# Human-Factors and Automation-Related Accidents in the Railway Industry

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Increasingly, control systems are being automated in industries that handle dangerous goods. These systems can both reduce and introduce human factors. A current example is the adoption of cab warning technologies and train control systems being deployed in the railway industry. Existing systems mainly focus on the prevention of signal passed at danger (SPAD), Overspeed, and collisions. These have evolved from simple warning of signal indications to monitoring of speed and automated braking to ensure compliance. While these systems can improve safety and efficiency, they may introduce potential weaknesses related to design and usability. The increased complexity of the systems caused by human-technology interactions can have adverse cognitive effects on the train operators. Moreover, upgrading systems over time can create a confusing array of train cab warnings and displays. These issues can lead to poor system performance and serious rail accidents in some cases. This paper reviews automation-related accidents in the railway industry, analyzes the contributing factors, and discusses the lessons learned. The reviewed accidents demonstrate that automated system failure, the complacency of the train operator, inconsistency of alarm performance with user expectations, and poor alarm design and management were common causes. Furthermore, research showed the limitations of train operators to handle alarms primarily related to workload, with their response varying greatly across individuals and situations. While underload of the train operator results in boredom, fatigue, overconfidence, and complacency, an overload results in irrational reactions, confusion, exhaustion, and loss of situational awareness. We discuss the broader implications for designing automated control systems.

**Keywords:** Human, Automation, Accidents, Incidents, Railways

## 1. Introduction

Automated control systems have been introduced to various industries including process control, transportation, and healthcare to assist human operators with tasks such as information acquisition and processing, decision making, and action execution (Parasuraman et al. 2000). While such systems can improve safety and efficiency, they may introduce potential weaknesses related to design and usability and may pose new human operator performance issues. These issues can lead to poor system performance and serious accidents in some cases.

Analyzing the relevant incident and accident data and learning from the past events is useful to understand issues associated with using automated systems. This equips us to, formulate and implement effective strategies to mitigate the negative impacts of such systems on human operators. Bliss (2003) investigated the NASA's Aviation Safety Reporting System (ASRS), National Transportation Safety Board (NTSB), and U.S. Army's Aviation Safety databases and statistically analyzed the alarm related (involving true, false, and missed alarms) incidents and accidents. The investigation revealed several common trends and showed a need for more research on human-automation and design. They found that the high number of false alarms as a result of conservative aircraft design and can cause pilot mistrust. Glussich and Histon (2010) examined the role of human factors in technology-dependent landing accidents of commercial flights using the Human Factors Analysis and Classification System (HFACS) method. Their results illustrated that mode confusion, which can be caused by poor display design, high complexity of the tasks, or an incorrect mental model, as well as out-of-the-loop (OOTL) degradation (i.e., loss of manual skills and loss of situation awareness), were the primary automation-associated issues. Analysis of 257 incidents related to automation failures and human factors reported on the ASRS database ascertained that the HFACS categories with the highest frequency of occurrence respectively were crew resource management, technology environment, and adverse mental state, followed by decision errors (Li et al. 2014). Poor vigilance, skill degradation, mistrust in automation, and complacency were recognized as the main reasons for automation-induced accidents in aviation by Gawron (2019). Recently, Read et al. (2020) analyzed automation-associated events that occurred in the airline industry and found that the main contributory factors were linked to shortcomings in situation awareness, compliance with procedures and unsafe acts, judgment and decision making, design of the automation, and organizational policy and procedures relating to the use of the automation.

Schmitt (2012) and Hardy (2014) focused on reviewing technology-involved occurrences in the nuclear and process industries. Schmitt (2012) highlighted a misunderstanding of automation, mistrust of automation, and lack of appropriate automation as the downside of automation. She believed that these issues stemmed from flawed design, training, or organizational processes. An overview of alarm-related incidents that happened in different industries can be seen in the study performed by Goel et al. (2017). They listed the main risk factors of the accidents as alarm flooding, false alarms, poorly prioritized alarms, and poorly design displays. HSE (2009) provided guidance for managers to show how human behaviour and contextual factors can impact health and safety and explain practical ideas to identify, assess and control human-induced risks.

