The final publication is available in: Safety Science, 63, 2014, 115-123
10.1016/j.ssci.2013.10.024

Challenges of improving safety in very safe transport systems

Rune Elvik and Nils Gaute Voll
Institute of Transport Economics
Gaustadalleen 21, 0349 Oslo

ABSTRACT

This paper discusses some challenges that may arise when trying to improve safety in systems that are already very safe. Railways in Norway are used as a case of a very safe transport system. The following challenges in improving safety are discussed: (1) A low number of accidents per unit of time makes it difficult to estimate both the current level of accident risk and changes over time in the level of accident risk. (2) Partly as a result of the low number of accidents, incident reporting has been introduced; however it is not always clear how to interpret changes in the number of incidents reported. One reason for this is that some incidents have a low potential for developing into accidents, because multiple safety barriers (defences-in-depth) stop incidents from escalating. (3) Knowledge of the effectiveness of safety barriers combined with a good safety record may lead to excessive reliance on the safety barriers and behavioural adaptation to them. The existence of these challenges is illustrated by means of data from Norwegian railways. It is discussed whether attaining a very high level of safety may lead to loss of information and loss of motivation that may slow down further progress in improving safety.

Key words: very safe systems, railways, Norway, challenges

1 INTRODUCTION

As knowledge about risk factors associated with accidents and how to control the hazards generated by these factors has improved, ambitions for improving safety have increased in all sectors of society. Norway has officially adopted Vision Zero as the long-term ideal for transport safety. Vision Zero states that the ultimate goal is a transport system in which nobody is killed or permanently injured. In Norway, Vision Zero applies to all modes of transport (Samferdselsdepartementet 2009).

The risks associated with travel in Norway are very similar to those found in most rich countries. Road travel typically accounts for more than 90 percent of all transport-related fatalities. Compared to road travel, aviation, railways and maritime travel are quite safe modes of transport. In Norway, it is not uncommon that there are zero passenger fatalities in aviation, rail and maritime travel. What happens when a transport system becomes very safe? Does the system reach a limit, beyond which the lack of information regarding safety prevents further progress from being made? Do transport operators and managers lose interest in trying to improve safety? This paper will explore these questions, using railways in Norway as an example of a very safe transport system. The paper is inspired by the points raised by Amalberti (2001) in his discussion of the paradoxes of almost totally safe transport systems.

The basic argument made in the paper is as follows: When a system becomes very safe, there will be few accidents and these accidents will have little in common and limited potential for learning. As a result of this, other indicators of safety will be created, such as incident reporting. Incidents are events or states that have the potential for developing into accidents. However, the relationship between incidents and accidents may be complex, as some incidents do not have the potential for developing into major accidents, because safety barriers have been introduced to prevent unwanted events from developing into accidents. If safety barriers are known to be highly reliable, an un-intended behavioural adaptation to the barriers may occur and this may reduce safety margins. The challenge is to prevent safety barriers from leading to behavioural adaptation.

2 A VERY SAFE TRANSPORT SYSTEM: RAILWAYS IN NORWAY

Railways in Norway are very safe. Figure 1 compares fatalities per billion kilometres of travel for railway passengers in Norway to corresponding fatality rates for travel by road. Nearly 90 percent of all kilometres of travel in Norway are by road (Vågane and Rideng 2011). Railways include mainline railways only, not trams and underground.

Figure 1 about here

The risk involved in travelling by rail is given for two periods: 1992-2011 and 2002-2011. It is seen that the risk was substantially lower in the 2002-2011 period than in the 1992-2011 period. The difference is almost entirely attributable to a major accident in 2000, in which 16 passengers and 3 train staff were killed. In the past ten years, travel by train in Norway has been extremely safe, considerably safer than travel by bus, which is the safest means of travel by road. There were only two railway passenger fatalities in Norway between 2002 and 2011. The total number of fatalities in railway accidents has been less than 10 every year since 1994, except for the year 2000. Driving a car, by far the most common means of travel in Norway, involves a fatality risk which is 5-35 times higher than being a passenger in a train, depending on whether the risk to train passengers refers to the 2002-2011 period or the 1992-2011 period. Train trips are not normally door-to-door, but contain a share of walking, driving a car or otherwise accessing the station at either end of the train trip. These access and egress parts of a journey add to the risk, but using the train for most of the distance covered is still likely to have the lowest overall risk compared to any means of road transport.

3 THE CHALLENGE OF ESTIMATING THE CURRENT LEVEL OF RISK AND TRENDS IN RISK

The fact that a single major accident may exert a large influence on the estimate of the risk involved in travelling by train illustrates one of the problems in reliably estimating the fatality risk associated with a very safe transport system. Major accidents are rare and unpredictable. The data collected for this paper cover a period of fifty years (1962-2011). During this period there were only two major accidents: one in 1975 (27 fatalities) and one in 2000 (19 fatalities). If one selects a shorter period as a basis for estimating risk, such as ten years, it is largely a matter of chance whether such a period will contain a major accident or not. In fact, the most frequently occurring number of train passenger fatalities in Norway between 1962 and 2001 was zero. Figure 2 shows the number of years with a given number of train passenger fatalities during the period 1962-2011. There were zero fatalities in 19 years, one fatality in 15 years, and more than five fatalities in just two years.

Figure 2 about here

Published accident statistics do not specify the number of fatal accidents involving 1, 2, 3 etc. fatalities. However, by combining information from several sources of data (statistics, annual reports of train operators, newspaper archives), an attempt has been made to reconstruct the number of fatal train accidents during the period 1962-2011. Train accidents include train collisions, derailments and trains striking fixed objects. While there remains a little uncertainty about the count of fatal train accidents, the best estimate was that during the period covered by the study, there were 23 fatal train accidents with a total of 81 fatalities. There were 14 accidents with 1 fatality, 4 with 2 fatalities, 1 with 3 fatalities, 2 with 5 fatalities, 1 with 19 fatalities and 1 with 27 fatalities.

Evans (2003, 2007) argues that estimates of risk based on long-term trends should be preferred to estimates of risk based on recent accident history in transport systems that are characterised by clear long-term trends in risk and a low annual count of accidents. He illustrates this approach using data for train accidents in Great Britain. The long-term trend in the risk of fatal accident (fatal accidents per billion train kilometres) was estimated according to the following function:

$$\lambda(t) = \alpha k_t \cdot exp^{\beta t} \qquad (1)$$

λ(t) is the predicted number of accidents in period t (the period could be a single year or several years), k_t is train kilometres in period t, α is a scaling constant (consistent with the assumption that the number of accidents is proportional to train kilometres) and the exponential function (exp) is intended to capture the long-term trend in the rate of accidents per train kilometre. The parameter β of the exponential functions is the rate of change per unit of time in the accident rate (accidents per million train kilometres). Evans (2003, 2007) estimated the coefficients α and β by means of Poisson-regression or negative binomial regression, the results of which did not differ much. This method for estimating risk has been applied in a number of papers (Evans 2007, 2010, 2011).

A similar approach has been applied in this paper in order to estimate current risk and changes over time in risk. For this purpose, a distinction is made between the following types of railway accident:

1. Train collisions: A train collision is a collision between trains in regular traffic or between shunting movements in shunting yards.
2. Trains striking fixed objects: These accidents include trains running into landslides or hitting buffers at the end of a track.
3. Derailments: This includes derailments both on track and in shunting yards.
4. Grade crossing accidents: These are collisions between a train and a road user or vehicle.
5. Other accidents: This category includes all accidents not classified as one of the above four types; most of these accidents involve trespassers struck by trains. Incidents judged to be suicides are not counted as accidents and are removed from statistics.

The total number of accidents is the sum of the five types listed above. Table 1 presents the number of accidents, the number of fatalities and train kilometres every year from 1962 to 2011. In addition, estimates have been made of the risk of fatal train accidents, i.e. train collisions, derailments or trains striking fixed objects.

Table 1 about here

The count of fatal train accidents was 4 during 1962-66, 5 during 1967-71, 5 during 1972-76, 2 during 1977-81, 0 during 1982-86, 2 during 1987-91, 3 during 1992-96, 1 during 1997-2001, 0 during 2002-06 and 1 during 2007-11. Models identical to equation 1 have been fitted to describe long-term changes in the risk of any type of accident (i.e. total accidents) and each type of accident. Model parameters were fitted by applying the built-in nonlinear least squares library (nls) in the R statistical programming environment (Core Team 2012). The nls library uses the Gauss-Newton algorithm to find the regression coefficients in equation 1, as outlined in Kutner et al. (2005) p. 518 – 521. The model developed for the total number of accidents relied on annual data. For the other models, data were aggregated into ten five-years periods. Table 2 shows estimated coefficients, their standard errors and P-values.

