accidents in Norway. This is done by reconstructing annual changes in factors known to influence the number of accidents and estimating the potential impacts of changes in these factors. The factors identified can only be regarded as potential causes, as the study design does not permit causal inferences. In total, 14 factors were identified. For 12 factors numerical estimates of the contributions to the declining trend were developed. The combined contribution of all factors accounted for 32.6%–37.5% of the decline in the number of heavy vehicles involved in injury accidents. More than 60% of the decline is not accounted for and must have been caused by factors not included in this study.

Keywords: accidents, contributing factor, decline, heavy goods vehicle

1 Introduction

1.1 Background

Truck transport is the dominant mode of goods transport in Norway (Hovi *et al.* 2014) and worldwide (Rodrigue 2020). Truck transport has, however, several unwanted effects. Accidents with heavy goods vehicles (HGVs) represent an important societal challenge. These are generally serious accidents with high proportions of killed and severely injured people, because of the weight of the heavy vehicles. In the EU, about 4 000 people were killed in road accidents involving HGVs in 2016, making up about 16% of all road fatalities (European Commission 2018). In the US, 4 761 people were killed in accidents involving large trucks in 2017, and 72% of these were other road users, i.e. not occupants of the truck (NHTSA 2019). In Norway, 20% of the people who were severely injured or killed in traffic in the period 2007–2016 could be attributed to accidents involving HGVs (Nævestad & Hovi 2020). Most of the people who were severely injured or killed were other road users, not drivers or passengers in the truck.

A recent study examining the accident risk of HGVs in Norway, has, however, found that the risk of personal injury accidents has been significantly reduced in recent years. Nævestad & Hovi (2020) measure risk as the number of heavy goods vehicles in personal injury accidents per million kilometres driven, and report that the risk of personal injury accidents with heavy goods vehicles in general in Norway has decreased by 58% from 2007 to 2018 (from 0.45 to 0.19 heavy goods vehicles in personal injury accidents per million kilometres driven).

1.2 Aim

The main objective of this paper is to identify factors that may have contributed to the decline in the number of HGVs involved in injury accidents in Norway and estimate the contributions of these factors to the decline.

1.3 Previous research

Previous studies have found similar reductions in accident risk over time for other road users. Bjørnskau (2020) examined long-term changes in risk for motorcycles, mopeds, bicycles, pedestrians, and for drivers and passengers in passenger cars. The study found that the risk of personal injury for both drivers, car passengers, pedestrians, cyclists and moped riders has been halved since 2010. Similarly, Elvik & Høye (2021) reported that from 2000 to 2019, the number of fatalities and serious injuries in traffic decreased by more than 50%. The number of fatalities decreased by almost 70%. We thus see that what Nævestad & Hovi (2020) found for heavy goods vehicles also applies to other road user groups.

No previous studies have attempted to estimate the effects of measures to increase the safety of heavy goods vehicles in Norway. Bjørnskau (2020) discussed various reasons for the decline in the risk of personal injury accidents that he found for car drivers, pedestrians, mopeds etc. The first potential explanation mentioned is that the car fleet is becoming increasingly safer. Second, he noted that there is a systematic effort to improve the road network. New and safer roads are being built with physical separation of traffic, intersections are being rebuilt into roundabouts, main traffic routes are directed around cities, pedestrians and cyclists are increasingly being shielded from other traffic, etc. A third point mentioned by Bjørnskau (2020) is that emergency medicine has steadily improved and that notification of ambulances in the event of accidents is happening faster than before. A fourth factor is that the speed on the roads has decreased in recent years. Bjørnskau (2020) also emphasized that surveys of road users' attitudes and behaviour show tendencies for more people to accept safety restrictions in traffic such as speed limits, more people use safety equipment, etc. This indicates the development of a better safety culture in traffic in Norway over time.

To explain the decrease in fatal accidents in Norway from 2000 to 2019, Elvik & Høye (2021) examined the contributions of: (*1*) road safety measures, (*2*) changes in road user behaviour, and (*3*) other social development features. They concluded that the three biggest contributions to reducing the number of killed and seriously injured were made by declining speeds, measures on the road network and safer cars.

None of the studies reviewed above focused on factors contributing specifically to the decline in the number of accidents involving heavy goods vehicles. To the best of our knowledge, the study reported in this paper is the first study of factors contributing to the improved safety of heavy goods vehicles.

2 Method

2.1 Data on exposure and personal injury accidents to calculate risk

In this study, we define HGV accident risk on Norwegian roads as the number of police reported injury accidents (including fatal accidents) per million vehicle km (cf. Nævestad *et al.* (2017)). We use three data sources to calculate risk. The first data source is Statistics Norway's Lorry surveys' data on the vehicle kilometres of Norwegian HGVs in Norway. This is a quarterly survey of domestic and foreign traffic with Norwegian-registered HGVs. The second data source is traffic to/from Norway and cabotage within Norway with foreign HGVs. This is based on European studies similar to the Lorry survey. Eurostat's statistics directive commits each member state to conduct such surveys, which means that Statistics Norway gets information on all trips in and out of Norway from EU-countries. Combined, the national Lorry Survey in Norway and Eurostat data from similar surveys in European countries cover all foreign and domestic lorry trips between municipalities and counties that are conducted within, to, and from Norway.

The third data source is accident data. The study is based on accident data from Statistics Norway. Data from all personal injury accidents are collected by Statistics Norway. The accident statistics include data on the countries in which the involved vehicles are registered, and the type of HGV involved. The official definition of a heavy goods vehicle in Norway is any vehicle designated for carrying goods having a total weight (of both the vehicle and the goods it carries) of at least 3.5 metric tonnes. Heavy goods vehicles have been classified into ten groups. To identify heavy vehicles (both buses and goods vehicles) at permanent traffic counting stations, vehicles are classified as heavy if their length is at least 5.5 metres. Our analyses of accidents and accident risk focus on the number of HGVs that have been involved in personal injury accidents in the period 2007–2020.

2.2 Identifying factors explaining the reduction in accident risk

It would be a major accomplishment to identify the causes of changes over time in road safety. Regrettably, doing so is impossible for a very elementary reason. If a cause is defined as an action or event that produces a change that would not otherwise have occurred (Elvik 2011), it is immediately clear that to establish causality we need to know what would otherwise (i.e. absent the cause) have occurred. Knowing this is generally referred to as establishing the counterfactual. The best way of establishing a counterfactual is to perform a randomised controlled trial, in which the control group represents the counterfactual. When studying past changes, there is no possibility of establishing a counterfactual by forming a control group. However, when trying to establish causality, historians often ask what might have happened if a certain event had not occurred (Førland 2013; Macintyre 1976). This kind of thinking involves reconstructing a hypothetical (i.e. non-observed) counterfactual.

Identifying factors explaining the reduction in accident risk involves four main steps.

The **first step** is to identify and describe the declining trend in accident risk (cf. section 3).

The **second step** is to explain the declining trend, by identifying factors that may have produced it. Counterfactual thinking proceeds by first thinking about factors that may have produced the trend. Such factors are identified through a literature review to identify previous high-quality studies of factors contributing to reductions in HGV accident risk. These factors include road safety measures whose effects have been estimated in evaluation studies. However, factors that are not commonly regarded as road safety measures are also included if there are sufficient data about them and how they influence accidents.

