In-Depth Analysis of Video-Recorded Traffic Accidents on Motorways with Roadwork

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ABSTRACT

During a 5-year period, videos of 92 traffic accidents were collected during road construction on four Danish motorway sections. These unique videos originate from cameras located along the motorways and provide information about what precede the accidents, the sequence of the accidents, and the on-site conditions. The purpose of this analysis is to determine causation and contributory factors in relation to accidents and provide a better basis for increasing road safety during future roadworks. The videos provide an opportunity to overcome several of the uncertainties associated with traditional accident analyses. Initially, each accident was analysed separately. The sequence of the accident and a number of relevant accident parameters were registered. Based on this work, accident factors explaining each of the 92 accidents' occurrence were then identified. The accidents were analysed across and according to road alignment. 90 accidents have at least one accident factor related to the behaviour of at least one of the involved parties (driver or vehicle). The most common accident factors are: Lack of attention to either traffic or road alignment, exceeding speed limit, and following too close. In 32 accidents, at least one accident factor is related to the road and its surroundings. In 28 of these 32 accidents, at least one of the accident factors are related to the roadwork e.g. inappropriate road design, missing signs/road markings and misleading signs/road markings. The analysis results in both road technical and behavioural recommendations.

Keywords: Accidents, video recordings, contributory factors, motorways, roadwork, in-depth analysis

INTRODUCTION

Road segments with roadwork are often characterised by narrow lanes, lateral displacement, lane closure, less carriageway width, lack of hard shoulders, roadwork vehicles, roadworkers on the road and increased congestion. These conditions challenge traffic flow, but also road safety.

The number of accidents on road segments tend to increase during roadwork. How much seems to vary a lot depending on different factors e.g. type of roadwork, type of road and how well the roadwork is organized (Høye, 2015). Evaluations of four recent major roadworks on motorways in Denmark showed varying effects on road safety as the change in number of accidents varied between a decrease of 10% and an increase of 63% during the construction periods (Andersson and Greibe, 2018). Even though many efforts are made to prevent accidents during roadwork there seem to be room for improvements.

Accident data collected by the police or hospitals is useful for quantitative studies of road safety, but the data is very weak when it comes to the interaction between the road user, the vehicle and the road and its surroundings. Recordings lack detailed information on sequence of events and road design, and accidents are not necessarily located very precisely. When analysing accidents during roadwork it can be particularly difficult to recover the exact road alignment, signs and road markings at the accident site at the time of accident because it is often very poorly documented. Therefore, it can be difficult to determine causation and contributory factors, and establish if specific design elements during the roadwork have been crucial.

Other methodologies can be used to get a deeper understanding of accident causation. Qualitative methods have been developed to reconstruct the interaction between the road user, the vehicle and the road and its surroundings. E.g. Danish Road Traffic Accident Investigation Board (AIB) investigates injury accidents (AIB, n.d.a) and Norwegian Public Roads Administration (NPRA) investigate all fatal traffic accidents (NPRA, 2019). The work is often carried out in co-operation between professions e.g. engineers, psychologists, doctors and police. They combine different data like interviews with involved parties, inspections of vehicles and accident sites with police and hospital data. It is a comprehensive methodology which require a lot of funding to carry out but still it is only reconstructions of accidents. Therefore, the methodologies are only used for investigations into a very limited number of accidents. The Norwegian data has been used for studying fatal accidents during roadwork, and the results showed that two thirds of 23 accidents were either caused or worsened by the roadwork e.g. lack of or misleading signs/road markings or lack of protection (NRPA, 2011). But only two accidents in the analysis happened on motorways.

Conche and Tight (2006) argued that closed-circuit television (CCTV) recordings, also known as video surveillance, could be a useful tool for a better understanding of accident causation and determination of contributory factors. Still, it seems like video recordings of accidents have only been used in larger scales in few analyses. The main reason is probably that accidents are rare events and it either requires access to a lot of cameras or a lot of time to gather a reasonable amount of accidents. Most analyses are based on dashboard cameras or other in-vehicle cameras (e.g. Carney et al., 2015). Depending on camera position investigators can get important information about the accidents and valuable information from inside the vehicle, but information on interaction between the road user and other parties or the road and its surroundings may be limited. A few studies are based on CCTV recordings or other video recordings outside the vehicles but rarely for determination of accident causation. Cheng et al. (2019) used reconstructions of 22 vehicle-pedestrian accidents based on CCTV and/or dashboard cameras along with police documents to determine causation and contributory factors. The primary purpose of the reconstructions was trials e.g. to prove or disprove a driver's statement of "looked-but-failed-to-see". In another study, Ling, Cherry and Dhakal (2017) compared 32 single-bicycle accidents at railroad crossings with 100 cases of successful traversing to explore factors that influence accident outcome (accident or no accident).