In contrast to relatively high numbers of research studies on human-automation accident analysis in the aviation and process industries, the number of publications in the railway domain is limited. For this reason, Papadimitriou et al. (2020) recommended transferring some experiences associated with human-automation issues from other modes of transport to the railway industry, such as misaligned trust in automation (i.e. mistrust vs overreliance), situation awareness in automated driving, the transition of control between human and machine, and the role of experience and training. Young (2020) is one of the limited studies in the railway domain that focused on automation-related accident analysis. They investigated three accident reports of the Rail Accident Investigation Branch (RAIB) and concluded that mental models, trust/reliance, and workload are the main impacts of automation on the users and should be addressed during the design process or through training programs. The importance of human-centered automation to mitigate risks posed by different degrees of automation and modalities of human-machine interaction was identified by Vanderhaegen et al. (2021) through accident analysis in combination with field and simulation studies.

To the best of our knowledge, there is a lack of review studies on automation-related accidents in the railway industry and lessons learned from these occurrences. To fill in the research gap, this paper reviews several accidents and incidents that happened in relation to in-cab warning systems or train automated technologies all around the world and extracts the important lessons that can be learned. The remainder of our paper is organized as follows: Section 2 provides an overview of automation-related incidents and accidents in the railway domain. Section 3 summarizes the most important lessons learned from the past events. Finally, our conclusions of this review are summarized in Section 4.

## 2. An overview of automation-related railway incidents and accidents

This section reviews notable incidents and accidents that have happened in relation to in-cab warning devices or train automated systems and summarizes the main human factors that contributed to these accidents (see Table 2).

### 2.1 Automation-related railway incidents and accidents in the U.S.

#### 2.1.1 Shady Grove accident

Automation was to blame in the collision between a Washington Metropolitan Area Transit Authority Train and a freight train at Shady Grove Passenger Station in 1996. The braking system of the metro train was automatic and the train operator had no control over the braking force. The automatic braking system (ABS) was not correctly designed for the icy surface and thus it caused the accident (Traub and Hudson 2007). On that snowy day, trains were encountering slippery conditions and less traction and in some cases were overrunning stations. Therefore, the train operator of the crashed train asked to turn off the automatic speed control system, a request that was denied. Thereafter, the train entered the station much faster than expected because of poor track friction and collided with a stationary train. It was later debated whether the accident could have been prevented if the train operator had been permitted to override the automation (Wreathall et al. 2007).

#### 2.1.2 Chlorine rail car accident

In 2004, at Macdona, Texas, a Union Pacific (UP) train collided with a Burlington Northern (BNSF) train causing the derailment of four locomotives and 35 railcars and the release of hazardous material. The train conductor died as a result of the collision. In addition, two people in a nearby house were killed and 43 people were hospitalized due to chlorine inhalation. The accident investigators determined the crew of the UP train did not handle the train in compliance with the operating rules and trackside signal aspect. They failed to make any attempt to bring the train to a stop in response to the red trackside signal, even when the BNSF train came into view (NTSB 2006). Although the train operator manipulated the throttle and horn, which prevented the Alerter alarm, and also inputted data into the control system, they were in a state of mental fatigue (i.e., were physically awake enough to continue train handling by automatic behaviour) (Stein et al. 2019; NTSB 2006).

#### 2.1.3 West India Quays derailment

On March 10, 2009, a Docklands Light Railway (DLR) service derailed while traveling through a series of trailing points that were not correctly set for this movement. On the day of the accident, several major signaling system failures occurred and train LEW109 was automatically brought to a halt because an axle counter was broken and incorrectly showed some tracks were closed. The control centre controller asked the train operator to operate in emergency shunt mode instead of automatic train operation (ATO) mode and check the point position indicators while he moved forwards. During communication, the controller had been checking 1125 points and they were displayed in the correct position as they had been set for trains from another direction. Train

LEW109 started to move through the 1125 points that were incorrectly set in reverse. The point position indicator remained unlit and did not display a red bar, and the passenger service agent did not identify that the point location indicator was not illuminated and proceeded to move the train through the 1125 points. Meanwhile, a train that was still operating in ATO mode arrived at the station and automatically requested a route through the 1125 points. The controller noticed that the 1125 points were incorrectly set for train LEW109 and made an emergency radio call to the passenger service agent onboard train LEW109 and told him to stop his train. At exactly this moment, the train derailed on the trailing points (RAIB 2010).