When a list of potentially contributing factors has been drawn up, the next stage is to estimate the contribution of each factor. This is the **third step**. To identify the contribution of each factor, two things had to be known about each factor: (*1*) the changes in it from year to year, (*2*) its effect on accidents. In general, a safety measure may produce a declining trend in the number of accidents if it becomes more widespread over time, i.e. its use grows over time. A safety measure whose level of use stays unchanged will only maintain a certain level of safety, not produce a declining trend. For each of the factors included, we ask: what would have happened if the factor had not been present or developed the way it did between 2007 and 2020? This means that we reconstruct a counterfactual development in which each of the factors considered is assumed to be absent. In most cases this is done by estimating changes from year to year in the exposure to a factor and the expected change in the number of accidents associated with the change in exposure.

The number of accidents is known to be influenced by a vast number of factors (Fridstrøm 1999). One might therefore think that the best way of estimating the contributions of each factor to the decline in the number of accidents would be by means of a multivariate statistical analysis. However, there are only 14 units of observation (14 years) and it is impossible to include more than 2, or maybe 3, variables in a multivariate analysis. Variables influencing accidents tend to be correlated and omitted variable bias is likely to be present in any multivariate analysis. The approach chosen in this study was therefore to collect data on year-to-year changes in a number of factors believed to influence the number of accidents involving heavy goods vehicles. For each of these factors, their effect on the number of accidents is known from evaluation studies. By combining data on annual changes with the results of evaluation studies, estimates of the contribution of each factor to annual changes in the number of accidents were developed. This approach is a numerical historical reconstruction, factor-by-factor.

2.3 Estimating the combined effects of the factors included in the study

The **fourth step** is to estimate the combined effects of the identified factors. In general, one cannot estimate the combined effects of several factors contributing to a reduction in the number of accidents by simply adding them. A numerical example, admittedly not very realistic, should convince readers of this. Suppose there are 100 accidents to begin with. Three measures may reduce the number accidents by, respectively 50%, 40% and 30%. These percentages add up to 120%. But it is not possible to reduce the number of accidents by more than 100%. Each of the three measures leaves behind a so called 'residual', i.e. a share of accidents it does not prevent. These residuals are, respectively, 50%, 60% and 70%. A method known as the method of common residuals estimates the combined effects of the three measures as: $1 - (0.5 \cdot 0.6 \cdot 0.7) = 1 - 0.21 = 0.79$ or 79% reduction of the number of accidents. To estimate the combined effects of several factors, a residual term was estimated for each factor for each year from 2007 to 2020. Combined effects were estimated by multiplying residual terms. Three versions of the common residuals method were used (Elvik 2009).

To explain these versions, suppose there are three residual terms: 0.9, 0.8 and 0.7. The first method, the common residuals method, estimates the combined effects as follows:

Model 1 (independent effects) $= 1 - (0.9 \cdot 0.8 \cdot 0.7) = 1 - 0.504 = 0.496$ (49.6% reduction).

This estimate assumes that the factors are independent, i. e. not correlated. The second method, referred to as the dominant common residual method, estimates combined effects as follows:

Model 2 (dominant effects) $= 1 - (0.9 \cdot 0.8 \cdot 0.7)^{0.7} = 1 - 0.619 = 0.381$ (38.1% reduction).

The dominant common residuals method is based on the assumption that the most effective factor (0.7) to some extent reduces the effects of less effective factors; it dominates these, so to speak. The most conservative method, is the double dominant common residuals method:

Model 3 (double dominant) $= 1 - (0.9 \cdot 0.8 \cdot 0.7)^{(0.7 \cdot 0.8)} = 1 - 0.681 = 0.319$ (31.9% reduction).

Elvik (2009) reviewed data sets that supported all the three methods. However, the double dominant common residuals method is preferred as it gives the most conservative estimates and is consistent with the fact that the factors contributing to the decline are correlated and act partly on the same risk factors.

3 The trend

Figure 1 shows the trend in the number of heavy goods vehicles involved in police-reported injury accidents in Norway from 2007 to 2020. An exponential trend line has been fitted to the data. It indicates a mean annual decline of 8%.

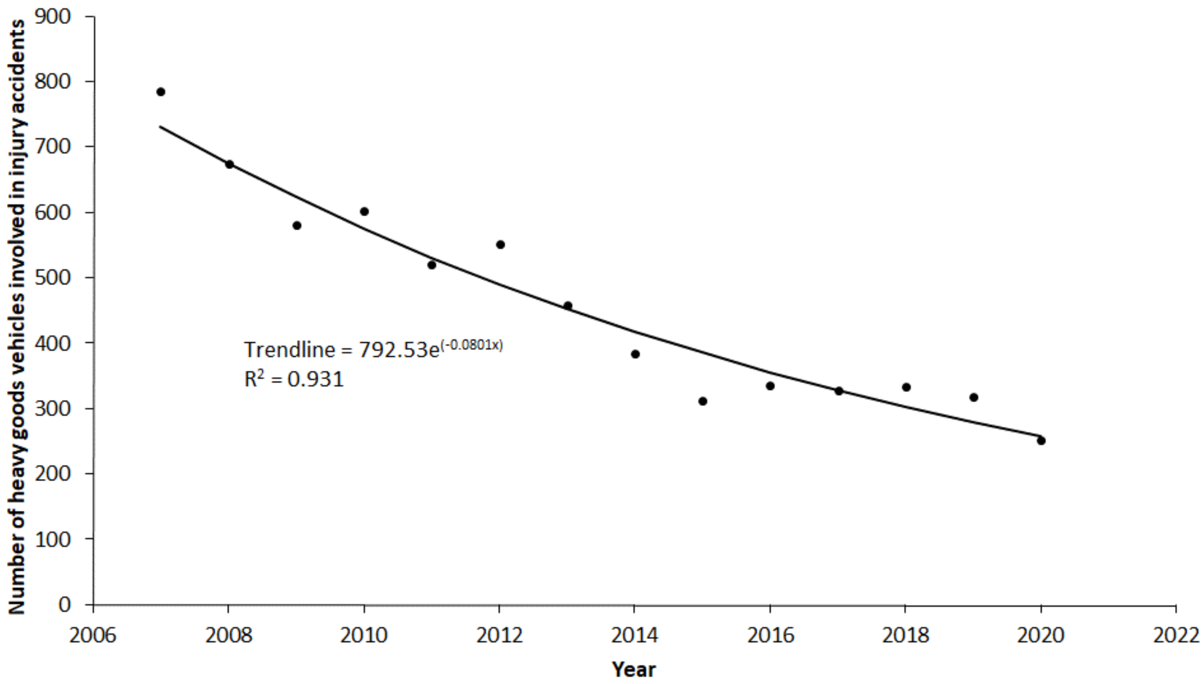

Figure 1 **Number of heavy goods vehicles involved in injury accidents in Norway 2007-2020.**

The trend line fits well to the data points. It is used as the basis for identifying factors producing it. No attempt is made to explain annual fluctuations in the number of accidents around the trend. Most of these are small and likely to be well within the bounds of purely random variation.

4 Factors that may produce a declining trend

The following factors were identified as potentially contributing to the declining trend in the number of heavy goods vehicles involved in injury accidents:

1. New motorways
2. New 2+1 roads with median barriers
3. Centre line rumble strips
4. Minor road improvements
5. Electronic stability control on new heavy goods vehicles

6. Adaptive cruise control on new heavy goods vehicles
7. Increasing use of fleet management systems in transport companies
8. Increasing use of speed cameras
9. Increasing use of section control
10. Technical inspections of heavy goods vehicles
11. Enforcement of hours of service and rest regulations
12. Police checks of drivers of heavy goods vehicles
13. Lower mean speed
14. The collective driving experience of the population of drivers.