The purpose of this analysis is to gain a deeper understanding of the accident causation and the sequence of events on motorways with roadwork and provide recommendations for increasing road safety during future roadworks. The analysis is carried out using unique video data from CCTV cameras along motorways.

As described, previous experience of determining causation and contributory factors in relation to accidents based on CCTV or other video recordings outside vehicles is still limited. In this study a methodology inspired by the one used by AIB (n.d.b) is applied. This study follows the same order of accident analysis, the same approach to how an accident is a failure in the interaction between the road users, the vehicles and the road and its surroundings, and make use of many of the same contributory factors. But while interviews and inspections are the main data source in the analyses by AIB, the video recordings are the main source in this study. This provides an opportunity to overcome several of the uncertainties associated with accident analyses based on traditional accident recordings just like Conche and Tight (2006) anticipated.

In connection with the analyses, emphasis is placed on descriptions of the importance of roadwork for the occurrence of the accidents. During analysis of the 92 accidents, problems and possible improvements associated with the roadwork are thoroughly analysed to formulate exact recommendations related to roadwork. Buch and Andersson (2019) describe the method and results in detail.

METHODS

Data collection

In the period from 2012 to 2017, the Danish Road Directorate collected video and photo material of traffic accidents during road construction periods related to four Danish motorway sections; two rural and two in the capital area, altogether about 43 kilometres of motorway. Three of the four sections were widened from dual two-lane motorways to dual three-lane motorways, and the last one from a dual three-lane motorway to a dual four-lane motorway. The construction period was 2-3 years at each section. The roadwork included shoulder work, median work and bridge work, and traffic experienced periods with narrow lanes, lane closure, crossover of traffic, lateral displacement, etc.

The videos originate from cameras located along the motorways, which have continuously recorded various types of traffic incidents, amongst them traffic accidents. The analysis includes 92 accidents. Video recordings from CCTV cameras during all these accidents were visually assessed by investigators. Accidents were only included if the video recordings were sufficient for performing a credible analysis and determination of accident causation with great certainty.

The accidents vary in severity; from minor material damage to extensive material damage and serious injury. 60 out of 92 accidents were recorded by the police, while 32 accidents were recorded by the Road Directorate's Traffic Management Centre only. In terms of the police recorded accidents, video data was complemented by accident information from the central register of police recorded accidents, and in terms of injury and some damage-only accidents by police reports as well. Police data was used to verify some uncertainties and to achieve some knowledge about road users and vehicles.

The videos of the 92 accidents provide information about what precedes the accident, the sequence of the accident itself, and the on-site conditions in connection with the accident. As such, the exact location of the accident, the traffic situation, the accident situation, the road alignment, road markings, signage, evasive actions, speeds etc. can be extracted from the videos.

The 92 accidents are not representative of accidents on motorways with roadwork in general. At the four motorway sections with roadwork, cameras were located around every 600-1,200 m. If possible, cameras were often placed at locations where the Danish Road Directorate expected risk of queues and problematic traffic behaviour beforehand, e.g. at median cross overs. When several accidents at the same locations were included in this study, it does not necessarily mean that these locations had a higher accident rate, than sites 300 m away which were not covered by a camera. Furthermore, some of the cameras were recording more reliable than others. Finally, accidents in darkness or in bad visibility were more often eliminated from the study because it was too difficult to see what happened. This means that the results cannot be generalized to all accidents on motorways with roadwork, but it can provide very important knowledge in relation to accident causation.

Analysis process and determination of contributory factors

The analysis process is outlined in **Figure 1**. Initially, each accident was analysed separately. Based on the videos, and if possible, supplemented by data from the central accident register and police reports, the sequence of events and a number of relevant accident parameters were registered. The accident parameters cover conditions related to road user behaviour, road conditions and surroundings, as well as background information on the road users and vehicles involved in the accident.