Table 2 about here

The left part of Table 2 shows the coefficient estimates for the multiplicative part of the model. All the scaling constants for the number of train kilometres are positive. These scaling constants must be positive; otherwise the accident rate would become negative, which is impossible. The right part of Table 2 shows coefficient estimates for the exponential part of the model. A negative coefficient means declining risk; a positive coefficient implies increasing risk. Coefficients were in most cases estimated for 5-year periods. To obtain the annual percentage change in risk per million train kilometres, these coefficients were divided by 5. Except for the coefficient for trains hitting fixed objects, all coefficients are negative and most of them are statistically significant at the five percent level. It is seen that the annual decline in risk is between 3 and 5 percent for most types of accident.

Figure 3 shows the total number of accidents per million train kilometres from 1962 to 2011 and the function fitted to the data by means of the coefficients reported in Table 2.

Figure 3 about here

The trend line indicates that risk was reduced by more than 80 percent from 1962 to 2011.The data points for the most recent years are located below the trend line, but these data points show an increasing trend after the year 2007 and the data point for the year 2011 is very close to the trend line. The accident rate during the years 2006 to 2009 was abnormally low and the increase in 2010 and 2011 could simply be regression-to-the-mean and not necessarily an indication of a turning point in the long-term trend.

The long-term trends in risk for the different types of accident vary considerably. The observed risk of train collisions declined until the five-year period 1977-81. Then there was an increase in the periods 1982-86 and 1987-91, followed by a sharp decline in the more recent periods. Observed risk was clearly below the trend line in the periods 2002-06 and 2007-11.

The observed risk of fatalities in train collisions was clearly below the trend line in the periods 2002-06 and 2007-11. The same applies to the risk of derailments, the risk of grade-crossing accidents and the risk of other accidents. One could argue that a period of ten years ought to provide enough data to estimate risk. Yet, even for a period of ten years, trends based on data for fifty years may differ considerably from observed risk.

It is of particular interest to estimate the current risk of fatal train accidents. These are the most serious accidents and considerable resources have been spent over the years to reduce the risk of fatal train accidents. Based on the coefficients in Table 2, the current (2011) risk of a fatal train accident is 3.7 per billion train kilometres, and the model-predicted number of fatal train accidents based on train kilometres in 2011 is 0.171. To estimate the current expected annual number of fatalities, it is first necessary to determine whether there is any long term trend in the number of fatalities per fatal train accident. Figure 4 sheds light on this question.

Figure 4 about here

The line fitted to the data points in Figure 4 indicates that the mean number of fatalities per fatal train accident is increasing. However, this trend is far from statistically significant, and one suspects that it might be influenced by the outlying value for the period 1997-2001. It would not be correct to omit this data point, but to reflect the uncertainty regarding the number of fatalities per fatal train accident, the current expected number of fatalities has been estimated according to three different assumptions:

1. The trend line in Figure 4 has been applied. According to the trend line, the predicted mean number of fatalities per fatal train accident during 2007-2011 was 5.89.
2. The mean number of fatalities per fatal train accident for the entire period has been applied. This number is 3.52.

3. The median number of fatalities per fatal train accident (as estimated on the basis of the mean values for the ten 5-year periods) for the entire period has been applied. This number is 1.92.

These assumptions result in an estimated number of fatalities in 2011 ranging between 0.33 and 1.01. Since the coefficients reported in Table 2 are uncertain, the real range is wider. It is nevertheless clear that the expected number of fatalities in train accidents is very low and pales completely when compared to, for example, road transport (208 fatalities in 2010, 168 in 2011, 145 in 2012).

4 THE CHALLENGE OF INTERPRETING INCIDENT REPORTING

The low number of accidents in Norwegian railways in the most recent ten years does not provide a firm basis for estimating risk. Railways in Norway have therefore introduced a system of incident reporting many years ago. Incident reporting is intended to provide information about unwanted events, defective equipment or any deviation from ordinary routines that may represent a hazard which has the potential of developing into an accident. Incidents are not classified as accidents. An accident involves at least property damage and is associated with a disruption of traffic lasting at least a few hours. A derailment is an accident. A train driver passing a stop signal by a few metres, because he did not manage to stop in time, is an incident. Signals showing a red light as a result of a technical error are incidents. Light bulbs that have gone out, cracked train windows or badly maintained platforms are examples of defective equipment needing repair. A train stopping before all carriages have reached the platform is a deviation from ordinary routine.

Incident reporting has been a great success in Norwegian railways. According to statistics published by the railway safety inspectorate (Statens Jernbanetilsyn 2012), the number of incidents reported on mainline railways increased from 2722 in 2002 to 15,995 in 2011. It is, however, not clear how this huge increase in the reported number of incidents should be interpreted. There are at least three ways of interpreting it.

The first interpretation would be that incidents are events, defects or deviations from routines that represent violations of safety barriers, signifying that safety margins have become smaller. Incidents, in other words, are evidence of hazards that are not fully controlled. If this interpretation is correct, one would expect there to be a positive association between the number of incidents and the number of accidents. If the number of incidents grows, one would expect the number of accidents to follow suit, though perhaps with some delay.

The second interpretation is the exact opposite of the first one. An increase in the number of incidents shows that vigilance is increasing, railway staff is more alert and more aware of hazards and detect them more effectively than before. Hazards may then be brought under control more effectively, while their potential for generating accidents remains small. If this interpretation is correct, one would expect a negative relationship between the number of incidents and the number of accidents. More incidents signify more effective hazard management and fewer hazards will then develop into accidents.

The third interpretation is that the huge increase in the reported number of incidents seen from 2002 to 2011 is partly an artefact. It could be the case that the true number of incidents has not increased so much, but that reporting has improved. This means that an incident which was not regarded as reportable in, say, 2002 would be reported in 2011, although the actions staff took to detect and control the incident may have been the same these two years. In 2002, the system of incident reporting was still quite new and there may have been a reluctance to report incidents based on fear of getting negative feedback from management. As the system became better known and staff found that reporting incidents did not have negative consequences, the propensity to report incidents may have grown. Currently, the reporting of incidents is strongly encouraged and this policy has been a huge success as evidenced in the enormous increase in the number of reported incidents.

Is it possible to determine which of these interpretations is correct? This study did not include interviews with railway staff regarding their perceptions of the incident reporting system, but available statistics permit a study of the relationship between the number of incidents reported and the number of accidents in the period from 2002 to 2011. Figure 5 shows the number of accidents per incident reported during this period.

Figure 5 about here

In the first part of the period, from 2002 until 2007, the number of accidents per reported incident fell dramatically. This suggests that during this period, the increasing number of incidents indicated an improvement in hazard control and management. After 2007, however, the number of accidents per reported incident has stopped to decline, and there is a (weak) hint of an increase. This suggests that the increased number of incidents reported after 2007 represent an increasing number of hazards that actually develop into accidents. The period is short, however, and an exponential trend line that does not have a turning point fits the data points better than a polynomial having a turning point. The number of accidents was very low from 2006 to 2009, and the increase seen in 2010 and 2011 could simply be regression-to-the-mean.

The evidence is, in other words, inconclusive and the ambiguity about how to interpret changes in the number of incidents remains. The number of accidents per reported incident is currently very low, about 0.002. This means that there on average are about 500 incidents per accident. Since there are so many incidents for each accident, and this has been the case for some years, there is a possibility that two kinds of behavioural adaptation may develop. One kind of behavioural adaptation would be that the incident reports get a more cursory follow-up as they are no longer regarded as predictive of hazards that may lead to accidents. A second kind of behavioural adaptation would be that fewer incidents get reported, as reporting is perceived as less useful than before. However, the annual growth in the number of incidents reported in Norwegian railways shows no sign of levelling off.

Unfortunately, detailed statistics about the type of incidents reported are not published. The only statistics that are fairly detailed concern so-called SPAD-events, or signals passed at danger. These events are discussed more in detail in the next section, as there is evidence that there is behavioural adaptation to the defences-in-depth against train collisions of which the signal is the first line of defence.

