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Railway Accidents Prevention – A Systematic Analysis

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Abstract – Rail transport is one of the safest means of transport. However, there have been in history some accidents with high death tolls, which could have been prevented had specific train protection systems been in place or had specific courses of action been correctly carried out. This article aims to present several railway accidents in history and the systems or actions which could have prevented them, respectively that were or should have been introduced after the inquiries that have taken place after these accidents.

Keywords: Train Accidents, Train Incidents, Accident Prevention, Train Protection Systems

I. INTRODUCTION

Throughout history rail transport has proven to be quite safe. It is much more probable, as studies like [1] have shown, to suffer a fatal accident for instance when traveling by car, but also less probable to die while traveling by plane. The aforementioned article postulates that the risk of death is 17 times higher for road transport by car then for rail transport (7,28 deaths per 1 billion passenger miles for the transport by car opposed to 0,43 deaths per 1 billion passenger miles for rail transport). However, transport by plane has proven to be 6 times safer than rail transport when considering the same statistic mass of 1 billion passenger miles.

This is somewhat surprising, if we factor in the subjective perception of the general population – aviophobia or the fear of flying has a lifetime prevalence rate of roughly 13.2% [2], while siderodromophobia or the fear of trains is very rare – nowadays virtually non-existent. What this tells us: there is no connection between the perceived risks of a type of transport and its actual safety.

It is also important to consider which death tolls these types of transport claim in the case of a catastrophic event [3]. The highest death toll in aviation was 583 in the Tenerife airport disaster in 1977, when two passenger jets collided on the runway. When regarding road accidents, the Salang tunnel fire stands out by far as the deadliest event, claiming an ultimately unknown number of lives (up to 3500)! For comparison: the second most deadly road accident in history (the Sange road tanker explosion in Congo) has claimed 230 lives.

The deadliest rail accident in history is considered by far the Sri Lanka tsunami train wreck in 2004, when more than 1700 lives were lost. This train accident was not caused by human error or a faulty technique (as is often the case in railway disasters), but by the tremendous force with which the overcrowded Matara Express was hit by a tsunami. The train was travelling on the Sri Lankan coast between the cities Colombo and Galle on a track that runs only about 200 m away from the sea.

It is important to note, that the second-most deadly rail accident in history happened in 1917 in Romania during World War I and is known as the Ciurea catastrophe. While there was no formal investigation into the event (as Romania was at the time in a state of political turmoil caused by the taking of the capital city Bucharest by the Central Powers), the main cause of this catastrophic event was break failure, further aided by the overcrowded train. The exact death toll is in this case uncertain, but it is estimated at 600 to 1000.

While human errors or mechanical failures can never be fully excluded, there are certain accident causes which can be at least mitigated by diverse security systems or actions.

II. MAIN CAUSES OF TRAIN ACCIDENTS

To be able to correctly recognize the main causes of train accidents and the possibilities of precluding them, it is necessary to define what counts as a train accident. In [4], these events are defined as "accidents in which moving trains are damaged, and

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persons either inside or outside trains may be killed or injured". Another important distinction is the type of train accident – train derailment, train collision or train fire. This distinction does not aid in identifying the underlying causes of the accidents, only defining the outcome of a series of events.

Train accidents are complex catastrophic events and more often than not there isn't a single cause, but a string of factors which lead to the final event (either a derailment, a collision or a train fire). Accordingly, when analyzing which course of action could have precluded the train accident there isn't only one right answer – many known train accidents would not have taken place if either of the factors leading to it would have been avoided or mitigated.

The aforementioned article by A.W. Evans centralizes data for the entire European Union plus Norway and Switzerland. In total train accidents from 27 countries (as EU member countries Malta and Cyprus do not have railways) between 1980 and 2019 were considered and analyzed regarding their causes.

A. *Signal passed at danger*

The most common cause of train accidents in the aforementioned study was the unauthorized passing of a halt signal known as signal passed at danger (SPAD) – every third train collision or derailment was caused by this fatal course of action.

The SPAD occurs when a train driver mostly accidentally passes a halt-showing signal. The road equivalent of this action would be the passing of a red traffic light – however with more serious consequences.