### 2.1.4 Washington Metropolitan Area accident

A metro train-to-train collision occurred in the Washington Metropolitan Area in 2009. This accident, which resulted in nine fatalities and 80 injuries, was attributed to a failure of the automatic train control (ATC) system. The track circuit malfunction made the control system unable to detect the track was occupied by a stopped train and hence the automatic brake was not initiated to bring the moving train to a halt. The emergency brake was activated by the operator of the moving train after noticing the stopped train, but there was insufficient time to avoid the crash (Li et al. 2017). The NTSB noted that "[o]perators could not have been expected to be aware of the impending collision due to the high number of track circuit failure alarms routinely generated by the system" (Heape 2015). In summary, NTSB pointed out that contributing factors to the accident were lack of a safety culture, lack of a good maintenance plan, and ineffective safety oversight (NTSB 2010).

## 2.2 Automation-related railway incidents and accidents in the U.K.

### 2.2.1 Southall train collision

In 1997, a collision happened between a high-speed passenger train and a freight train at Southall near Paddington Station. The collision led to seven fatalities and 139 injuries. The train operator of the high-speed train passed through three consecutive cautionary signal aspects without slowing down and showed reaction only when the freight train was in his sight distance, but the two trains ultimately collided. The high-speed passenger train was equipped with AWS, like most other British trains; however, on the day of the accident, the system failed to warn the train operator. The train operator was also distracted by getting his bag ready to finish his journey at Paddington Station. Therefore, he neither monitored the signal aspects nor received alarms from the failed AWS, which resulted in the accident. In this accident, the complacency of the high-speed passenger train operator was identified as the primary cause (Roth and Multer 2009).

### 2.2.2 Ladbroke Grove accident

One of the most serious rail accidents in Britain happened at 8:05 a.m. on 5 October 1999 at Ladbroke Grove near Paddington Station in London. The trains and the lines were fitted with an AWS aimed at warning train operators of the presence of a restrictive signal. However, a Turbo train that departed from Paddington failed to stop at a red signal and collided with a high-speed train (HST) approaching the station from the opposite direction on the same line. The collision followed by derailment and fires resulted in 31 deaths and more than 400 injuries. The SPAD of the Turbo train was the crucial event for this accident, though investigators did not find any evidence to prove the signal was violated on purpose (Lawton and Ward 2005).

Lawton and Ward (2005) carried out a systematic accident analysis and categorized five contributing factors: active failures, local working conditions, situational and task factors, inadequate defences, and (latent) organizational failures. The explanations for these factors are provided below.

(a) Active failures: The operator of the Turbo train passed the cautionary signal although they acknowledged the AWS alarm. Moreover, the signaller did not show a timely reaction to the SPAD event and did not send emergency stop signals to the Turbo train as well as the HST.

(b) Local working conditions: inexperience, expectation, distraction, strong motor programs, false perceptions, confirmation bias, and situational unawareness were identified as Subcategories for the local working conditions factor. The operator of the Turbo train was a novice that had passed their training just two weeks before the accident. Moreover, they had never experienced a red signal at this point of the line during their training. The evidence shows the train operator habitually canceled the AWS horn as they had been presented with several successive cautionary signals before this red signal.

(c) Situational and task factors: track layout, poor human-system interface, poor feedback from the system, and poor communications were the main situational and task factors that contributed to the accident. The complexity of the layout, multiple signals on the gantry, number of approaches, and obscuration of signals by overhead bridges and electrification equipment caused difficulties in line of sight and poor human-system interface. Furthermore, the AWS system sounds the same horn for all restrictive signals and does not distinguish between cautionary (yellow or double yellow) and stop (red) signal aspects, which creates ambiguity about the current condition and no feedback on the action to be taken by the train operator.

(d) Inadequate defences: poorly engineered safety devices, poor signalling, poor policies and standards, and the lack of awareness of hazards were identified as the main accident causes related to inadequate defences. None of the ATP systems or TPWS were installed on the Turbo train.