Most of these factors are road safety measures. They were identified on the basis of previous studies (Elvik & Høye 2021; Nævestad 2020) that have found them to influence long-term trends.

The objective of the study was to develop numerical estimates of the contribution to the declining trend of each factor. Technical inspections of heavy vehicles varied irregularly from year to year in the study period (according to data provided by the Public Roads Administration). There was, however, an increasing trend. A function describing this trend was applied, rather than the annual number of inspections; see further details in section 5. Police checks of drivers of heavy goods vehicles declined early in the period, then increased. A function was fitted to the data and applied in the analysis; see section 5 for details.

Data indicated that the enforcement of hours of service and rest regulations did not change during the period studied. It was therefore not possible to attribute any contribution to the declining trend to that measure. This does not mean that the measure is ineffective; simply that during this period the use of it has not been increased in a way that could produce a declining trend in the number of accidents.

Fleet management systems are known to improve safety in transport companies (Nævestad 2020). However, too little is known about their use in Norwegian transport companies to include them in the study. Therefore, only 12 of the 14 factors considered were included in the study.

5 Estimation of the contribution of each factor

For each of the factors included, we ask: what would have happened if the factor had not been present or developed the way it did between 2007 and 2020? This means that we reconstruct a counterfactual development in which each of the factors considered is assumed to be absent. The following sections explain this for each factor. In all sections, exposure (vehicle kilometres) refers to all motor vehicles, not just heavy goods vehicles.

5.1 New motorways

From 2007 to 2020, 350 kilometres of new motorways were opened to traffic in Norway. Vehicle kilometres driven on these roads in 2020 can be estimated to 2 130 million, an increase from 132 million vehicle kilometres in 2007. If these roads had not been built, one can estimate that their mean injury accident rate in 2020 would have been 0.043 injury accidents per million vehicle kilometres (based on accident rates estimated by Høye (2016)). The expected accident rate on motorways in 2020 is 0.022 accidents per million vehicle kilometres. The difference in accident rates implies that the motorways prevented 45.8 injury accidents in 2020. From 2007 to 2020, the share of injury accidents involving a heavy goods vehicle declined from 9.1% to 7.6%. Assuming that motorways are equally effective for all groups of vehicles, it can be estimated that 3.5 of the 45.8 injury accidents prevented in 2020 would have involved a heavy goods vehicle.

The safety benefit is confirmed by evaluation studies (Elvik *et al.* 2017). The evaluation study by Elvik *et al.* (2017) did not find a large reduction of the number of accidents. However, the road that was studied had a large increase in traffic volume (80%) during the after-period. Other studies, reviewed by Elvik *et al.* (2017), have found large accident reductions.

5.2 2+1 roads with median barrier

These are three lane roads with a median barrier. 383 kilometres of these roads were built between 2007 and 2020. Vehicle kilometres driven on these roads increased from 540 million in 2007 to 1 071 million in 2020. In 2020, the accident rate on these roads was 0.052 injury accidents per million vehicle kilometres. Converting a two-lane rural road into a 2+1 road with a median barrier reduces the number of injury accidents by 13% (Carlsson 2009). Hence, the number of accidents expected in 2020 if the roads had not been built was $(1071 \cdot 0.052) / 0.87 = 64$. In 2020, the roads prevented 8.3 injury accidents, of which an expected 0.6 involved heavy goods vehicles.

5.3 Centre line rumble strips

Centre lines on two lane roads are increasingly designed as rumble strips. From 2007 to 2020 vehicles kilometres driven on roads with these rumble strips increased from 450 to 4 552 million vehicle kilometres (Elvik & Høye 2021). The 2020 injury accident rate on roads with centre line rumble strips was 0.065. Without the rumble strips, the accident rate would have been 10% higher (Høye 2015a). In 2020, centre line rumble strips prevented 32.9 injury accidents, of which an expected 2.5 involving heavy goods vehicles.

5.4 Minor road improvements

This factor consists of the following road safety measures: (*1*) pedestrian bridge or tunnel, (*2*) upgrading pedestrian crossings, (*3*) marking cycle lanes, (*4*) minor improvements, (*5*) roadside safety treatments, (*6*) treatment of horizontal curves, (*7*) roundabouts, (*8*) guardrail along roadside, (*9*) road lighting, (*10*) traffic signals in junctions, and (*11*) traffic signals in pedestrian crossings. Selvik *et al.* (2020) report a fairly detailed analysis of these measures. EB-estimates of the expected number of injured road users in the period before implementation of the measures were developed. It has been estimated that the measures prevent 0.16% of injury accidents each year. In 2020, it was estimated that the measures prevented 121.5 injury accidents, of which 9.2 involving heavy goods vehicles.

5.5 Electronic stability control on heavy goods vehicles

Electronic stability control became mandatory for heavy goods vehicles in Norway from 2013. Based on statistics provided by Statistics Norway, vehicle kilometres driven by heavy goods vehicles by vehicle age can be estimated. Figure 2 shows how the share of vehicle kilometres driven by heavy goods vehicle equipped with electronic stability control has changed from 2013 to 2020. By 2020, 85% of all vehicle kilometres were performed by vehicles with electronic stability control.

According to Teoh *et al.* (2017), electronic stability control reduces accident involvement by 19%. This implies that in 2020, 49.7 injury accidents involving heavy goods vehicles were prevented.

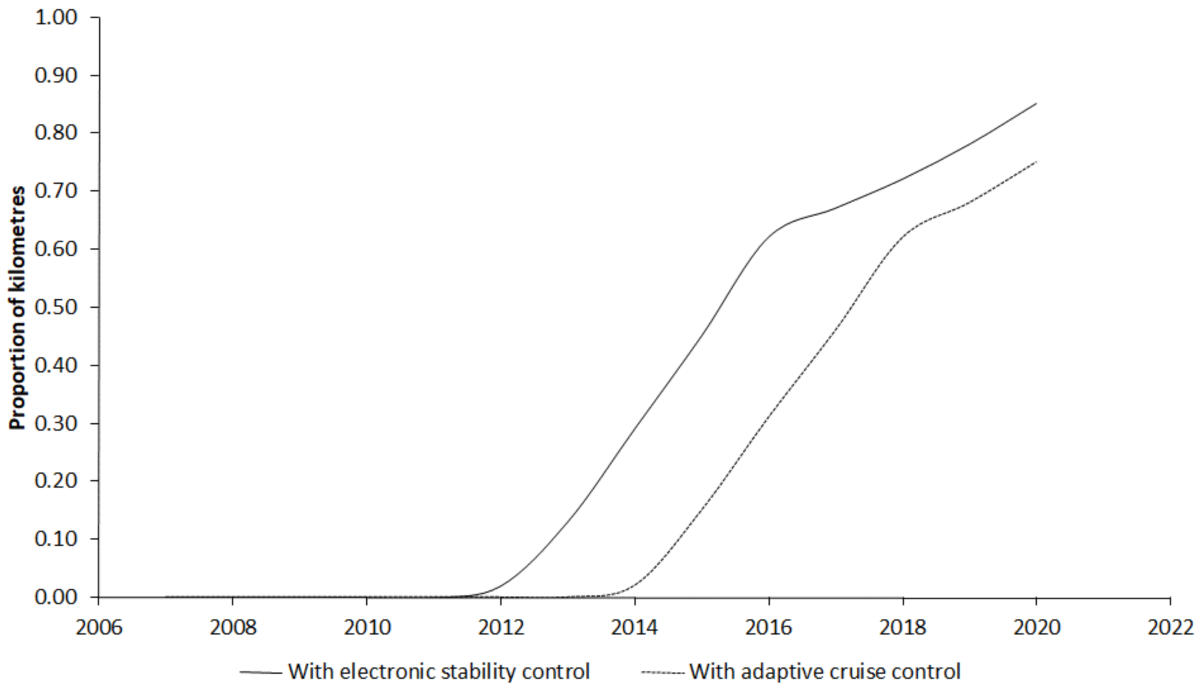

Figure 2 **Share of kilometres by cars with electronic stability control and adaptive cruise control**