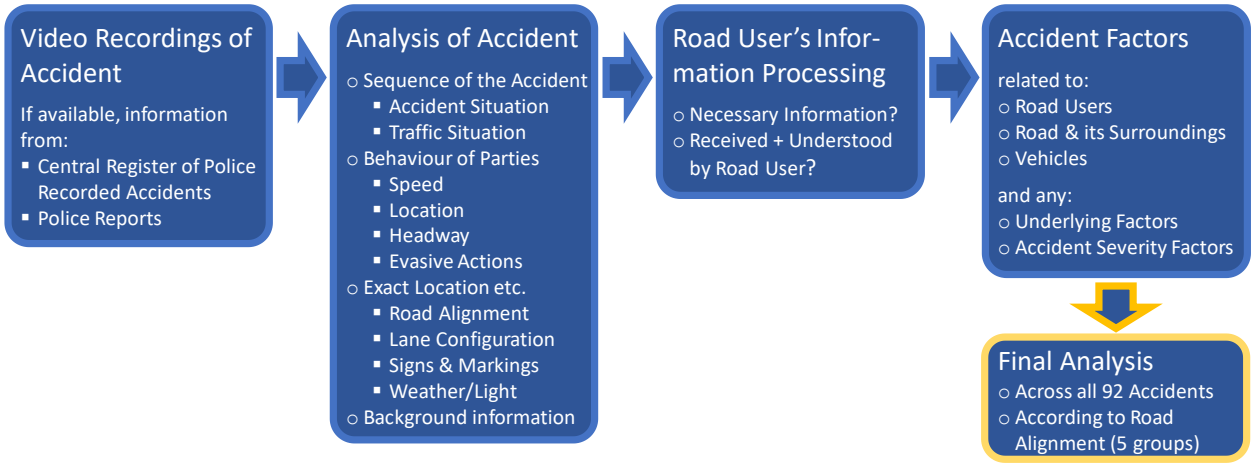

Figure 1 Sketch of the analysis flow. First each accident is analysed separately.

In the next step the road users' information processing was investigated. Did the road users have the information needed to avoid the accident? If the necessary information was available, did the road users gather it? And did they understand the information? The videos are a good basis for answering the questions. The road users' evasive action (or lack of evasive action) combined with the recordings of the surroundings are a very clear hint of the road users' information processing. This step of the analysis is very useful to ensure a systematic approach when clarifying what goes wrong in an accident and determining contributory factors. Road users', vehicles' and the road and its surroundings' contribution to each accident was assessed. Particularly, the role of the roadwork was in focus.

Based on the previous steps, the contributory factors explaining each of the 92 accidents' occurrence were then identified. Factors relate either to the road user, the vehicle or the road and its surroundings. There seems to be no general definition of a contributory factor except that it is a circumstance that is important for the occurrence of an accident. In this study, the contributory factors were divided in:

- Accident factors
- Underlying factors
- Accident severity factors

The deviation in these three categories and the list of potential factors are very much inspired by the studies by AIB (n.d.b), and only a few changes were applied – mainly due to the use of different data sources and scope of study. AIB's potential factors are generally in line with contributory factors used internationally (e.g. Conche and Tight, 2006; Nævestad and Phillips, 2013).

Of most importance is accident factors. An accident factor is defined as *an adverse factor without which the accident would not have occurred.* If just one of the determined accident factors had not been present, the accident would not have occurred. Examples of accident factors could be "exceeding speed limit", "incorrect coupling of car and trailer/caravan", "missing signs/road markings" and "blinding by the sun". The number of accident factors determined per accident varies between one and four. Note that

just because a road user is exceeding the speed limit it is not necessary an accident factor – the accident might have happened anyway.

In addition, it was assessed whether any contributing underlying factors could be identified to explain the accident factors based on accident information or road user behaviour. "Alcohol", "hazardous driving" and "roadwork" are examples of underlying factors. Due to limited background information on road users and limited information on what is going on inside the vehicles, the determination of underlying factors is incomplete and only used as a supplement.

Furthermore, it was assessed whether there were any contributing *accident severity factors*, a cause that increases or worsens the severity of the accident in term of either injuries and/or obvious increasement of material damages, e.g. involvement of an extra vehicle. Examples of accident severity factors are the accident factors mentioned above and e.g. "seat belt not used" and "start/ending of traffic barriers". Note that the same factor cannot be used both as an accident factor and as an accident severity factor in relation to the same object.

The analyses of the 92 accidents were carried out by two experienced investigators within traffic safety and traffic behaviour. First each accident was thoroughly described and analysed by one investigator. Afterwards both investigators analysed and discussed each accident together with the purpose of agreeing on sequence of events, causation and contributory factors. The analyses of the 92 accidents were finally discussed with two other experienced investigators within traffic safety and traffic behaviour.