(e) Organizational failures: although many SPAD incidents had occurred at this location, no safety improvement measures were implemented to mitigate the risk. Furthermore, there were no official standards for train operator training. In addition, in the development of track and signalling at Paddington Station, safety issues and human factors related to the close proximity of the gantry were not taken into account.

The systematic accident model of the Ladbroke Grove crash is summarized in Figure 1.

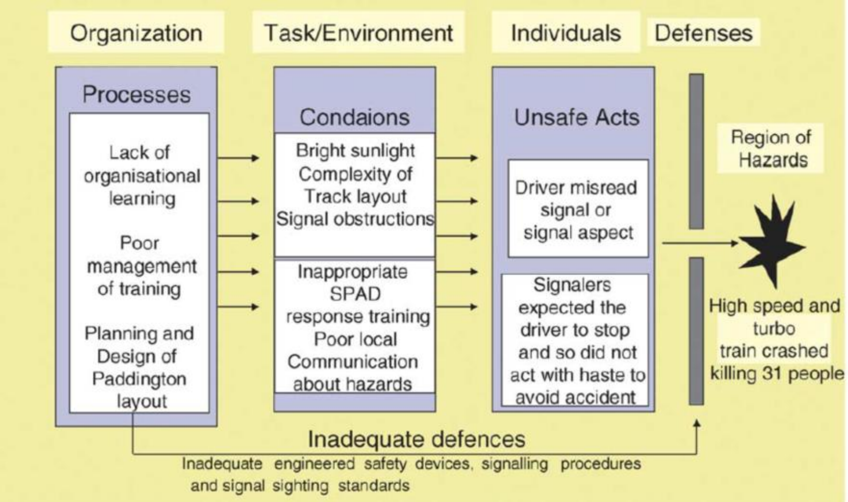

Figure 1. Systematic accident analysis of the Ladbroke Grove crash (Lawton and Ward 2005)

Stanton and Walker (2011) explored the psychological factors involved in the Ladbroke Grove accident. They found five aspects of train operation as contributing factors: (1) custom and practice in the use of the drivers' reminder appliance (DRA) that prevents the driver from applying power, (2) operation and use of the AWS, (3) the sequence of signaling information, (4) methods of supplying route information, and (5) speed restrictions.

DRA is an additional defence to reduce the likelihood of a driver starting to move when the signal ahead is red. It can be used while the train passes a cautionary signal aspect, though it was designed to be used in stations. The operator of the Turbo train was also trained to activate the DRA at single yellow signal aspects. However, they failed to apply it, which created the conditions for a mode error. This loss of activation may be coupled with a data-driven activation error (i.e., the train operator took the triangular speed restriction under the bridge as the cause of the AWS activation) to create a form of local rationality for the train operator).

### 2.2.3 Llanbadarn incident

On 19 June 2011 a passenger train, traveling from Aberystwyth to Machynlleth, ran onto the level crossing with the barriers raised at Llanbadarn. There were no road vehicles or pedestrians on the crossing at the time. The crossing was automatic and locally monitored and the line was equipped with the European Train Control System (ETCS) Level 2. In the ETCS Level 2, traditional trackside signals and signs are replaced with speed and movement authorities displayed on the driver-machine interface (DMI). It monitors speed and warns of approaching a crossing, but no other protection. So that, the driver had to check a signal and a movement authority to make sure the crossing is operating correctly.

The immediate cause of the incident was that the train operator did not notice the flashing red signal until it was too late to stop. Investigators identified high workload as a main causal factor and no interface between ETCS and Cambrian automatic crossings as a primary underlying reason. The high workload of the train operator at the incident time resulted from the fact that they were focusing on DMI to monitor the speed and also make a transition from Staff Responsible (SR) mode to Full supervision (FS) mode (RAIB 2012; Young 2020).

### 2.2.4 Cambrian Coastline incident

In an incident on 20 October 2017, that fortunately was not escalated into an accident, a train approached a level crossing at 80 km/h (50 mph), significantly exceeding the temporary speed restriction of 30 km/h (19 mph). The main reason for this incident was the loss of safety-critical signaling data (i.e., temporary speed restrictions (TSR) data) due to a database fault for uploading TSR data during an automated overnight computer restart. However, the signallers' display screen incorrectly showed the restrictions as being loaded, because it was holding previous data. Eventually, train operators' and signallers' trust in and mental models of systems resulted in the incident (RAIB 2019; Young 2020).