5.6 Adaptive cruise control

Adaptive cruise control became mandatory for heavy goods vehicles in Norway from 2015. A rapidly increasing share of driving is performed by heavy goods vehicles that have adaptive cruise control, see Figure 2. Based on Høye (2015b), it is estimated that adaptive cruise control reduces accident involvement by 11%. This means that in 2020, the system prevented 23.2 injury accidents involving heavy goods vehicles.

5.7 Speed cameras

Vehicle kilometres driven on roads with speed cameras has increased from 1 755 million in 2007 to 2 350 million in 2020 (Elvik & Høye 2021). The mean 2020 injury accident rate on these roads is 0.075 injury accidents per million vehicle kilometres. According to Høye (2015c), speed cameras reduce injury accidents by 9%. In 2020, speed cameras prevented 17.4 injury accidents, of which 1.3 involving heavy goods vehicles.

5.8 Section control

Section control was introduced in Norway in 2009. Section control is the co-ordinated use of at least two speed cameras, monitoring speed on the section of road located between them. For cars passing both speed cameras, average speed on the section is computed and tickets issued if mean speed was higher than the speed limit (allowing for a certain error margin). Since 2009, vehicle kilometres driven on roads with section control has increased from 25 to 295 million vehicle kilometres. The injury accident rate in 2020 on roads with section control was 0.038 injury accidents per million vehicle kilometres. Section control reduces the number of injury accidents by 12% (Høye 2015d). In 2020, section control prevented 1.5 injury accidents, corresponding to 0.1 injury accident involving heavy goods vehicles.

5.9 Technical inspections of heavy goods vehicles

Figure 3 shows the annual number of technical inspections of heavy goods vehicles per registered vehicle from 2008 to 2020. The data were provided by the Public Roads Administration.

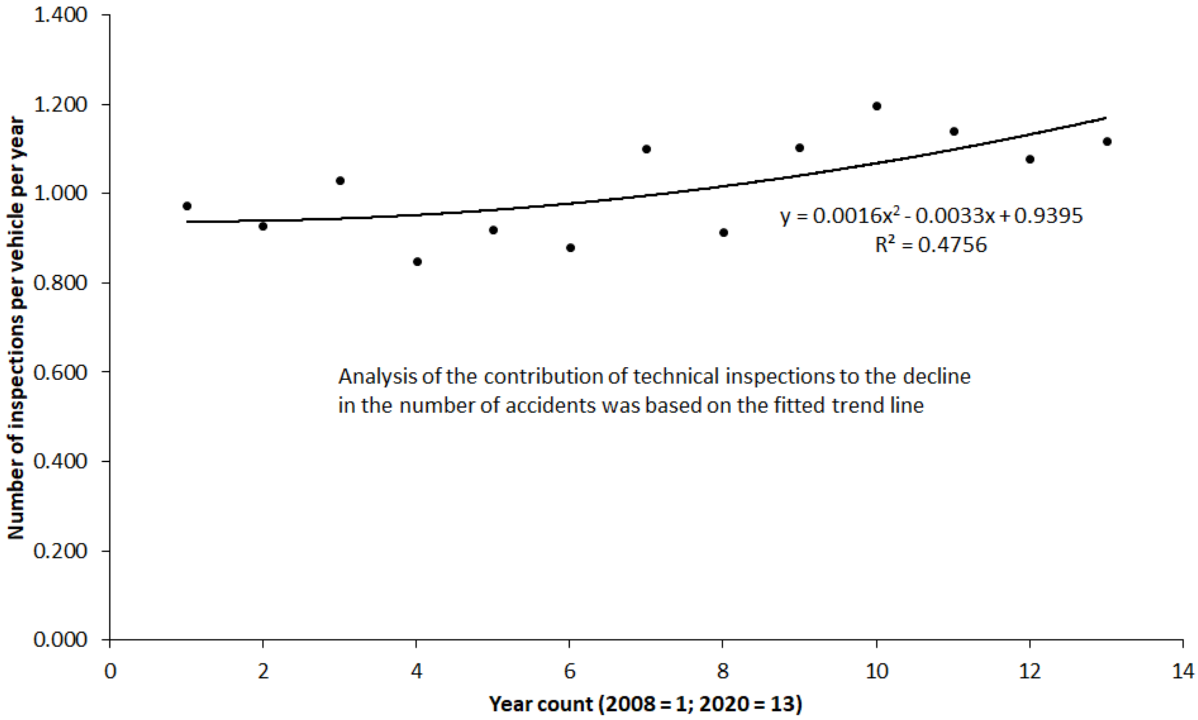

Figure 3 **Number of technical inspections per heavy goods vehicle per year**

The analysis of the contribution made by technical inspections to the decline in the number of accidents involving heavy goods vehicles was based on the trend line shown in Figure 3. The data provided by the Public Roads Administration were applied in an evaluation study to estimate the effects on accidents of changes in the number of inspections per vehicle per year (Elvik 2022). It was found that the relationship between changes in the number of inspections from one year to the next, and corresponding changes in the number of accidents, was well described by a logarithmic function. By applying that function, it was estimated that in 2020, technical inspections contributed to preventing 18.5 injury accidents involving heavy goods vehicles, i.e. if inspections had not increased according to the trend line in Figure 3, the number of accidents in 2020 would have been 18.5 higher than it actually was.

5.10 Police checks of drivers of heavy goods vehicles

The Norwegian traffic police stop and check drivers of heavy goods vehicles. These checks target driver behaviour, like speed, use of alcohol or drugs, compliance with service and rest hours or seat belt wearing. During the period from 2007 to 2020, the annual number of drivers checked varied considerably. There was a decline in the first part of the period, followed by an increase in the last part of the period, see Figure 4.

An analysis has been made of the association between these annual variations and corresponding changes in the number of accidents (Elvik *et al.* 2022). Based on this analysis, police checks did not contribute to a declining trend in the years before 2016 but started to do so from that year onwards. For 2020, it was estimated that police checks of drivers of heavy goods vehicles prevented 21.1 injury accidents involving these vehicles.

5.11 Lower mean speed

Data from permanent traffic counting stations were used to estimate the mean speed of heavy goods vehicles in different years from 2007. Heavy vehicles are identified by length: any vehicle with a length of more than 5.5 metres is classified as heavy.