Based on the analyses of each accident, the 92 accidents were analysed both across and according to the road alignment at the accident site. The following five categories of road alignment are relevant:

1. Lateral displacement (14 accidents)
2. Lane closure (17 accidents)
3. Bifurcation or exit (13 accidents)
4. Convergence or entry (9 accidents)
5. Straight section (39 accidents)

RESULTS

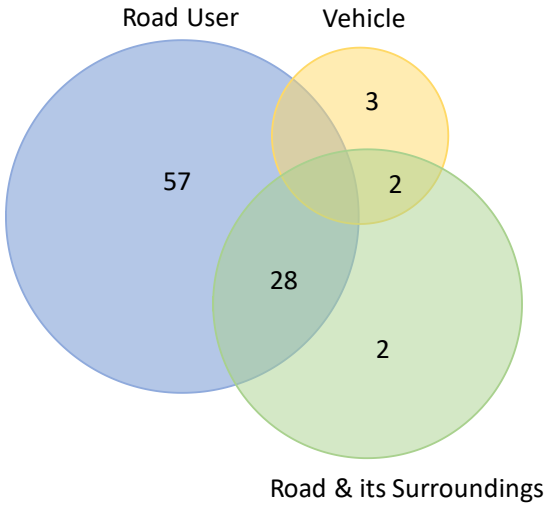

Figure 2 92 accidents divided according to accident factors related to road user, vehicle and road & its surroundings.

All accidents across

Approximately 1/3 of the 92 accidents are rear-end collisions, while another approximately 1/3 of the accidents are single-vehicle accidents in which a road user unintendedly leaves the roadway. Most accidents occurred in favourable weather conditions; dry weather, dry roadway and good visibility.

A total of 200 vehicles are involved in the accidents, including 154 passenger cars and 23 heavy vehicles. 103 of the vehicles are accident contributing either by accident factors related to the road user or the vehicle.

85 accidents have at least one accident factor related to the behaviour of at least one of the involved parties (**Figure 2**). In further 5 accidents, an accident factor is related to a vehicle of one of the involved parties. In 32 accidents, at least one accident factor is related to the road and its surroundings. It is worth to mention that at the same time, at least one accident factor is related to a road user or a road user's vehicle in 30 of these 32 accidents.

TABLE 1 Accident factors related to either road user, road & its surroundings and vehicle. A total of 179 accident factors in 92 accidents. All accidents.

Accident factors related to	Number of accidents	Share of accidents
Road user		
Lack of attention to traffic	39	42%
Lack of attention to road alignment	22	24%
Exceeding speed limit	19	21%
Following too close	15	16%
Intentional but illegal lane change	9	10%
Misjudgement/misinterpretation	8	9%
Wrong manoeuvre/reaction	6	7%
Lack of consciousness	5	5%
Lack of manoeuvre/reaction	3	3%
Harassment	1	1%
Signal error	1	1%
Traveling too fast for conditions	1	1%
A general road user factor (undefined)	1	1%
Road & its surroundings		
Inappropriate road design	13	14%
Missing signs/road markings	11	12%
Misleading signs/road markings	8	9%
Darkness or twilight	4	4%
Lost goods, animals and other things on the roadway	4	4%
Blinding by the sun	3	3%
Road segments with median cross over	1	1%
Vehicle		
Incorrect coupling of car and trailer/caravan	3	3%
Incorrect loading of goods	1	1%
Sudden defect on vehicle	1	1%

The most common accident factors among the 92 accidents are “1ack of attention to traffic”, “lack of attention to road alignment” and “exceeding speed limit” present in 42%, 24% and 21% of the accidents respectively (**Table 1**). In 28 accidents, an accident factor related to the roadwork has been

identified. The most common ones are "inappropriate road design", "missing signs/road markings" and "misleading signs/road markings".

Among underlying factors, "lack of vigilance", "risk blindness" or "hazardous driving" are most often identified. Accident severity factors have been identified in 22 accidents. These are usually factors associated with road user behaviour, but "road segments with median cross over" and "start/ending of traffic barriers" are identified in 5 accidents, respectively.

Accidents at lateral displacements

S-shaped curves cause both single-vehicle accidents and multiparty accidents. Data suggests that accidents, in which roadwork is an accident factor are most serious. Most common accident factors are "lack of attention to road alignment" and "missing signs/road markings" (**Table 2**).