## 2.3 Automation-related railway incidents and accidents in China

On July 23, 2011, a rail accident occurred on the Yong-Wen high-speed railway line at Wenzhou in China that caused 40 fatalities and 172 injuries. At a speed of 99 km/h, the China Railway Highspeed (CRH) train D301 rear-ended another CRH train, D3115. As a result of this collision, six cars derailed and two went off the bridge.

The Chinese Train Control System (CTCS) technology, consisting of five levels (CTCS-0 – CTCS-4), has been developing with the same goals as ETCS in Europe. The signaling and train control system used on the accident line was the CTCS-2. Approximately one hour before the accident, severe lightning at this location resulted in a flaw in the control system. Consequently, the signal displaying the track occupancy in the train control centre (TCC) remained red and could not indicate if the track segment was occupied by a train because of the track circuit failure. The maintenance staff was asked to fix the problem, and thus the maintenance engineer checked the machine room of Wenzhou station. He observed numerous alarm signals related to the track circuit equipment. The engineer tried to replace the defective devices and then the alarm signals disappeared.

Train D3115 was commanded to leave Yongjia station and was notified that the train may brake due to the ATP system in the flawed section of track and, once this occurs, the train must be restarted and continue to travel. As expected, the train automatically stopped, but the train operator failed to restart the train. The train operator contacted the dispatcher and station operator and also was called by them several times; however, all calls were lost. During this period, train D301 departed from Yongjia station as normal. Due to the track circuit breakdown, D301 neither received information about D3115 nor stopped automatically and the two trains then collided (Li et al. 2019; Zhan et al. 2017).

This accident has been analyzed with a range of accident causation models including Systems Theoretic Accident Model and Processes (STAMP) (Song et al. 2012; Dong 2012; Niu et al. 2014), STAMP combined with Petri net (Dirk et al. 2013), AcciMap (Chen et al. 2015), the Human Factors Analysis and Classification System-Railway Accidents (HFACS-RA) (Zhan and Zheng 2016; Zhan et al. 2017), HFACS-STAMP (Li et al. 2019), and the Functional Resonance Analysis Method (FRAM) (Liu and Tian 2017). For example, Zhan et al. (2017) adopted the HFACS-RA method in combination with the Analytic Network Process (ANP) and the Fuzzy Decision Making Trial and Evaluation Laboratory (Fuzzy DEMATEL) techniques to identify the leading causes of this accident. The ranked causal factors were considered in "Unsafe Acts" (showed by "A"), "Preconditions for Unsafe Acts" (showed by "P"), "Unsafe Supervision" (showed by "S"), and "Organizational Influence" (showed by "O") categories (see Table 1.

Table 1**.** Causal factors of Yong-Wen high-speed accident (Zhan et al. 2017)

| **Causal factors** | **Ranking** |
|---|---|
| A2: Failure to contact train D301 and inform the train operator regarding train D3115 | 1 |
| A1: Dispatch the train with the red zone of track circuit unclear | 2 |
| A4: No follow up instrument to keep a record of equipment failures | 3 |
| A3: Substandard troubleshooting operation | 4 |
| P1: Lack of teamwork | 5 |
| S2: Unqualified follow up inspection for crew training | 6 |
| P2: Lack of emergent fault processing experiences | 7 |
| S6: Failure to correct wrong maintenance operation | 8 |
| P3: Inadequate personnel assignment | 9 |
| P5: Substandard implementation of operation standard | 10 |
| S3: Lack of qualification examination for the new signal product | 11 |
| P4: Negligence of equipment failure, lack of safety meeting | 12 |
| S5: Improper train departure plan on the fault train line | 13 |
| O1: Negligence of safety corrective actions | 14 |
| S4: Unconfirmed fault track circuit equipment downtime registering | 15 |
| S1: Lack of effective crew safety training | 16 |
| O2: Insufficient training quality and management | 17 |
| O3: Purchasing substandard equipment for track circuit | 18 |
| O5: Chain of command disorder | 19 |
| O7: Insufficient risk assessment of new signal equipment | 20 |
| O4: Lack of emergency disposal instructions | 21 |
| O6: Lack of safety training program | 22 |

## 2.4 Automation-related railway incidents and accidents in Iran

A good illustration of an alarm-related accident is a catastrophic accident involving two trains near Haft-Khan station in Iran in 2016. Two passenger trains collided in a rear-end collision followed by a fire, killing 47 passengers and crew and injuring many others. Although different factors such as human error, complex operation process, poor safety management system, and environmental factors contributed to this accident, the faulty ATC system played a pivotal role.