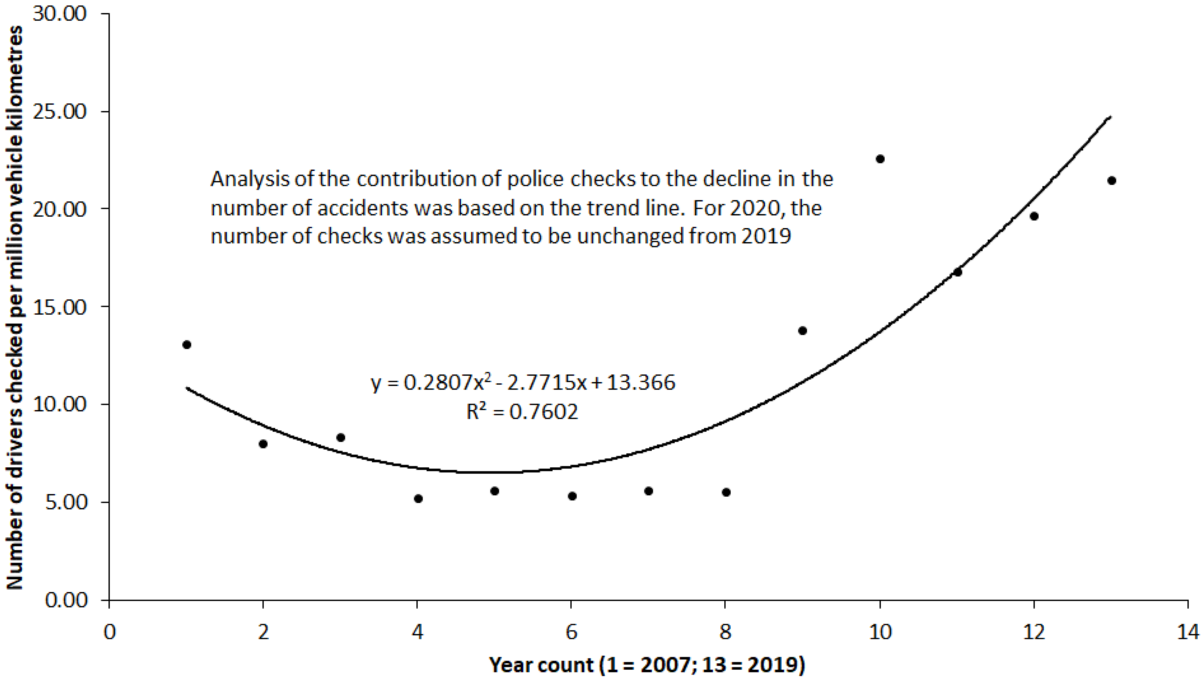

Figure 4 **Police checks of drivers of heavy goods vehicles**

Speed data for heavy vehicles were available for six permanent counting stations. There was not speed data for all years, but enough to determine a trend, which is shown in Figure 5.

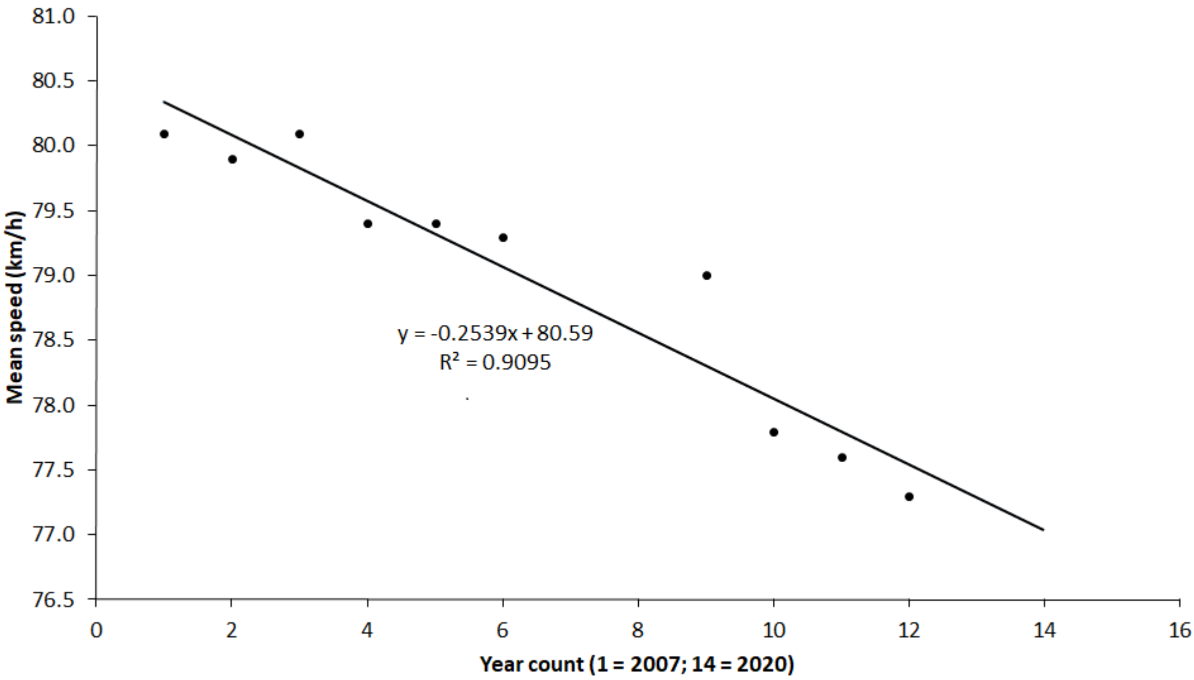

Figure 5 **Change in mean speed of heavy goods vehicles from 2007 to 2020. Data for speed limit 80 km/h.**

Speed has declined by about 0.25 kilometres per hour each year. This amounts to a decline of 3.3 kilometres per hour from 2007 to 2020. This trend is similar to that found for all motor vehicles (Elvik & Høye 2021). The exponential model (Elvik 2019) was applied to estimate the effect of the decline in speed on injury accidents. A coefficient of 0.045 was applied. In 2020, lower mean was estimated to prevent 41.4 injury accidents involving heavy goods vehicles.

5.12 The collective experience of the population of drivers

When mass automobilism came to Norway during the 1960s, many drivers were comparatively inexperienced. Over time, the collective driving experience of the population of drivers has grown. An attempt was made to estimate the potential effects of this for drivers of heavy goods vehicles. Accident rate by driver age was estimated. Unfortunately, these estimates could only be made for a single point in time during the period covered by the study. Changes in accident rates over time are therefore not known. However, it is known how the distribution of licence holders by age has changed over time. Table 1 presents the distribution of licence holders by age for 2007 and 2020. The data refer to licence holders for heavy goods vehicles and come from the Registry of Driving Licences kept by the Public Roads Administration.

Table 1 **Changes in the age distribution of licence holders for heavy goods vehicles**

Age group (years)	Accidents per million kilometres	Distribution of drivers in 2007 (%)	Distribution of drivers in 2020 (%)
18-24	3.4	0.7	1.4
25-34	2.2	6.8	5.3
35-49	1.6	47.4	24.1
50-64	1.2	41.2	48.0
65-74	1.5	3.8	19.5
75 and above	1.5	0.1	1.6
WEIGHTED MEAN RISK		1.486	1.444

An age-weighted mean risk was computed by multiplying the accident rate in each age group by the share (proportion) it made up of the total. The resulting mean risk is shown at the bottom of Table 1. It is seen that the share of licence holders belonging to the oldest groups increased substantially from 2007 to 2020. A trend line was fitted to the annual values of the weighted mean risk and used as the basis for analysis. For 2020, a contribution of 6.1 injury accidents was estimated, i.e. the number would have been 6.1 higher if the collective experience of drivers had not increased.