TABLE 2 Accident factors related to either road user, road & its surroundings and vehicle. A total of 30 accident factors in 14 accidents at lateral displacements.

Accident factors related to	Number of accidents	Share of accidents
Road user		
Lack of attention to road alignment	8	57%
Exceeding speed limit	3	21%
Following too close	3	21%
Lack of attention to traffic	2	14%
Lack of manoeuvre/reaction	1	7%
Road & its surroundings		
Missing signs/road markings	5	36%
Misleading signs/road markings	4	29%
Inappropriate road design	3	21%
Darkness or twilight	1	7%

A total of 10 out of 14 accidents at lateral displacements could have been avoided had the road alignment been more visible, clear and unambiguous to the road users. Depending on the location of the lateral displacement in the remainder road alignment, lateral displacements may require increased notification. This is especially relevant when placed in existing curves, but also on sections with a large share of heavy vehicles and narrow lanes. Road users may be misled by old edge lines, which have not been removed (**Figure 3**), and by remains from old lane lines.

However, the road users themselves could have avoided all 14 accidents: Increased attention to the road alignment, but also compliance with the traffic regulations would have made a difference. In dense traffic, the S-curve together with a median cross over often act as a bottleneck, hence causing congestion. The congestion causes sudden braking and inattentive road users and/or road users driving too close to vehicles ahead may cause a rear-end collision.

Accidents at or before lane closure (or loss of left-hand lane)

14 out of 17 of these accidents are multiparty accidents. These are more often rear-end collisions between same lane road users as a result of decelerations towards a lane closure, rather than accidents due to late lane merging or lane changes at the actual lane closure itself. The accidents are of varying severity. Nothing indicates that the accidents with factors related to roadwork are more serious. The most common accident factors are "lack of attention to traffic" and "following too close" (**Table 3**).

The road users could have avoided the accidents related to lane closures: Increased attention to the traffic ahead or the road alignment, a larger distance to vehicles ahead and compliance with the speed

limit would have made a difference. Congestion towards a lane closure in combination with inattentive road users and/or too short headway to vehicles ahead very often lead to a rear-end collision.

Figure 3 Example of old edge line and delineators misleading some road users. The driver of the truck follows the old edge line and continues straight in the S-curve.

TABLE 3 Accident factors related to either road user, road & its surroundings and vehicle. A total of 35 accident factors in 17 accidents at or before lane closure.

Accident factors related to	**Number of accidents**	**Share of accidents**
Road user		
Lack of attention to traffic	11	65%
Following too close	7	41%
Exceeding speed limit	5	29%
Lack of attention to road alignment	4	24%
Misjudgement/misinterpretation	1	6%
Traveling too fast for conditions	1	6%
Road & its surroundings		
Inappropriate road design	2	12%
Missing signs/road markings	2	12%
Darkness or twilight	1	6%
Misleading signs/road markings	1	6%

Accident factors related to roadwork have been identified in 4 out of 5 accidents occurring in the actual lane closure. In these cases, the lane closure seems to take the road users by surprise. This is partly due to the placement of the lane closure in relation to the remainder road alignment and partly to the lack of signs or misleading road markings (**Figure 4**) - and thus notification of the lane closure. Among accidents occurring upstream the lane closure no accident factors have been identified in relation to roadwork.

Figure 4 Example of a loss of left-hand lane taking the road users by surprise. The lane loss is placed under a bridge in a curve just before a lateral displacement. Furthermore, the taper is very short, notification of the lane loss is poor and the old edge line can be misleading the road users.

Accidents at bifurcations or exit

At bifurcations or exits, accidents are mainly single-vehicle accidents. In most cases, a road user has attempted a lane change (too late) between two bifurcating motorways or between a motorway and an exit slip road. Most accidents cause limited damages to vehicles and road equipment. However, some accidents have caused extensive damage to vehicles. The most common accident factor is "intentional but illegal lane change" (**Table 4**).

TABLE 4 Accident factors related to either road user, road & its surroundings and vehicle. A total of 30 accident factors in 13 accidents at bifurcations or exits.