The accident happened when an express train from Tabriz to Mashhad with 432 passengers stopped due to technical problems in its brake system associated with cold weather between Semnan and Damghan and informed the Centralized Traffic Control (CTC). The second express train with 110 passengers traveling from Semnan to Mashhad on the same track controlled by the ATC system stopped after seeing the red signal of the previous block. Meanwhile, the shift for the CTC operator changed and the new operator was replaced before the problem with the first train was resolved. At this point, the operator of the second train asked for instructions from the CTC operator with respect to permission to resume their journey. Verbal approval via radiotelephone giving permission to the operator of the second train to deactivate the ATC system and continue to Haft Khan Station was given. The second train traveled at a speed of 132 km/h and hit the first train, resulting in its derailment and subsequent fire, which affected the last three cars of the first train as well.

While human error may appear to be the key factor in this accident, the underlying reasons for operators to ignore alarms made by the ATC system are worth noting. The accident investigation revealed it was not the first time the CTC operators decided to neglect alarms made by the system. The train control system had reported an error 2000 times from its launch in March 2014 until the accident day. The faulty performance of the ATC system and its frequent incorrect warnings in the past caused the operators of the control unit to distrust the warnings generated by the system. Making such an assumption toward the control system as well as not being aware of the situation, the second operator decided to ignore the warning of the ATC system showing an occupied block ahead and assumed it to be a system fault, as it had been many times in the past, and issued permission for the second train to move, resulting in a fatal accident (Sameni et al. 2018; Eftekhari et al. 2020).

## 2.5 Automation-related railway incidents and accidents in Korea

Korea reported a collision between two trains that were expected to pass each other at a local station in 2014. The first train operator continued their trip without noticing the stop signal as well as the Automatic Train Stop (ATS) system alarm and collided with an approaching train. The ATS warning was triggered when the train reached the stop signal. However, because the train operator acknowledged the alarm, the safety system no longer worked to apply emergency brakes (Lee and Lyou 2018).

## 2.6 Automation-related railway incidents and accidents in Singapore

In 2017, the train-borne signaling system of a Singapore metro train failed to work normally, leading to an interruption in communication between the train and the trackside control. The metro line was partly equipped with the Communications Based Train Control (CBTC) system. Hence, the train was moving on the line with both a new and legacy signaling system.

Train 3535/3536 collided with train 3547/3548 when it was leaving the station and returning to the library at Joo Koon station as planned. The CBTC system did not detect the presence of train 3535/3536 and thus provided the movement authority for train 3547/3548 according to the condition that the track ahead was free. The dispatcher and the operator of train 3535/3536 both supposed the control commands of the CBTC system were correct. Consequently, train 3547/3548 drove towards Joo Koon Station and collided with train 3535/3536 that had stopped ahead (Yan et al. 2018).

## 2.7 Automation-related railway incidents and accidents in Australia

On 10 January 2018, a Queensland Rail (QR) passenger train exceeded its limit of authority by passing a red signal and was near collision with another passenger train. The rail network was fitted with an automatic warning system (AWS) that provided a driver with an audible and visual alarm when approaching a restricted signal. The Australian Transport Safety Bureau (ATSB) investigation report disclosed that although the train operator acknowledged the AWS audible alarm, this was almost certainly an automatic response that did not result in an effective check of the signal. ATSB highlighted the safety issues of AWS including the potential for habituation and the absence of a higher priority alert due to the fact that it provides the same audible alarm and visual indication to a driver on the approach to all restricted signals (ATSB 2021).