Accidentally occurring SPAD can be caused by a number of factors:

- Not acknowledging the meaning of the signal due to inattention or fatigue;
- Impaired sight on the signal (for instance due to weather conditions);
- Misunderstanding or miscommunication [5];
- Medical conditions (heart attack, stroke).

There are some cases in which train mechanics have also committed SPAD purposely – mostly with suicidal reasoning. However, such cases are fortunately enough very rare.

A well-known example for such an accident caused by a SPAD is the Ladbroke Grove rail crash in 1999 (31 casualties and 417 injuries) – an inexperienced train mechanic was blinded by the low sun and overran a halt-showing signal thus causing a head-on crash with another passenger train.

B. *Over speeding*

The second most common cause of train accidents was over speeding – the situation in which the train travels at a higher speed than the maximum allowed speed on the respective track. This is almost always caused by an incorrect behavior of the train mechanic – in most cases this resides in not decelerating the train when the track requires the driver to do so (for instance when nearing a curve).

A high-profile example for over speeding ending in disaster is the Santiago de Compostela disaster in 2013 leaving 79 dead and 143 injured. In this case the train driver failed to reduce the speed after a long stretch of track with a maximum speed of 200 km/h for a stretch of track with a maximum speed of 80 km/h thus entering a curve with about 160 km/h and causing the derailment of all thirteen train cars.

C. *Signaling or dispatching error*

Train accidents can also be caused by signaling or dispatching errors committed by the train dispatcher of the infrastructure company. These situations occur when the train dispatcher is inattentive or distracted, thus setting the wrong signals for one or more trains. When these trains follow the wrongly set signals, it usually comes to a train collision.

One example for a signaling error with dire consequences is the Bad Aibling train crash in February 2016 – a Deutsche Bahn train dispatcher distracted by a mobile phone game he was playing while on duty firstly allowed two trains to proceed on a single track and then also failed to launch a life-saving emergency call causing them to collide head-on, killing 12 and injuring 85 passengers onboard the two trains.

D. *Infrastructure failure*

In some cases, train accidents do not have anything to do with human errors, like in the three most common causes under A, B and C. Although offering a high degree of security, railway infrastructure is also susceptible to failures – like a railway bridge collapsing under the load of a train or a signal failure.

The Clapham Junction rail crash in 1988 (with 35 deaths and 484 injured) was caused by faulty wiring which prevented a signal from falling on red when the track circuit behind the signal was occupied by another train. This led to a passenger train ramming another stopped passenger train from behind.

E. *Rolling stock failure*

Not only infrastructure failure can cause train accidents, but also rolling stock failure – this occurs when trains or their components experience failures. This was for instance the case in Germany's most horrific train accident to date – the Eschede catastrophe [6].

This train derailment was caused by a crack in the rubber damping ring of one of the wheels of the ICE train – when the wheel failed, a part of it became caught in a railroad switch, whose setting was hereby changed. The train's wagons split into two tracks derailing and crashed in a concrete road bridge, killing 101 passengers and injuring 88 others.

F. *External causes*

Not all identified causes regard human errors or component failure. Sometimes, as seen in the introduction of this article in the case of the 2004 Sri Lankan train disaster, external factors (like extreme weather conditions) lead to catastrophic railroad accidents.

III. PREVENTING OPERATIONAL ERRORS

In modern times all train accidents are investigated in-depth and in most cases the causes are correctly identified, while also defining courses of action or developing technical systems which would preclude a similar accident from happening in the future. Of course, not all causes can be avoided through specific courses of action or technical systems – there is no possibility of avoiding the devastating effect of an earthquake or a tornado taking place in an area the train is passing through.

The two most-common causes for train accidents – the signal passed at danger (SPAD) and over speeding – can both be mitigated and, in some cases, completely avoided when the necessary advanced train systems are installed and in use.

There are three main types of systems in use with European railroads specifically designed to avoid such causes [7].

The simplest and earliest developed system is the so-called train stop or tripper – when the signal is showing halt, a moveable mechanical element is oriented towards the rail, so that a counterpart mechanical element of a train committing a SPAD would be physically activated – this in turn triggers the emergency braking. This system is still in use on some important tracks like the S-Bahn Berlin in Germany or the London Underground in the United Kingdom.