Accident factors related to	Number of accidents	Share of accidents
Road user		
Intentional but illegal lane change	9	69%
Lack of attention to road alignment	3	23%
Misjudgement/misinterpretation	3	23%
Exceeding speed limit	3	23%
Harassment	1	8%
Lack of attention to traffic	1	8%
Lack of consciousness	1	8%
Road & its surroundings		
Blinding by the sun	3	23%
Missing signs/road markings	3	23%
Darkness or twilight	1	8%
Inappropriate road design	1	8%
Misleading signs/road markings	1	8%

Despite errors and inappropriate signs, road markings and alignment at several of the accident sites, road users could have avoided 12 out of 13 accidents through a more law-abiding behaviour, increased attention and/or more self-awareness in their own driving skills. More than half of the accidents could have been avoided had the road users accepted a detour instead of making an illegal lane change across a continuous white line or chevron markings (**Figure 5**).

Wrong and inappropriate signs, road markings and/or road alignment have been considered decisive for 4 out of 13 accidents. An insufficient/ambiguous signage and road marking is more often considered decisive for the occurrence of an accident when the lightning conditions are difficult, such as darkness, twilight or blinding by the sun. Unclear guidance towards a bifurcation of two motorways is in some cases an underlying factor explaining, why a road user makes a late and risky lane change.

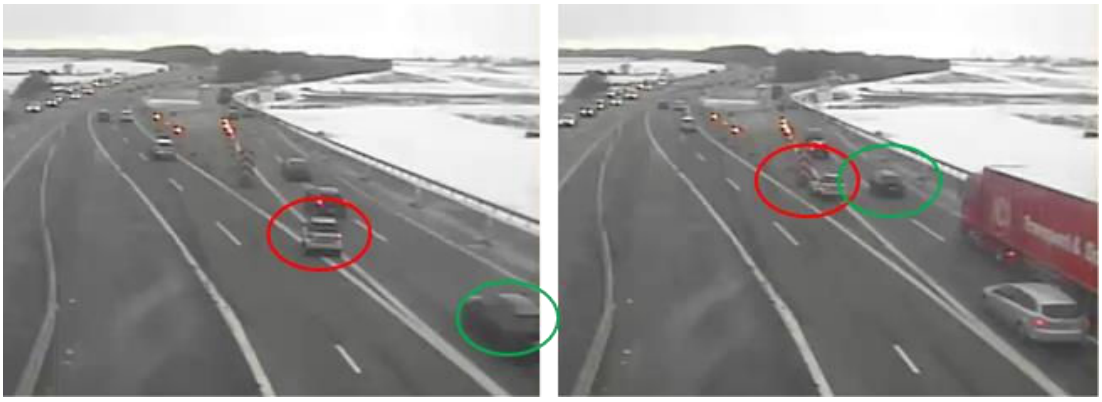

Figure 5 The car driver in the red circle illegally tries to change from one diverging road to another at very low speed. The car driver is unaware of the much faster car approaching from behind (the green circle). At the last movement the driver turns to the left but hits the sign.

Accidents at convergence or entry

The accidents at convergences of two motorways or entry tapers involve at least two vehicles. 7 of the 9 accidents involve a heavy vehicle, which is considerably more than in the overall study. Very often, the accidents happen in congested traffic. Despite the high proportion of accidents involving heavy vehicles, the severity of such accidents does not seem to be higher than for the study as a whole. Most common accident factors are "lack of attention to traffic" and "inappropriate road design" (**Table 5**). In relation to merge between a motorway and an entry slip road in Denmark, the road users in the merging lanes must give way to any vehicle ahead of them.

TABLE 5 Accident factors related to either road user, road & its surroundings and vehicle. A total of 18 accident factors in 9 accidents at convergences or entries.

Accident factors related to	Number of accidents	Share of accidents
Road user		
Lack of attention to traffic	7	78%
Lack of manoeuvre/reaction	2	22%
Misjudgement/misinterpretation	2	22%
Lack of attention to road alignment	1	11%
Road & its surroundings		
Inappropriate road design	5	56%
Misleading signs/road markings	1	11%

The road users could have prevented the 9 accidents. In 7 accidents, lack of attention to traffic is an accident factor. The accident contributing party, typically the truck driver, has in many cases had ample opportunity to notice the counterparty. For some reason, truck drivers often seem to not even register or relate to traffic on entry slip roads (**Figure 6**).

Roadwork contributes to the occurrence of accidents in about half of these, mainly due to inappropriate road design such as short tapers and reduced sight, which is considered problematic. Frequently, road users from entry slip roads find it difficult to obtain a gap large enough for merging, especially in case of dense traffic and/or a large share of heavy vehicles.

Figure 6 The car drivers in both accidents do not accelerate sufficient enough on the slip road to pass the truck completely. The truck drivers do not give way even though the cars are ahead of them. Furthermore, the taper is too short in both merge areas.