5 THE CHALLENGE OF BEHAVIOURAL ADAPTATION

One of the most common incidents reported in Norwegian railways is so called SPAD-events, an abbreviation for signals passed at danger. These events involve a train passing a signal indicating that the train should stop. During the years from 2006 to 2011 there were on average close to 700 SPAD-events per year (Statens Jernbanetilsyn 2012) and one might think that these events are quite hazardous, since the primary function of signals is to prevent train collisions. There are three types of SPAD-events:

1. Events involving a technically defective signal. The signal suddenly becomes red, but the track section is actually free.
2. Events involving late change of signal indication by traffic management. Traffic managers may decide to indicate a stop signal, but sometimes this decision is made too late for the train to be able to stop in time.
3. Events where a train passes a stop signal that correctly indicates an occupied track section.

The mean annual number of SPAD-events in each of these categories is shown in Figure 6.

Figure 6 about here

The first type of SPAD-event does not have the potential to become an accident. The track section is actually free, but the signal erroneously indicates otherwise. The second type of SPAD-event will in most cases also be low-risk. Train drivers and traffic management can communicate by means the GSM-R cell phone system, so that train drivers will be informed about why the signal was changed to red. A frequently occurring reason for it will be train delays, which may require intervention from traffic management to minimise further delays. The third type of SPAD-event may have the potential to develop into a train collision. However, even this type of event is sometimes quite innocent, such as when dwarf signals in shunting yards are overrun. Speed will in most of these cases be very low. There will be no passengers on board the train and the train driver will in most cases discover the mistake quickly.

With so many false alarms every year, there is actually a risk that the respect for signals is reduced. The last train collision in Norway that may have been caused by violating a stop signal occurred in 2000. There were indications that the northbound train in that collision had violated a stop signal, but it was not possible to reach a firm conclusion, as there had been cases of technical errors in signalling on the line (NOU 2000:30). Since then there have been thousands of SPAD-events in Norwegian railways and not a single of them has lead to a train collision.

One reason for this is the extensive system of barriers that have been put in place to prevent train collisions. The barriers against train collisions involving passenger trains on electric train lines are shown in Figure 7.

Figure 7 about here

The first barrier consists of signals and their automatic operation in terms of track locks. The lock is an automatic device activated when a train passes a green signal: the section of track extending to the next signal is then automatically indicated as "occupied", i.e. there is a train on the section, and the signal turns red. It will remain red until the train has cleared the section and another train is approaching it. For passenger trains, however, the departure routine is intended as an additional barrier to prevent a train from departing a station against a stop signal. The train driver will flash lights signalling to the conductor that the train is ready to depart. The conductor will then assure that everybody has gone on board, double-check the signal, and give the departure signal. Many years ago, this procedure was simplified for freight trains. These are staffed by a train driver only; there is nobody to double-check the signal when departing a station. This simplified departure routine may be regarded both as a cost-cutting measure and as a kind of behavioural adaptation to defences-in-depth: Should a freight train violate a red signal, the next safety barriers in the chain of defences will detect this and action preventing an accident can be taken.

If a train departs by violating a stop signal, this is likely to be observed by traffic management. Traffic managers watch all train movements in a large control room, where a panel indicates all signals and all trains. However, this barrier is in principle fallible: When there are many trains to watch, the information load could be at a level where missing an observation becomes more likely. On electric lines, traffic managers will normally not have to intervene, since automatic train control (barrier 4) will be activated and brake the train to a controlled stop. Should even this fail, for example because the brakes of the train are defective, traffic managers may communicate directly with train drivers by means of the GSM-R phone network. Should the driver fail to respond, the traffic manager can turn off power (barrier 6).

Getting as far as barrier 6 is only possible in a highly unlikely scenario. The train must first violate a stop signal, which means that neither the driver nor the conductor will have observed the signal correctly. Then, automatic train control must fail, which probably can only occur if the brakes are defective. Then, the train driver must fail to respond to calls from the traffic manager. In short, a lot of things must go wrong to get as far into the barriers as stage 6.

In most cases, train drivers will notice that they have violated a stop signal and immediately stop the train. Usually, that brings the event to an end: Nothing further happens once the train has been stopped. In that sense, most SPAD-events do not have any serious consequences. Many train drivers will have experienced this, and one can easily imagine that this may lead to a form a negative learning: Train drivers learn that passing a stop signal is not associated with any serious impacts. Two studies (Nordbakke and Sagberg 2007, Phillips and Sagberg 2010) have applied cognitive reliability and error analysis to try to find out why train drivers violate stop signals. It is clear that SPAD-events are involuntary; no train driver violates signals intentionally.

Most train traffic in Norway is controlled by traffic managers. Traffic managers control traffic by setting up routes for trains. A route consists of the tracks that will be used and the signals that will be passed. When a route has been set, the train is normally cleared for the entire route and the normal signal indication will be green (proceed). A route can be more than 100 kilometres long; on long routes, a train driver may pass more than a hundred signals, all of which will normally show a green light to proceed. Train drivers therefore form an expectation that signals will instruct them to proceed. When this expectation is violated, train drivers are surprised and may react too late to be able to stop in time.

It is likely that most SPAD-events are primarily caused by violations of expectations: a signal that would normally be green is surprisingly red. The most frequent cause of this is a faulty signal. The section is actually not occupied, but the signal erroneously instructs the train driver to stop. Most train lines in Norway have automatic train control (ATC). This is a system based on dual signals. The first signal (the approach signal), usually located about 0.8 to 1 kilometres upstream of the second signal (the main signal), will indicate what the second signal will show. If a train passes an approach signal indicating that the main signal will instruct the train driver to stop, devices in the track will communicate with the train and calculate its speed. Brakes will then be applied automatically to make sure the train stops in time for the main signal. It has been found that some train drivers rely on this – a form of behavioural adaptation sometimes referred to as "ATC-behaviour". One of the train drivers interviewed by Phillips and Sagberg (2010) stated that: "You feel the distance and brake accordingly with your body. You are not always so worried when ATC sounds because you use ATC now and then for automatic stopping."

This quote illustrates than when safety barriers are felt as ample and technically highly reliable, behaviour may adapt to the barriers and become less cautious than it would otherwise have been. A train driver knowing that there is no ATC to assist him may be less inclined to pass approach signals at high speed.

When multiple barriers have been installed to prevent errors from leading to accidents, some of the barriers may be felt as unnecessary and may not be used consistently. A case in point is found in the report of the Norwegian Accident Investigation Board on an accident on March 24, 2010, when a set of empty container cars rolled without control from the Alnabru shunting yard down to Oslo Harbour (Accident Investigation Board Norway, 2011). The train had been parked awaiting shunting to the container terminal where containers were to be loaded onto it. It was held in place by a track mechanical brake. These brakes are operated from the control tower of the shunting yard. By mistake, the operator released the brakes and the train then started rolling. Had the prescribed safety routines been followed, this would not have happened. Safety routines state that when a train is parked for more than four hours, the parking brake should be engaged. The parking brake is operated by the train driver or, in the case of empty cars, by a shunting yard employee. The investigation found that this safety routine was unknown at Alnabru shunting yard and had never been practised. The personnel working there did not understand the rationale behind the safety routine. The shunting yard had been operating without any serious accidents for nearly forty years when the accident occurred on March 24, 2010.

A long period without accident may generate overconfidence and less interest in consistently applying safety routines, in particular when the routines are felt as unjustified. Actually, engaging the parking brake is an ambiguous safety routine; it may both cause and prevent accidents. A well-known accident in 1993 occurred because the train driver had started driving a heavy diesel locomotive without releasing the parking brake. After driving about 10 kilometres, he noticed smoke and reacted to the fact that the locomotive did not respond as usual to his attempt to speed up. He stopped, went out and discovered that the parking brake was engaged. He then released the brake. The locomotive immediately started to roll backwards and the driver was unable to get back onboard it. After a few kilometres the locomotive crashed with a local train and several people were killed. Any safety routine that relies exclusively on human memory is ambiguous, as errors can be made both by forgetting to carry out the routine and by forgetting to complete the routine once it has been started.