The train stops are usually positioned so that the train can be stopped before it reaches a certain danger point (like a switch or another stationed train). This system is however nowadays not considered safe enough: the train would only be stopped before it reaches the danger point if its speed is not greater than the maximum allowed speed, as there is no speed monitoring when this system is in use. If a train driver is travelling at a higher-than-normal speed, the train stop is ineffective and the train would come to a halt only after passing the danger point, thus possibly causing a train collision or a train derailment.

The aforementioned limitation is one of the reasons why other systems had to be developed (and also the reason why railway companies that still use them – like the S-Bahn Berlin – are phasing them out successively). The nowadays widely used inductive system bypasses this crippling limitation: in the case of this system track and locomotive communicate through magnets installed on both rolling stock and track. In the base version of the inductive system, communication is intermittent, as information is exchanged between locomotive and track only at given points, where magnets are installed on the tracks. These magnets (with different frequencies) are usually placed near signals and have the role of checking whether the speed of the train lies below the maximum speed of the track, but also whether the train has acknowledged an upcoming signal and already reducing its speed [8].

There are many local versions of this inductive system being used in EU countries – such as PZB/Indusi, which is used in Germany, Austria, Romania or Croatia or Crocodile which is used in France and Belgium.

PZB Indusi operates on three frequencies with different purposes (500 Hz, 1000 Hz, 2000 Hz) – requiring the train driver to acknowledge a warning regarding an upcoming main signal and/or to reduce the speed of the train. Failure to acknowledge the warning by pressing a button, not complying with the maximum speed at the location of the track magnet or even too timid braking (not respecting the calculated braking curve) lead to a forced stop of the train.

PZB is used for instance in Germany on virtually all lines and has proven throughout its use history to be quite safe. It is however possible for the train driver to override the forced stop, by pressing a button, which releases the train allowing it to travel with a speed up to 40 km/h. Use of this command button (Befehlstaste in German) is marked in the train recorder and should only take place after consulting with or being instructed to do so by the train dispatcher. This overriding option theoretically opens the possibility for the train driver to continue his journey without consulting with the dispatcher – an example for such an action was the 2000 Hannover-Langenhagen train crash. In this case the train was halted by the PZB well ahead of the danger point, but the train driver released the train and went on to hit another passenger train, injuring 16 passengers. The German railway authority specified after this incident, that the use of the command button to free a halted train is only allowed after consulting with the train dispatcher [9] – this is however not technically enforced in any way.

A more advanced train protection system is in use in Germany, Austria or Spain on high-speed tracks – this system is an upgraded version of the PZB (punktuelle Zugbeeinflussung in German) called LZB (Linienzugbeeinflussung in German – continuous train control). Evolving from PZB, the LZB no longer relies on strategically placed magnets, but on a wire placed on the middle of the sleepers, between the two rails.

The LZB system boasts a few crucial advantages. These are:

- The continuous exchange of information between track and train (regarding maximum speed, current speed, speed changes);

- Included automatic train protection (any overspeeding leads to a warning, not decreasing the speed after the warning leads to a forced stop);
- Included automatic train operation system called AFB (Automatische Fahr- und Bremssteuerung in German, an autopilot function).

To date there are no accidents registered on tracks fitted with the LZB system – there have been however some minor incidents or near-accidents, mainly caused by software errors or miscommunications between databases. This was the case for instance in 2001 in Oschatz when the LZB system showed an allowed speed of 180 km/h although the set route was over the junction of a switch which could only be passed with 100 km/h – the train driver managed to slow the train down to about 170 km/h avoiding derailment [10].

Although virtually flawless, LZB and other similar systems in Europe (like ATB in the Netherlands – introduced after the country's most disastrous railway accident in Harmelen in 1962) will be replaced by 2030 in the whole EU by the new harmonized European Train Control System (ETCS), allowing rolling stock to travel through the EU without needing to have all national systems installed. This harmonized system defines 4 levels, with level 0 defining rolling-stock-only technique (no communication between track and train, only admissible in Germany for instance on tracks with a maximum speed of 50 km/h), level 1 defining the punctual communication (like PZB Indusi), level 2 defining the continuous communication (like LZB) and level 3 (currently under development) defining an improved level offering additionally track vacancy detection and train integrity check [11].