Accidents on straight road sections

The 39 accidents on straight road (including slight curves) are primarily rear-end collisions and single-vehicle accidents which eventually develop into multiparty accidents. While single-vehicle accidents often occur outside rush hours, rear-end collisions occur primarily during periods of dense traffic in connection with sudden congestion or braking. The severity of the accidents corresponds well to findings of the overall study, hence, a variety of accidents with minor material damage-only to serious injury accidents.

The road user could have prevented 37 of the 39 accidents on straight road. An accident factor related to the road user is identified in 33 of these accidents. A factor related to the vehicle, for which the road user is in fact responsible, is identified in further 4 accidents. The single-vehicle accidents are particularly characterized by lack of attention to the road alignment and exceeding speed limits. Most of the rear-end collisions could have been avoided had the road user been sufficiently attentive to the traffic. Following too close is also a frequent accident factor in rear-end collisions. Lack of attention to traffic and, in one case, lack of attention to road alignment is an accident factor in connection with side-swipe collisions.

Roadwork is an accident factor in only 5 out of 39 accidents. None of these accidents are rear-end collisions, but single-vehicle accidents and side-swipe collisions. Especially inappropriate road design and misleading or missing road markings are considered to have had an impact on the occurrence of the accidents.

DISCUSSION

The video data constitutes the main data material of the analysis and only accidents covered by good video recordings have been used in the study. Hence, the uncertainty in the analyses of the 32 non-police-recorded accidents is not necessarily larger. The uncertainties associated with the analyses of each individual accident depend more on e.g. camera angle and complexity of the sequence of events.

It is assumed that the accident factors are determined quite precisely. Examination of thorough police reports including e.g. testimonies and examination of the vehicles only caused minor adjustments of accident factors determined in relation to 2 out of 18 accidents. Video recordings are very useful for determination of sequence of events and accident causation and proved in many cases more accurate than testimonies. It is believed that accident factors related to the road users are estimated with a high accuracy after adjusting the definitions in line with both the data material and the aim of the study. For instance, it is not possible to determine the quality of road users' orientation, but it also seems sufficient to determine if road users are paying enough attention to the traffic and the alignment of the road. Accident factors related to road and its surroundings (including roadwork) are also assumed to be determined quite exact. The video recordings in the minutes prior to the accidents often document whether the behaviour of the involved parties immediately before the accident is unusual. This is particularly relevant when assessing the road design and the signs/road markings influence on the accident. It can be difficult to notice a vehicle defect from video recordings. Therefore, a defect on a vehicle may under some circumstances be missed. The determination of underlying factors is incomplete while accident severity factors are believed to be determined with almost the same accuracy as accident factors.

Collecting video recordings as accident data is unfortunately still a challenge because it requires either a lot of time or a lot of cameras and sometimes both. Compared to other data sources the video recordings make in-depth analysis of accidents a lot more accessible. There is no need to reconstruct the accidents and it is easy to clarify important parameters such as other road users' position, evasive actions and parties' speed and distance to vehicles ahead. The systematic investigation of the road users' information processing is helpful to keep focus on what goes wrong in an accident and eliminate possible accident factors. Like all other accident data, video recordings cannot give a complete picture of the accidents, but video recordings seem more informative than many other data sources. The supplementary data from police-recordings can verify some uncertainties but they are much less useful than the video recordings when determining causation and contributory factors. Despite the video recordings, the investigators still have to use their analytical skills in the analysis of each accident with a risk of bias due to the uncertainties. In addition to the systematic approach, the investigators' experience within analysing traffic safety and traffic behaviour and extensive knowledge about the roadwork on the four motorway sections have been important.

Even though, the accidents are not representative of all accidents on motorways with roadwork, it seems fair to conclude that accident factors related to roadwork have more often been determined in relation to lateral displacements, lane closures and bifurcations/exits than straight road sections. Driving through sections like lateral displacements is often complex, and even though the road users are aware of that they are driving through a roadwork, a sudden change in alignment may take the road user by surprise. Therefore, they need sufficient guidance to pass such sections safely.