6 DISCUSSION

What happens when a system becomes very safe? Are there limits to how far safety can be improved? In very safe systems, information about safety may become difficult to interpret. By definition, accidents are few and far between and may not have very much in common. Thus, using accident statistics to estimate risk and determine if it is increasing or decreasing becomes difficult. Since accident statistics no longer provide sufficient information, it is common to introduce incident reporting in order to monitor and control hazards that may lead to accidents. But the information obtained by means of incident reporting is fundamentally ambiguous. An increasing number of incidents can be interpreted both as a sign that hazards are getting out of control and as an indication that vigilance is high and hazards effectively controlled before they cause harm. It is difficult to determine which interpretation is correct, but in Norwegian railways, the number of reported incidents has grown dramatically in the past ten years, whereas the number of serious accidents has remained low. While safety barriers prevent most incidents from developing into accidents, these barriers do not prevent the incidents from occurring in the first place. Incidents may not be completely negative. They serve as reminders that safety needs to be monitored and one may learn from them. As pointed out be Amalberti (2001), errors have the benefit that one may learn from them.

There are parallels between Norwegian railways and other complex technical systems where a number of safety barriers have been introduced. Hopkins (2012) describes how the Macondo oil-well blowout could occur because some safety barriers were dispensed with and because information was misinterpreted. Analogous phenomena have been found in railway accidents. In the largest ever train accident in Norway in 1975 (27 fatalities), the train crew on the northbound train insisted that the departure signal was green, although it is quite likely that it was red. The train crew may have been victims of the same type of confirmation bias in their thinking that Hopkins identified in the oil-rig crew in the Macondo disaster. The train crew were used to seeing a green signal; that is the normal indication and that was what they were looking for. As it happened, glare from the sun made it difficult to see whether it was the red or green lights that were lit; this may have contributed further to the confirmation bias.

Very safe systems are characterised by ambiguous information. It is not always clear, or possible to find out, whether risk is continuing to decline or has reached a plateau from which further progress is difficult. The reporting of an increasing number of incidents does not necessarily suggest that risk is increasing, but could just as well indicate the opposite. On the other hand, some incidents – in particular SPAD-events – are unwanted and an increase in their number is therefore not desirable. Although multiple barriers prevent passing a stop signal (a SPAD-event) from becoming an accident, it is desirable to prevent all SPAD-events. However, interest in doing so may be reduced if barriers always prevent these events from getting out of control. Even safety routines can become ambiguous. The accident history of Norwegian railways show that both forgetting to engage parking brakes on trains, as well as forgetting to release them when starting to drive the train may cause accidents. It seems clear that safety routines that rely on human memory are likely to be unreliable.

Although overall safety for railways in Norway has improved greatly over the last 50 years, there are notable differences between the different types of accident. Grade-crossing accidents and other accidents have been reduced fairly steadily throughout the entire period. Train collisions and derailments had a top during 1987-91; the reasons for this are unknown. Train crashes into fixed objects appear to have increased recently. It has been speculated that increasingly wet weather, possibly associated with global warming, leading to an increased frequency of landslides and floods may to some extent account for this.

7 CONCLUSIONS

The main conclusions of the research reported in this paper can be summarised as follows:

1. The number of passenger fatalities on Norwegian railways has been zero for eight of the past ten years. The risk of a passenger fatality is very low compared to other modes of transport.
2. The low number of accidents makes it difficult to estimate risk and determine if risk is increasing or declining.
3. Incident reporting was introduced in the mid-nineteen nineties. The number of incidents reported has grown dramatically since then and is now nearly 16,000 per year.

4. The growing number of incidents has not been associated with a growing number of accidents. A growing number of incidents does therefore not seem to indicate that accident risk is increasing.
5. Multiple safety barriers exist to prevent train collisions. There is evidence suggesting that train drivers adapt their behaviour to the barriers, trusting that automatic train control will intervene if a signal is passed at too high speed or the train does not stop in time for stop signal.

ACKNOWLEDGEMENT

The research reported in this paper was funded by the Research Council of Norway, grant number 210486.

REFERENCES

Accident Investigation Board Norway. 2011. Report on railway accident with freight car set that rolled uncontrolledly from Alnabru to Sydhavna on March 24, 2010. Lillestrøm, Accident Investigation Board Norway.

Amalberti, R. 2001. The paradoxes of almost totally safe transportation systems. Safety Science, 37, 109-126.

Core Team. 2012. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org/

Evans, A. W. 2003. Estimating transport fatality risk from past accident data. Accident Analysis and Prevention, 35, 459-472.

Evans, A. W. 2007. Rail safety and rail privatisation in Britain. Accident Analysis and Prevention, 39, 510-523.

Evans, A. W. 2010. Rail safety and rail privatisation in Japan. Accident Analysis and Prevention, 42, 1296-1301.

Evans, A. W. 2011. Fatal train accidents on Europe's railways: 1980-2009. Accident Analysis and Prevention, 43, 391-401.

Hopkins, A. 2012. Disastrous Decisions. The human and organisational causes of the Gulf of Mexico blowout. Sydney, CCH Australia limited.

Kutner, M. H., Neter, J., Nachtsheim, C. J., Wasserman, W. 2005. Applied linear statistical models. Fifth edition. Boston, McGraw-Hill.

Nordbakke, S., Sagberg, F. 2007. CREAM analysis of "Signal Passed at Danger" (SPAD) events. Report 915. Oslo, Institute of Transport Economics.

Norges Offentlige Utredninger (NOU). 2000. Åsta-ulykken 4. januar 2000. Hovedrapport. Rapport fra undersøkelseskommisjon oppnevnt ved kongelig resolusjon 7. januar 2000. NOU 2000:30. Oslo, Statens forvaltningstjeneste.

Phillips, R. O., Sagberg, F. 2010. Helping train drivers pass signals safely: Lessons from 10 case studies. Report 1066. Oslo, Institute of Transport Economics.

Samferdselsdepartementet. 2009. Stortingsmelding 16 (2008-2009). Nasjonal transportplan 2010-2019. Oslo, Samferdselsdepartementet.

Statens Jernbanetilsyn. 2012. Sikkerhetsrapport 2011. Oslo, Statens Jernbanetilsyn.

Vågane, L., Rideng, A. 2011. Transportytelser i Norge 1946-2010. Rapport 1165. Oslo, Transportøkonomisk institutt.

LIST OF FIGURES AND TABLES

TABLE 1:

Year	Train collisions	Killed in collisions	Train hit fixed object	Killed in fixed object	Derail-ments	Killed in derail-ments	Grade-crossing accidents	Killed in grade-crossing	Other accidents	Killed in other accidents	Total accidents	Total killed	Million passenger km	Million train km
1962	14	2	7	0	41	0	37	15	70	8	169	25	1734	34.703
1963	15	0	5	0	34	0	23	3	47	13	124	16	1758	33.493
1964	23	2	2	0	30	0	32	9	60	8	147	19	1755	34.164
1965	7	0	7	0	34	0	45	13	37	11	130	24	1748	32.265
1966	19	2	10	0	39	0	33	9	43	12	144	23	1745	32.598
1967	10	1	6	0	28	0	30	11	43	7	117	19	1707	32.934
1968	9	0	1	0	29	0	35	14	86	16	160	30	1643	33.093
1969	12	2	0	0	23	0	47	30	50	12	132	44	1564	32.337
1970	16	2	1	0	26	0	32	6	40	13	115	21	1568	32.131
1971	16	0	1	0	25	0	27	5	35	2	104	7	1588	32.055
1972	6	1	0	0	18	0	24	5	37	9	85	15	1607	31.708
1973	3	0	0	0	35	0	38	17	24	8	100	25	1625	31.173
1974	13	1	2	0	23	0	24	9	38	10	100	20	1870	32.369
1975	9	27	1	0	17	1	34	8	16	7	77	43	1925	33.073
1976	8	0	6	0	33	1	28	4	37	10	112	15	1979	33.912
1977	5	2	1	0	18	1	21	6	25	5	70	14	2001	34.174
1978	10	0	1	0	25	0	29	4	29	8	94	12	2061	34.022
1979	9	0	4	0	37	0	22	1	23	9	95	10	2290	34.098
1980	12	0	3	0	25	0	27	2	28	10	95	12	2394	34.733
1981	7	0	1	0	21	0	18	1	25	8	72	9	2423	34.610