6 The combined contribution of all factors

The estimated prevented number of injury accidents involving heavy goods vehicles each year is summarised in Table 2. These estimates will be referred to as first-order estimates. A first-order estimate shows the estimated isolated contribution of a factor without considering possible interactions with the contributions of other factors.

In total, the factors contributed to preventing about 177 injury accidents in 2020. This means that without these factors, one would have expected 436 accidents in 2020, rather than 258 according to the trend line (Figure 1).

To estimate the combined effects of several factors, a residual term was estimated for each factor for each year from 2007 to 2020. The residual term is the ratio between the number of accidents according to the trend line in a given year, and the estimated number of accidents in the absence of a factor contributing to the declining trend.

According to the trend line (Figure 1), the expected number accidents in, for example 2020, was 258.2. If speed had not declined, the number would have been 41.4 higher, or 299.6. Thus, the residual term for decline in speed for the year 2020 was: 258.2 / 299.6 = 0.862.

Table 2 **Estimated number of prevented injury accidents involving heavy goods vehicles by year and contributing factor**

Year	Motorways	2+1 roads	Rumble strips	Minor measures	Stability control	Cruise control	Speed cameras	Section control	Technical inspections	Police checks	Lower speed	Collective experience	Total
2007	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2008	0.35	0.38	0.37	2.24	0.00	0.00	1.20	0.00	0.00	-17.38	7.76	4.08	-1.00
2009	1.50	0.41	0.59	3.21	0.00	0.00	1.22	0.01	0.30	-25.70	14.41	6.30	2.25
2010	1.68	0.45	0.80	4.09	0.00	0.00	1.24	0.02	1.16	-29.61	20.06	6.99	6.89
2011	1.69	0.50	0.91	4.89	0.00	0.00	1.26	0.03	2.44	-29.09	24.83	7.54	15.00
2012	1.80	0.53	1.00	5.61	0.00	0.00	1.28	0.04	4.01	-24.77	28.81	7.97	26.29
2013	1.77	0.55	1.19	6.27	11.46	0.00	1.29	0.05	5.78	-17.88	32.10	7.82	50.41
2014	2.00	0.59	1.45	6.85	24.35	0.00	1.30	0.06	7.68	-9.81	34.77	7.65	76.89
2015	1.95	0.61	1.79	7.38	36.03	6.47	1.31	0.07	9.62	-1.65	36.89	7.46	107.94
2016	2.05	0.64	2.00	7.85	47.50	12.56	1.32	0.08	11.56	5.92	38.53	7.26	137.27
2017	2.31	0.63	2.18	8.26	47.90	17.50	1.33	0.09	13.45	12.57	39.74	7.04	153.02
2018	2.55	0.63	2.32	8.63	48.03	22.18	1.34	0.10	15.26	18.20	40.59	6.82	166.66
2019	3.42	0.62	2.44	8.96	48.67	22.62	1.35	0.11	16.95	22.83	41.11	6.59	175.67
2020	3.48	0.63	2.50	9.24	49.74	23.22	1.33	0.12	18.52	21.07	41.35	6.08	177.27

Table 3 **Estimated residual factors for each year and each factor**

Year	Motorways	2+1 roads	Rumble strips	Minor measures	Stability control	Cruise control	Speed cameras	Section control	Technical inspections	Police checks	Lower speed	Collective experience	Product
2007	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000
2008	0.999	0.999	0.999	0.997	1.000	1.000	0.998	1.000	1.000	1.026	0.989	0.994	1.002
2009	0.998	0.999	0.999	0.995	1.000	1.000	0.998	1.000	1.000	1.043	0.977	0.990	0.998
2010	0.997	0.999	0.999	0.993	1.000	1.000	0.998	1.000	0.998	1.054	0.966	0.988	0.990
2011	0.997	0.999	0.998	0.991	1.000	1.000	0.998	1.000	0.995	1.058	0.955	0.986	0.975
2012	0.996	0.999	0.998	0.989	1.000	1.000	0.997	1.000	0.992	1.053	0.944	0.984	0.951
2013	0.996	0.999	0.997	0.986	0.975	1.000	0.997	1.000	0.987	1.041	0.934	0.983	0.898
2014	0.995	0.999	0.997	0.984	0.945	1.000	0.997	1.000	0.982	1.024	0.923	0.982	0.837
2015	0.995	0.998	0.995	0.981	0.915	0.984	0.997	1.000	0.976	1.004	0.913	0.981	0.763
2016	0.994	0.998	0.994	0.978	0.882	0.966	0.996	1.000	0.969	0.984	0.902	0.980	0.690
2017	0.993	0.998	0.993	0.975	0.873	0.949	0.996	1.000	0.961	0.963	0.892	0.979	0.640
2018	0.992	0.998	0.992	0.972	0.863	0.932	0.996	1.000	0.952	0.943	0.882	0.978	0.592
2019	0.988	0.998	0.991	0.969	0.852	0.925	0.995	1.000	0.943	0.925	0.872	0.977	0.551
2020	0.987	0.998	0.990	0.965	0.839	0.918	0.995	1.000	0.933	0.925	0.862	0.977	0.523

Note that the denominator is the counterfactual, higher number of accidents expected to occur if speed had not declined. Table 3 shows estimated residuals for each factor and each year.

Figure 6 shows the combined contributions of all factors. The sum of first order effects accounts for 37.5% of the decline from 2007 to 2020 in the number of heavy goods vehicles involved in injury accidents in Norway. The estimate based on the double dominant common residuals method is lower and the combined contribution of all factors account only for 32.6% of the decline. Thus, most of the decline cannot be accounted for by means of the factors included in this study.