The aim of the study has not been to check whether the roadwork at the accident sites are in line with existing regulations and recommendations. Several of the 64 accidents without accident factors related to roadwork have happened at locations where e.g. signs and road markings do not comply with the regulations. The breach of regulations is simply not crucial for the occurrence of the accidents, because the road users have had all the information needed to prevent the accidents. At the same time, accident factors related to roadwork have been determined in relation to some accidents, even though both signage/road marking and road alignment follow regulations at the time of the accidents. Although the regulations are followed, it is judged that either road alignment, signage or road marking could have been improved, and in that way prevented the accident. Therefore, recommendations for roadwork managers are a mix of recommendations to ensure that existing regulations and recommendations are adhered to, and conditions that can be beneficially incorporated into the regulations in the future.

CONCLUSION AND RECOMMENDATIONS

The presence of accident factors related to roadwork seem to depend very much on the road alignment at the accident site (**Table 6**). At lateral displacements, improvement of design, signage and road marking could have prevented 71% of the accidents. Especially better road marking could have

made a difference. At convergences/entries, 56% of the accidents could have been prevented by improvements of the road alignment. Among accidents happening at or close to lane closures, roadwork is only determined as an accident factor in 24% of the accidents, but in 4 out of 5 accidents occurring at the actual lane closure. At straight road sections, roadwork seems much less crucial for occurrence of accidents. No matter the road alignment at the accident site, almost all accidents could have been prevented if the road user had been more cautious in relation to either their driving or their vehicle.

TABLE 6 The share of accidents with accident factors related to road user, vehicle, road & its surroundings (including roadwork) and roadwork depending on road alignment category. Example: Among 13 accidents occurring at "Bifurcation or exit", 92% of these have accident factors related to road users. There are no accident factors related to vehicles, while 38% of the 13 accidents have accident factors related to road & its surroundings. 31% of the 13 accidents have accident factors related to roadwork.

	Share of accidents with accident factors related to			
Type of road alignment at accident site	**Road user**	**Vehicle**	**Road & its surroundings**	**Roadwork**
Lateral displacement (14)	100%	0%	71%	71%
Lane closure (17)	100%	0%	24%	24%
Bifurcation or exit (13)	92%	0%	38%	31%
Convergence or entry (9)	100%	0%	56%	56%
Straight road (39)	85%	13%	21%	13%
All (92)	92%	5%	35%	30%

The study has shown that the CCTV recordings can provide a deeper understanding of accidents. In this case, results cannot be generalized to all accidents on motorways with roadwork, but it provides very important knowledge in relation to accident causation. Such information about accident causation would be very difficult to identify in analyses based on traditional accident data. Based on the study, a list of recommendations is identified. If the listed recommendations had been followed, it is expected that the majority of the accidents would have been prevented.

Recommendations based on the study

The recommendations are divided into road related technical recommendations targeted at roadwork managers, and behaviour related recommendations targeted at road users.

In most cases, accidents with accident factors related to roadwork could have been prevented by a clearer and more unambiguous road alignment at roadwork sections. Recommendations for roadwork managers are:

- Changes in the road alignment (i.e. lateral displacement, bifurcation/exit and lane closure) should be pre-warned and obvious for the road users
- Avoid combinations of lateral displacement, bifurcation/exit, lane closure and/or sharp curves
- Avoid combination of convergence of two motorways, S-curve and narrow lanes
- Ensure adequate access conditions from entry slip roads - or close the entry!
- Establish continuous white lines between lanes in S-curves
- Old edge lines must be completely removed
- Use edge lines with rumble effect
- In S-curves, edge lines should be established in the right as well as the left roadside
- Remains of non-valid (old) road markings should be avoided
- Direction signs must be placed on both sides of the road or on portals

- Signs and symbols must illustrate the actual road alignment

Road users are encouraged to make some behavioural changes to comply better with traffic regulations and what they were taught during driving lessons. Had the road users behaved more correctly, the majority of the accidents could have been avoided. The following recommendations for road users can be included in future traffic safety campaigns and communication:

- Do not use "Lane Assist" on roadwork sections
- Respect the speed limits
- Make room for other road users at entry tapers
- Increase attention to traffic and road alignment
- Keep a safe distance
- Accept an incorrect choice of lane - this is better than crashing due to a late and illegal lane change
- Do only stop outside the roadway i.e. in hard shoulders, emergency refuge areas or verges
- Check clamping of cargo and coupling of vehicle and trailer

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AUTHOR CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: T. S. Buch, P. K. Andersson; data collection: T. S. Buch, P. K. Andersson; analysis and interpretation of results: T. S. Buch, P. K. Andersson; draft manuscript preparation: T. S. Buch, P. K. Andersson. All authors reviewed the results and approved the final version of the manuscript.

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