Coming back to the accidents mentioned in the last subchapter, we can conclude that both the Ladbroke Grove and the Santiago de Compostela accidents would not have taken place, had the advanced inductive system been in place. For instance, the Spanish infrastructure company Adif installed three ASFA (Anuncio de Segnales y Frenado Automatico in Spanish – Automatic Announcement of Signals and Braking in English) following the investigation into the accident, effectively monitoring the correct decrease of the speed before the curve where the accident took place.

Another important system used to avoid medically-caused SPAD is the so-called dead man's switch – a button or a pedal which must be pressed or released in a set interval of time (every 30 seconds for the German system Sifa). If the train driver fails to press or release the button or the pedal, a warning is heard, after which the train is halted, as there is no way to know whether the train driver is still alive.

To prevent errors committed by the train dispatcher, other systems have to be taken into consideration – such systems are sadly not widely used at the moment. For instance, trains fitted with the Railway Collision Avoidance System (RCAS) communicate their geographical position and speed as soon as two such trains are in radio range one to another. If the system should detect an imminent collision, both train drivers are warned and assisted in avoiding the train collision [12]. A comparable system is in use with the Indian railways and bears the similar name Train Collision Avoidance System (TCAS).

RCAS or TCAS would have probably prevented the Bad Aibling train collision in 2016. Thus, we can conclude that such a system would also aid in correcting albeit not precluding fatal errors of the train dispatcher.

IV. PREVENTING TECHNICAL ERRORS

The prevention of technical errors (like infrastructure or rolling material failures, as stated in II D and II E) is far more complex, as there isn't a system which can prevent each and every mechanical malfunction.

In order to mitigate risks of technical failures, the regulations in each EU country provide for thoroughly defined inspections at certain fixed intervals. These inspections are carried out by specially trained personnel of the infrastructure or rolling stock company.

For instance, the German railway infrastructure company DB Netz AG defines cyclical inspections for every component, like signals, railway crossings or track switches. Through these inspections the infrastructure company aims to assess the degree of wear of the facilities and to derive courses of actions (like repairing or changing certain components) allowing to avoid an infrastructure failure.

The subjective factor is however here also present: while there are strict rules for the conducting of any given inspections (defining what to look for and which course of action is necessary if a defect is found) and in most cases more than one employee respectively another employee as in the last inspection (4-eyes-principle) is tasked with an inspection for any infrastructure component, there is still room for human error. The Clapham Junction rail crash under II D took place because new wiring was installed, while the old wiring was left in place uninsulated. Furthermore, the signaling technician was heavily overworked, having worked for 13 consecutive 7-days-weeks and his work was not supervised and controlled by any other employee. While there is no way to know for sure, the faulty wiring could have been avoided had the signaling technician not been exhausted or could have been fixed had another employee supervised the action, thus effectively saving the lives of the victims.

The Eschede train disaster in 1998 might have been prevented if the inspection of the rolling stock had been more thorough. At the time, there was no possibility of actually testing the fatigue limit of wheels in Germany; furthermore, the new rubber damping ring used on the wheels of the ICE1 was not tested in high-speed conditions before launch. After the accident all wheels were replaced with monolithic wheels without the applied rubber damping ring.

These two accidents (Clapham Junction and Eschede) show that inspections of rolling stock and infrastructure bear a great importance for the safety of rail transport. While respecting all regulations and using well-rested employees is a minimum requirement, advanced testing and inspecting techniques are necessary in order to mitigate the risks of fatal railway accidents.

V. CONCLUSIONS

Trains are a safe way to travel – there is very little risk when boarding a train. However operational errors and mechanical failure must be prevented accordingly in order to achieve an even higher transport safety. While operational errors can be prevented by using modern safety systems (like PZB Indusi, LZB or the new harmonized ETCS), the mechanical failures can be avoided through punctual, in-depth inspections conducted by highly skilled, top-trained and well-rested employees using state-of-the-art techniques and tools.

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