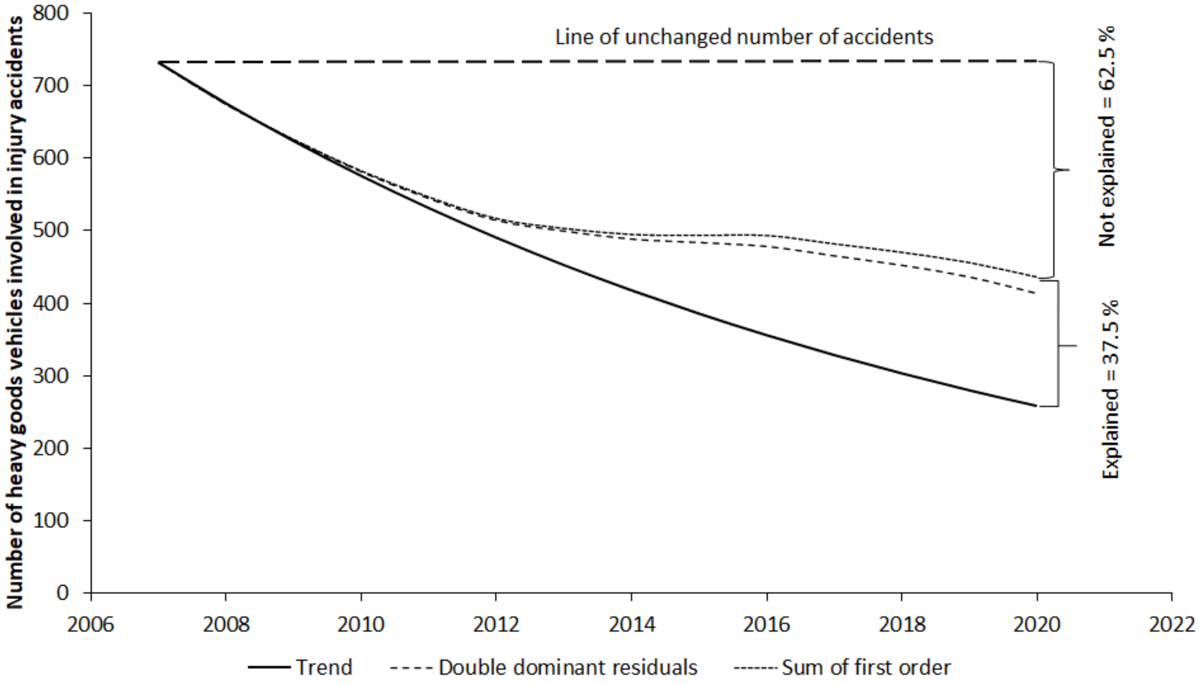

Figure 6 **Contribution of identified factors to the decline of heavy goods vehicles in injury accidents**

7 Discussion

7.1 Not all factors contributing to the decline are included

The study presented in this paper did not succeed in explaining the decline from 2007 to 2020 in the number of heavy goods vehicles involved in injury accidents in Norway. According to the most optimistic estimate, 37.5% of the decline is accounted for by the factors included in this study, leaving most of the decline, 62.5%, unaccounted for.

Among the factors that were considered for inclusion in the study, it is highly likely that increased use of fleet management systems has contributed to the decline in accidents. A fleet management system monitors driver behaviour in detail and can serve as a basis for systems rewarding safe and economic driving. Nævestad (2022) found that the use of fleet management systems in two firms in order to promote economic driving was associated with large reductions in accident rates. Accident rate declined by 52% in one firm and by 36% in the other. Unfortunately, data on the use of these systems are too incomplete to estimate their contribution. The other factor that was considered, but not included, enforcement of hours of service and rest regulations, is less likely to have contributed to the decline, as it remained at a stable level during this period. This contributes to a lower number of accidents than if the measure was not used at all, but it does not contribute to a declining trend over time.

There are clearly many omitted factors. It is widely recognized that safety culture is important for safety in organizational settings in hazardous industries (Nævestad 2010). Research also indicates a relationship between safety culture and safety performance in road transport, although this relationship is challenging to measure (Bjørnskau & Nævestad 2012). Goods transport companies with a good safety culture have a lower accident risk than companies that score lower on safety culture (Nævestad *et al.* 2020). Many transport companies work systematically in many ways to improve their safety culture (Nævestad *et al.* 2017). However, it is challenging to quantify the contributions from this to the decline in the number of accidents. There is little doubt that a contribution exists, but estimating its size very precisely is not possible.

7.2 Alternative approaches to analysis

It is very unlikely that a multivariate statistical analysis would have produced more convincing results. This study included 12 factors – many more than one can include in a statistical analysis of a data set consisting of 14 observations (14 years). Besides, a multivariate statistical analysis would quickly encounter the problems of high correlations between the variables – most of them change gradually over time at comparable rates, generating extremely high correlations between them – and omitted variables. It is obvious that even when 12 factors are included, many important factors are omitted. Otherwise, much more than 37.5% of the decline in the number of accidents should have been accounted for.

In summary, there are three main weaknesses of this study. First, it was clearly not able to include everything that has contributed to the decline in the number of accidents involving heavy goods vehicles. Second, the estimated contributions of the factors that were included rely on assumptions whose validity could not be tested directly as part of the study. It was, for example, assumed that changes in speed affect the safety of heavy goods vehicles according to the same functional relationship as other types of vehicles. To give another example, it was assumed that the relative risks of accident involvement for drivers of different ages remained constant throughout the period. Longitudinal data for drivers of passenger cars shed doubt on this assumption (Bjørnskau 2020). Third, there are different methods for estimating the combined contributions of all factors, but none of these methods are well supported by evidence from research.

7.3 Comparison to other studies

There are few studies employing the same design as the current study. The most comparable study is the study by Elvik & Høye (2021) of factors contributing to the decline in the number of killed or seriously injured road users in Norway from 2000 to 2019. Some of the factors included in that study were the same as those included in this study and estimates of their contributions based on the same sources of data.

The estimated contributions of the main factor are nevertheless somewhat different. Thus, new vehicle safety systems contributed to 41.2% of the explained decline for heavy vehicles, but only 16.5% of the explained decline in the number of killed or seriously injured road users. Lower speed contributed to 23.3% of the explained decline for heavy vehicles; 22.2% of the explained decline for killed or seriously injured road users. Road improvements contributed to 8.9% of the explained decline for heavy vehicles; 21.2% of the explained decline for killed or seriously injured road users. Some road improvements, notably motorways and 2+1 roads with median barriers have a much larger effect on fatal and serious injuries than on injury accidents in general.

8 Conclusions

The aim of the study reported in this paper was to identify and estimate the contributions of factors that may explain the decline from 2007 to 2020 in the number of heavy goods vehicles involved in police reported injury accidents in Norway. The study included 12 factors, but these factors accounted for only 32.6%–37.5% of the decline in the number of accidents. Therefore, most of this decline must have been caused by factors not identified in this study. Potentially important factors not included in the study are changes in safety culture and safety management systems in transport companies, such as the use of fleet management systems.

CRediT contribution statement

Rune Elvik: Conceptualisation, Data curation, Formal analysis, Methodology, Writing—original draft, Writing—review & editing. **Tor-Olav Nævestad**: Conceptualisation, Data curation, Funding acquisition, Methodology, Project administration, Supervision, Writing—review & editing. **Fridulv Sagberg**: Data curation, Software, Writing—review & editing. **Ingeborg Storesund Hesjevoll**: Formal analysis, Writing—review & editing. **Inger Beate Hovi**: Conceptualisation, Data curation, Resources, Writing—review & editing.

Declaration of competing interests

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.

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References

Bjørnskau, T., T.-O. Nævestad (2012), 'How Can the Safety Culture Perspective be Applied to Road Traffic?', *Transport Reviews*, 32 (2), 139–154, https://doi.org/10.1080/01441647.2011.628131.

Bjørnskau, T. (2020), 'Risiko i veitrafikken 2017/18' [Road traffic risk in Norway 2017/18] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1782/2020, https://www.toi.no/getfile.php?mmfileid=54458, accessed 11 December 2022.

Carlsson, A. (2009), 'Uppföljning mötesfria vägar: slutrapport' [Evaluation of 2+1 roads with cable barriers] (Linköping, Sweden: Swedish National Road and Transport Research Institute), VTI rapport 636, https://www.diva-portal.org/smash/get/diva2:670551/FULLTEXT01.pdf, accessed 12 December 2022.

Elvik, R. (2009), 'An exploratory analysis of models for estimating the combined effects of road safety measures', *Accident Analysis & Prevention*, 41 (4), 876–880, https://doi.org/10.1016/j.aap.2009.05.003.