TABLE 1, continued

Year	Train collisions	Killed in collisions	Train hit fixed object	Killed in fixed object	Derail-ments	Killed in derail-ments	Grade-crossing accidents	Killed in grade-crossing	Other accidents	Killed in other accidents	Total accidents	Total killed	Million passenger km	Million train km
1982	11	0	3	0	17	0	18	2	32	9	81	11	2240	34.206
1983	6	0	2	0	10	0	18	3	24	7	60	10	2162	33.210
1984	5	0	1	0	17	0	20	3	26	6	69	9	2181	32.837
1985	4	0	1	0	14	0	23	4	23	9	65	13	2221	32.794
1986	4	0	1	0	30	0	30	12	28	7	93	19	2231	33.441
1987	10	0	0	0	44	0	18	6	32	2	104	8	2188	32.939
1988	17	0	5	0	23	0	20	3	14	4	79	7	2122	31.535
1989	22	0	1	0	18	0	15	3	14	7	70	10	2133	31.022
1990	28	5	5	0	20	0	24	5	11	3	88	13	2116	32.504
1991	25	2	0	0	22	0	11	3	21	4	79	9	2139	33.358
1992	14	2	1	0	27	0	14	6	24	4	80	12	2229	34.208
1993	5	5	4	0	20	0	12	2	8	4	49	11	2280	34.754
1994	10	0	3	0	18	0	12	2	7	3	50	5	2386	37.342
1995	4	0	3	0	16	0	5	0	25	2	53	2	2350	36.712
1996	5	0	4	0	15	0	9	1	7	1	40	2	2431	37.364
1997	0	0	5	0	11	0	9	1	12	2	37	3	2561	37.103
1998	2	0	2	0	18	0	12	6	18	1	52	7	2602	37.417
1999	7	0	4	0	15	0	17	2	13	3	56	5	2909	37.871
2000	20	19	0	0	9	0	18	10	12	2	59	31	2857	38.325
2001	8	0	0	0	8	0	15	2	12	4	43	6	2850	38.779

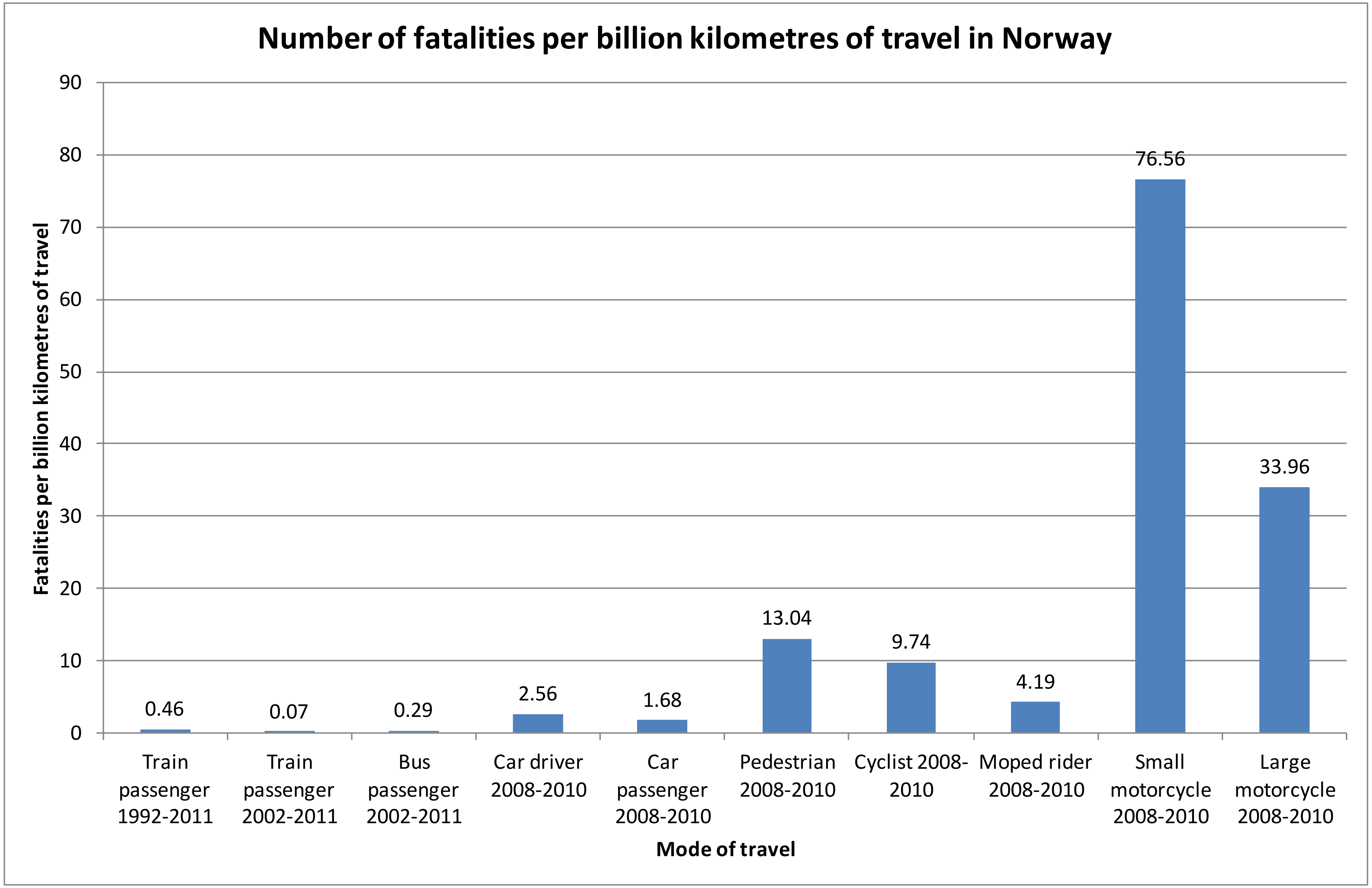
TABLE 1, continued

Year	Train collisions	Killed in collisions	Train hit fixed object	Killed in fixed object	Derail-ments	Killed in derail-ments	Grade-crossing accidents	Killed in grade-crossing	Other accidents	Killed in other accidents	Total accidents	Total killed	Million passenger km	Million train km
2002	4	0	5	0	6	0	8	0	12	3	35	3	2564	39.223
2003	10	0	26	0	18	0	20	4	4	1	78	5	2487	39.686
2004	5	0	16	0	8	0	12	3	5	0	46	3	2683	41.217
2005	3	0	6	0	12	0	7	1	9	2	37	3	2723	40.853
2006	0	0	5	0	3	0	2	0	6	1	16	1	2821	41.828
2007	0	0	4	0	0	0	2	0	6	2	12	2	2957	42.904
2008	0	0	6	0	3	0	0	0	5	1	14	1	3122	42.025
2009	1	0	4	0	3	0	2	2	6	1	16	3	3080	43.064
2010	0	0	9	0	4	0	3	3	4	6	20	9	3134	46.097
2011	0	0	15	0	9	0	2	1	9	4	35	5	3013	46.306

TABLE 2:

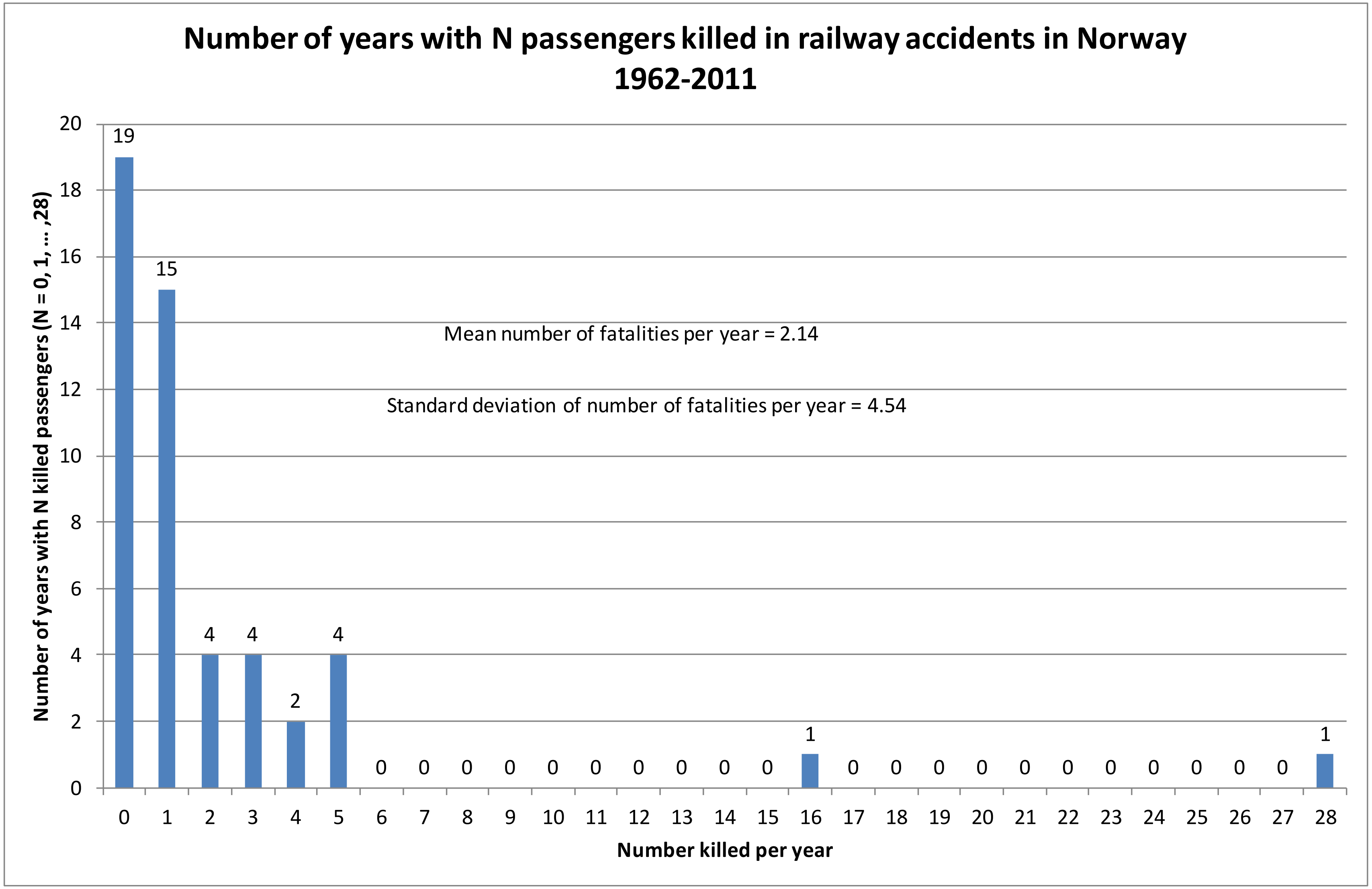
	Parameter estimates, standard errors and P-values for model: $\alpha k_t \cdot \exp(\beta t)$					
	Parameter estimates for multiplicative part of model (α)		Parameter estimates for exponential part of model (β)			
Dependent variable	**Estimate**	**Standard error**	**Estimate**	**Standard error**	**P-value**	**Coefficients for annual changes**
Total accidents (annual data)	4.884	0.218	-0.035	0.002	0.000	-0.035
Total fatalities (five year periods)	0.952	0.135	-0.200	0.038	0.001	-0.040
Train collisions (five year periods)	0.495	0.163	-0.129	0.070	0.104	-0.026
Fatalities in train collisions (five year periods)	0.072	0.054	-0.104	0.147	0.498	-0.021
Train hit fixed object (five year periods)	0.050	0.037	0.110	0.091	0.264	0.022
Fatalities in fixed object accidents	No model developed as there were only 3 fatalities during the period 1962-2011					
Derailments (five year periods)	1.259	0.158	-0.160	0.029	0.001	-0.032
Fatalities in derailments	No model developed as there were only 3 fatalities during the period 1962-2011					
Grade crossing accidents (five year periods)	1.414	0.142	-0.189	0.026	0.000	-0.038
Fatalities in grade crossing accidents (five year periods)	0.462	0.086	-0.244	0.057	0.003	-0.049
Other accidents (trespassers etc) (five year periods)	2.099	0.158	-0.230	0.022	0.000	-0.046
Fatalities in other accidents (five year periods)	0.437	0.047	-0.196	0.028	0.000	-0.039
Fatal train accidents (collisions, derailments, fixed object)	0.038	0.010	-0.222	0.075	0.018	-0.044

FIGURE 1:



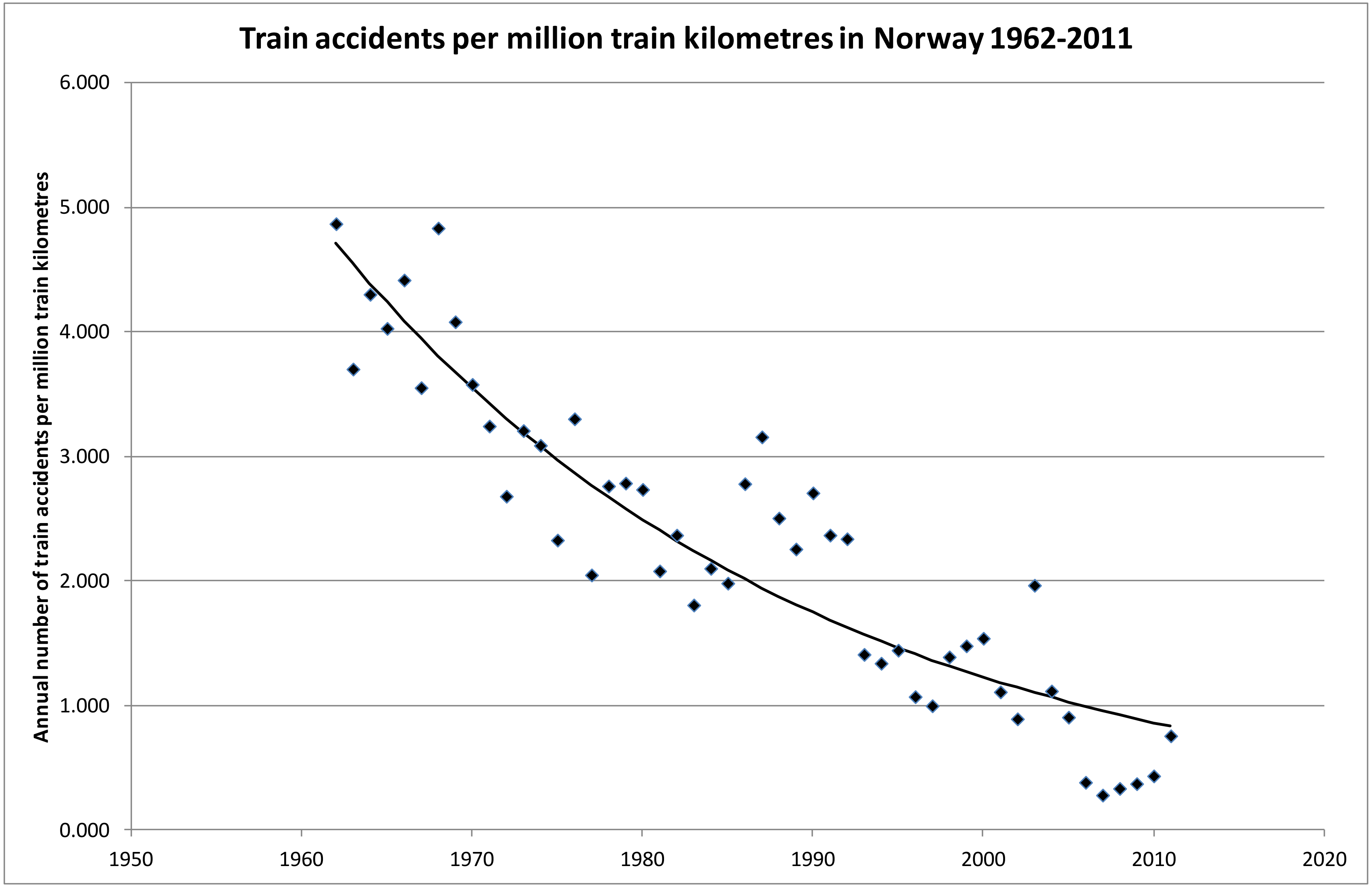
Number of fatalities per billion kilometres of travel in Norway
Fatalities per billion kilometres of travel
90
80
70
60
50
40
30
20
10
0
0.46
0.07
0.29
2.56
1.68
13.04
9.74
4.19
76.56
33.96
Train passenger 1992-2011
Train passenger 2002-2011
Bus passenger 2002-2011
Car driver 2008-2010
Car passenger 2008-2010
Pedestrian 2008-2010
Cyclist 2008-2010
Moped rider 2008-2010
Small motorcycle 2008-2010
Large motorcycle 2008-2010
Mode of travel

FIGURE 2:



Number of years with N passengers killed in railway accidents in Norway 1962-2011
Mean number of fatalities per year = 2.14
Standard deviation of number of fatalities per year = 4.54
Number of years with N killed passengers (N = 0, 1, ... ,28)
Number killed per year
0
2
4
6
8
10
12
14
16
18
20
19
15
4
4
2
4
0
0
0
0
0
0
0
0
0
0
1
0
0
0
0
0
0
0
0
0
0
0
1
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28