Elvik, R. (2011), 'Assessing causality in multivariate accident models', *Accident Analysis & Prevention*, 43 (1), 253–264, https://doi.org/10.1016/j.aap.2010.08.018.

Elvik, R., H. Ulstein, K. Wifstad, *et al.* (2017), 'An Empirical Bayes before-after evaluation of road safety effects of a new motorway in Norway', *Accident Analysis & Prevention*, 108, 285–296, https://doi.org/10.1016/j.aap.2017.09.014.

Elvik, R. (2019), 'A comprehensive and unified framework for analysing the effects on injuries of measures influencing speed', *Accident Analysis & Prevention*, 125, 63–69, https://doi.org/10.1016/j.aap.2019.01.033.

Elvik, R., A. K. Høye (2021), 'Hva forklarer nedgangen i antall drepte eller hardt skadde i trafikken etter 2000?: En oppdatering' [What explains the decline in number of killed or hard injured in traffic after 2000?: An update] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1816/2021, https://www.toi.no/getfile.php?mmfileid=55883, accessed 11 December 2022.

Elvik, R. (2022), 'Effects on accidents of technical inspections of heavy goods vehicles in Norway: A re-analysis and a replication', *Journal of Safety Research*, https://doi.org/10.1016/j.jsr.2022.10.021.

Elvik, R., L. Tanum Pasnin, T.-O. Nævestad (2022), 'Effects on accidents of police checks of drivers of heavy goods vehicles in Norway', *Transportation Research Interdisciplinary Perspectives*, 14, 100606, https://doi.org/10.1016/j.trip.2022.100606.

European Commission (2018), 'Monitoring Road Safety in the EU: towards a comprehensive set of Safety Performance Indicators', https://road-safety.transport.ec.europa.eu/system/files/2021-07/ersosynthesis2018-performanceindicators.pdf, accessed 12 December 2022.

Fridstrøm, L. (1999), 'Econometric models of road use, accidents, and road investment decisions ' (Oslo, Norway: Institute of Transport Economics), TØI rapport 457/1999, https://www.toi.no/getfile.php?mmfileid=6030, accessed 11 December 2022.

Førland, T. E. (2013), 'Årsaksproblemer i historisk forskning' [Problems of Causation in Historical Research], *Tidsskrift for samfunnsforskning*, 54 (3), 355–370, https://doi.org/10.18261/issn1504-291x-2013-03-05.

Hovi, I. B., E. Caspersen, P. B. Wangsness (2014), 'Godstransportmarkedets sammensetning og utvikling' [The freight transport market composition and development] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1363/2014, https://www.toi.no/getfile.php?mmfileid=39223, accessed 11 December 2022.

Høye, A. (2015a), 'Forsterket og profilert midtoppmerking. Kapittel 3.26 i Trafikksikkerhetshåndboken. ' [Reinforced and profiled center marking. Chapter 3.26 in the Traffic Safety Handbook.] (Oslo, Norway: Institute of Transport Economics), https://www.tshandbok.no/del-2/3-trafikkregulering/326-forsterket-midtoppmerking/, accessed 11 December 2022.

Høye, A. (2015b), 'Autonom avstandsregulering, kollisjonsvarsling og automatisk nødbrems. Kapittel 4.18 i Trafikksikkerhetshåndboken.' [Autonomous distance control, collision warning and automatic emergency braking. Chapter 4.18 in the Traffic Safety Handbook.] (Oslo, Norway: Institute of Transport Economics), https://www.tshandbok.no/del-2/4-kjoeretoeyteknikk-og-personlig-verneutstyr/doc690/, accessed 11 December 2022.

Høye, A. (2015c), 'Safety effects of fixed speed cameras—An empirical Bayes evaluation', *Accident Analysis & Prevention*, 82, 263–269, https://doi.org/10.1016/j.aap.2015.06.001.

Høye, A. (2015d), 'Safety effects of section control - An empirical Bayes evaluation', *Accident Analysis & Prevention*, 74, 169–178, https://doi.org/10.1016/j.aap.2014.10.016.

Høye, A. (2016), 'Utvikling av ulykkesmodeller for ulykker på riks- og fylkesveger i Norge (2010-2015)' [Development of accident models for accidents on the national and county road network in Norway (2010-2015)] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1522/2016, https://www.toi.no/getfile.php/1344942-1494242006/Publikasjoner/T%C3%98I%20rapporter/2016/1522-2016/1522-2016_Sammendrag.pdf, accessed 11 December 2022.

Macintyre, A. (1976), *Causality and History: Essays on Explanation and Understanding. Studies in the Foundations of Humanities and Social Sciences* (Dordrecht ,Holland, Boston , USA D. Reidel Publishing Company), https://link.springer.com/chapter/10.1007/978-94-010-1823-4_8, accessed 11 December 2022.

Nævestad, T.-O. (2010), 'Cultures, crises and campaigns: examining the role of safety culture in the management of hazards in a high risk industry', PhD thesis, University of Oslo, Centre for Technology, Innovation and Culture, Faculty of Social Sciences.

Nævestad, T.-O., R. Phillips, I. Hovi (2017), 'Internationalisation in Road Transport of Goods in Norway: Safety Outcomes, Risk Factors and Policy Implications', *Safety*, 3 (4), 22, https://doi.org/10.3390/safety3040022.

Nævestad, T.-O. (2020), 'Økonomisk kjøring som trafikksikkerhetstiltak: Før-og etter studie av tre bedrifter' [Economical driving as traffic safety measures: Before and after study of three companies] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1813/2020, https://www.toi.no/getfile.php?mmfileid=56562, accessed 11 December 2022.

Nævestad, T.-O., J. Blom, R. O. Phillips (2020), 'Safety culture, safety management and accident risk in trucking companies', *Transportation Research Part F: Traffic Psychology and Behaviour*, 73, 325–347, https://doi.org/10.1016/j.trf.2020.07.001.

Nævestad, T.-O., I. B. Hovi (2020), 'Ulykkesrisikoen til norske og utenlandske tunge godsbiler i Norge' [The accident risk to Norwegians and foreign tongue goods vehicles in Norway] (Oslo, Norway: Institute of Transport Economics), TØI rapport 1801/2020, https://www.toi.no/getfile.php?mmfileid=54467, accessed 11 December 2022.

Nævestad, T.-O. (2022), 'Eco driving as a road safety measure: Before and after study of three companies', *Transportation Research Part F: Traffic Psychology and Behaviour*, 91, 95–115, https://doi.org/10.1016/j.trf.2022.09.012.

NHTSA (2019), 'Large Trucks. 2017 Data: Traffic Safety Facts' (Washington, DC, USA: National Highway Traffic Safety Administration), https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812663, accessed 11 December 2022.

Rodrigue, J.-P. (2020), *The Geography of Transport Systems* (London: Routledge) 5th Edition, https://doi.org/10.4324/9780429346323.

Selvik, J. T., R. Elvik, E. B. Abrahamsen (2020), 'Can the use of road safety measures on national roads in Norway be interpreted as an informal application of the ALARP principle?', *Accident Analysis & Prevention*, 135, 105363, https://doi.org/10.1016/j.aap.2019.105363.

Teoh, E. R., D. L. Carter, S. Smith, A. T. McCartt (2017), 'Crash risk factors for interstate large trucks in North Carolina', *Journal of Safety Research*, 62, 13–21, https://doi.org/10.1016/j.jsr.2017.05.002.

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