FIGURE 3:



Train accidents per million train kilometres in Norway 1962-2011
Annual number of train accidents per million train kilometres
6.000
5.000
4.000
3.000
2.000
1.000
0.000
1950
1960
1970
1980
1990
2000
2010
2020

FIGURE 4 :

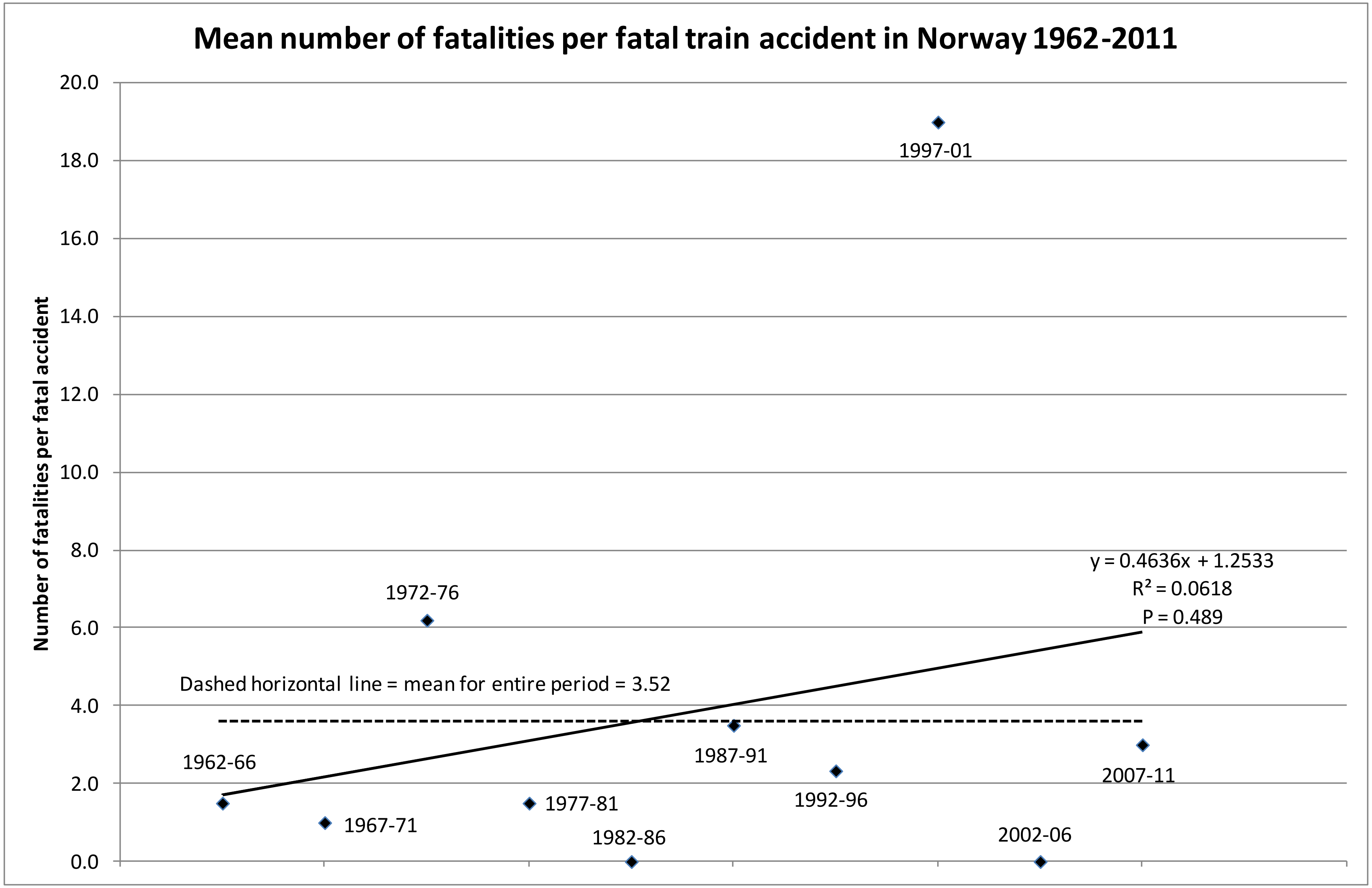

Mean number of fatalities per fatal train accident in Norway 1962-2011
Number of fatalities per fatal accident
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
1997-01
1972-76
y = 0.4636x + 1.2533
R² = 0.0618
P = 0.489
Dashed horizontal line = mean for entire period = 3.52
1962-66
1967-71
1977-81
1982-86
1987-91
1992-96
2002-06
2007-11

FIGURE 5:

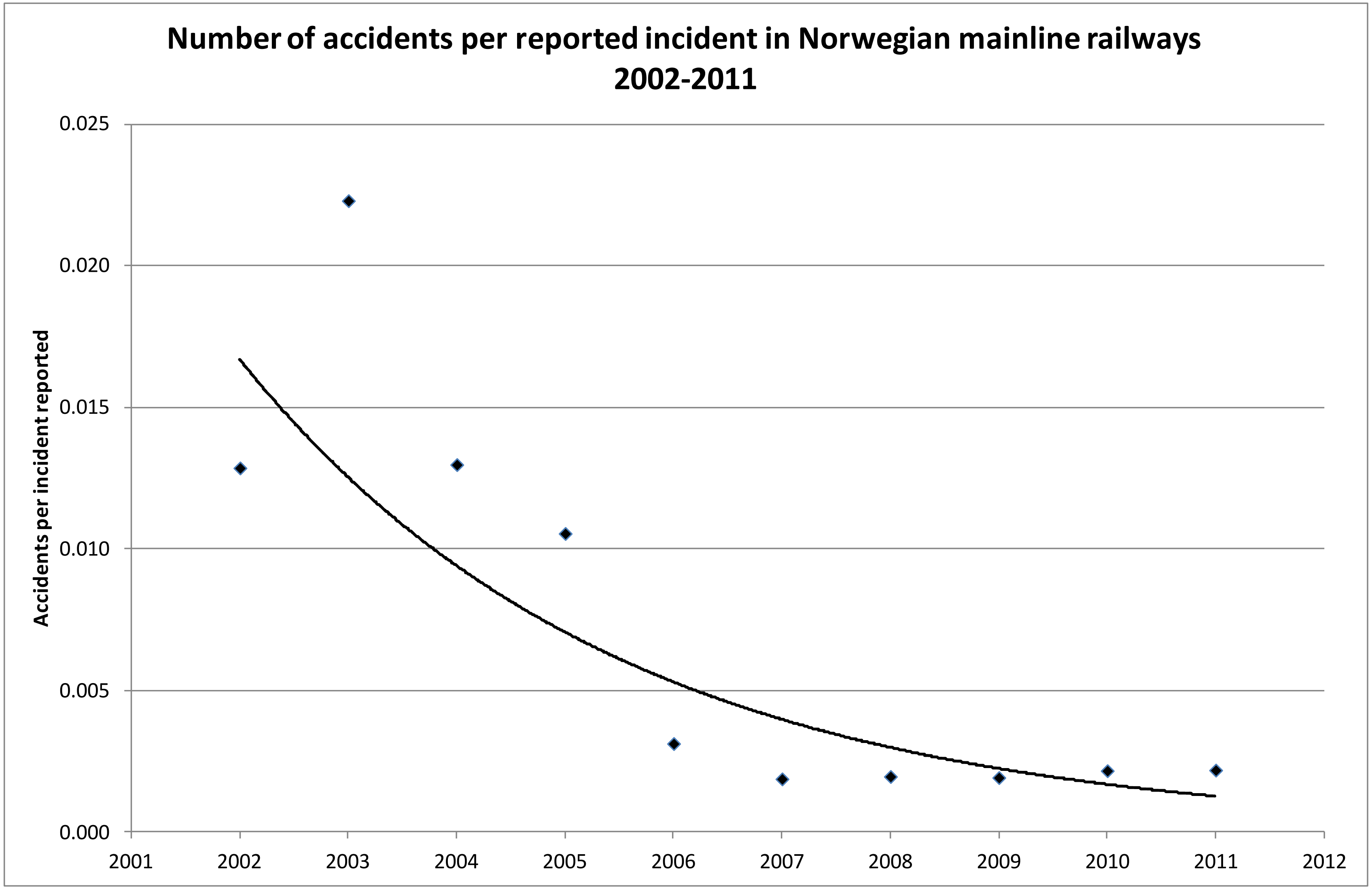

Number of accidents per reported incident in Norwegian mainline railways 2002-2011
Accidents per incident reported
0.025
0.020
0.015
0.010
0.005
0.000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012

FIGURE 6:

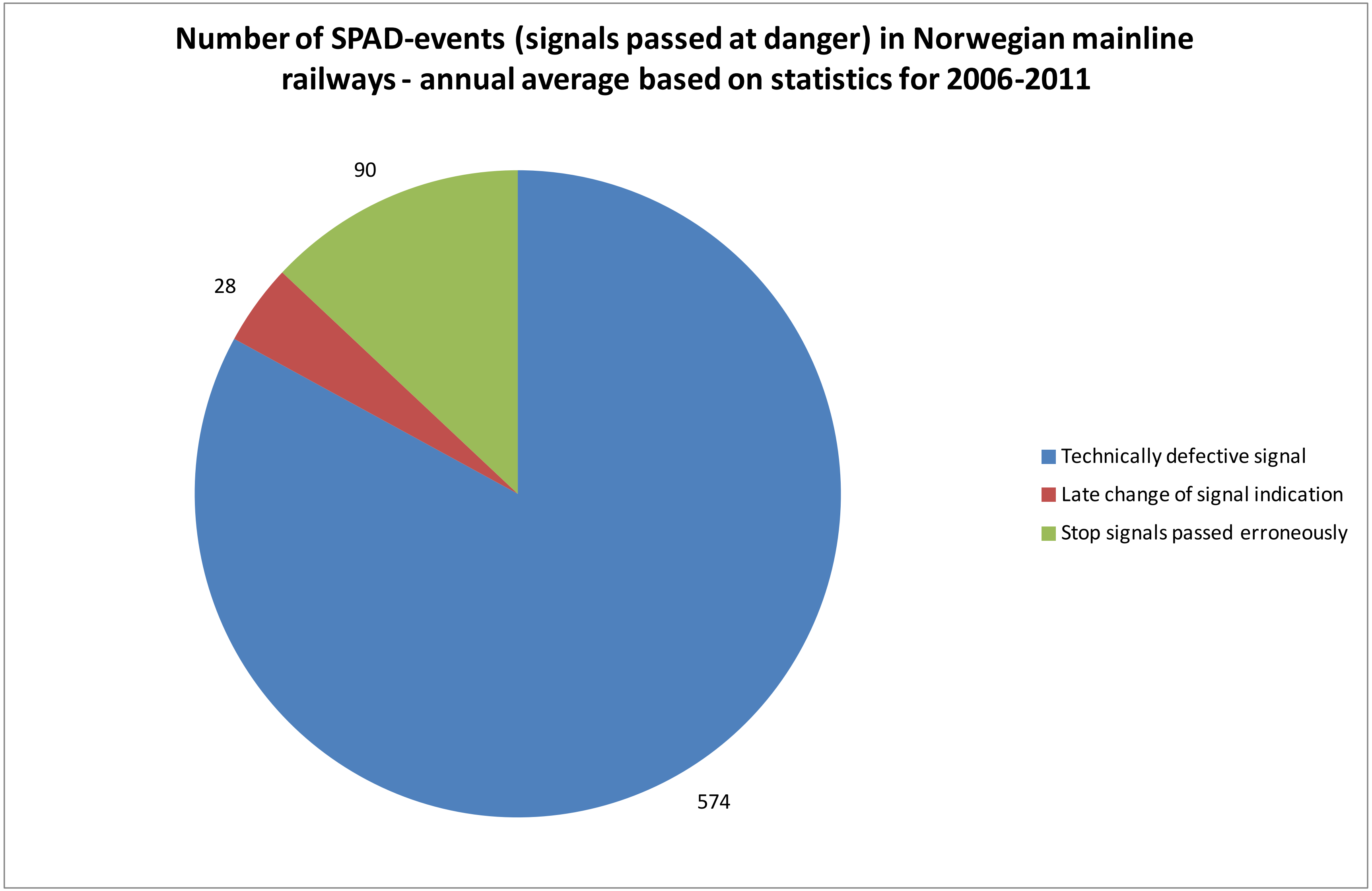
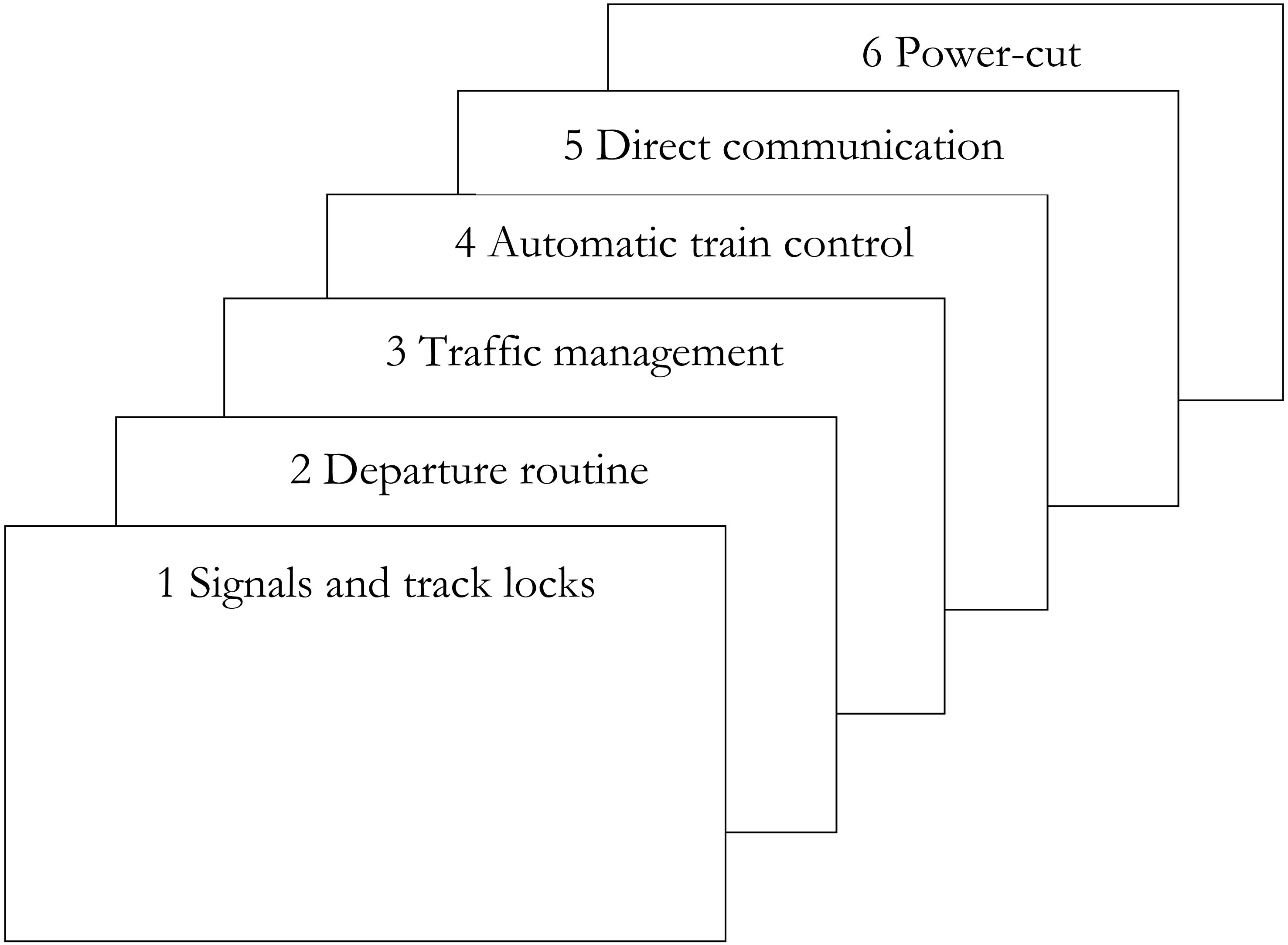

Number of SPAD-events (signals passed at danger) in Norwegian mainline railways - annual average based on statistics for 2006-2011
90
28
574
Technically defective signal
Late change of signal indication
Stop signals passed erroneously

FIGURE 7:


6 Power-cut
5 Direct communication
4 Automatic train control
3 Traffic management
2 Departure routine
1 Signals and track locks