## 2.8 Summary of the main human factors that contributed to the reviewed accidents

The most important human factors that were involved in the above-described occurrences are summarized

Table 2. Summary of human-factors and automation-related railway incidents and accidents

| | | | | | **Human Factors** | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Incident/Accident** | **Country** | **Year** | **Type of system** | **Immediate cause** | **High workload** | **Over-trust** | **Mistrust** | **Distraction** | **Automatic responding** | **Mental fatigue** |
| Shady Grove accident | U.S. | 1996 | ABS | Poor automatic braking system for the icy surface | | ▨ | | | | |
| Chlorine rail car accident | U.S. | 2004 | Alerter | Passing the red signal because of Alerter inactivation | | | | | | ▨ |
| West India Quays derailment | U.S. | 2009 | ATO | System failure | | ▨ | | | | |
| Washington Metropolitan Area accident | U.S. | 2009 | ATC | System failure | | ▨ | | | | |
| Southall train collision | U.K. | 1997 | AWS | System failure | | ▨ | | ▨ | | |
| Ladbroke Grove accident | U.K. | 1999 | AWS | Passing a red signal after alarm acknowledgment | | ▨ | | | ▨ | |
| Llanbadarn incident | U.K. | 2011 | ETCs-Level 2 | Not noticing the red signal | ▨ | | | | | |
| Cambrian Coastline incident | U.K. | 2017 | ETCs-Level 2 | System error and displaying incorrect TSR data | | ▨ | | | | |
| Yong-Wen accident | China | 2011 | CTCS-2 | System failure | | | | | | |
| Haft-Khan accident | Iran | 2016 | ATC | Ignoring the ATC alarms | | | ▨ | | | |
| Korea | Korea | 2014 | ATS | Passing a red signal after alarm acknowledgment | | | | | ▨ | |
| Singapore | Singapore | 2017 | CBTC | System failure | | ▨ | | | | |
| Australia | Australia | 2018 | AWS | Passing a red signal after alarm acknowledgment | | | | | ▨ | |

The human factors in Table 2 are briefly explained as follows:

- High workload: Workload may be characterized as the reaction to demand or stress, with either positive or negative consequences (Oppenheim et al. 2010). It can be physical (e.g., pressing a button), visual (e.g., scanning the light on the display), and cognitive (e.g., interpreting a signal) (Halliday et al. 2005). The ideal workload situation happens when "homeostasis" is achieved, which can be described as a balance where coping and adaptation to task demands are optimal. Any deviations from the optimal workload level, either an increase or a decrease, can contribute to lower performance (FRA 2014; Oppenheim et al. 2010).
- Over-trust: The more operators trusted the automation, the more they left it in control without supervision. When train operators are passive and observant, they are more prone to perform a task based on system feedback rather than anticipatory, self-identified strategies (Giesemann 2013). Overreliance and excessive trust may also instill complacency, which is the incapability of a train operator to act as well without a system as they could before the system was installed (Roth and Multer 2009).
- Mistrust: When trust is low or absent, the automated system might not be used (e.g., warnings might be ignored). The low reliability of automation is one of the main reasons for distrust and under-reliance. Operators may consider automation to be less reliable if they do not understand why it makes errors, causing them to mistrust and disregard an aid that may actually be beneficial (Papadimitriou et al. 2020).
- Distraction: It is defined as a "diversion of attention away from activities critical for safe driving towards a competing activity". Competing activity may or may not be driving-related, and it may be inside or outside the vehicle (Lee et al. 2008).

Automatic responding: A train operator may read or hear an alarm without understanding its importance and meaning and show a skill-based, reactive response to it, called automatic responding (Oppenheim et al. 2010; Carey 2018).

- Mental fatigue: A train operator may be mentally fatigued but physically awake enough to press the push button or enter data into the train control system because motor reflex actions generally need a lower level of cognitive endeavor (Stein et al. 2019).

## 3. Lessons learned from accidents

The following lessons can be learned from the analyzed accidents:

1) False alarms result in perceived low system reliability causing the train operator to lose confidence. As a result, alarms may be ignored, disabled, or responded to slowly as in the Haft Khan accident.
2) Highly reliable systems can cause complacency and over-reliance. A train operator loses situational awareness and cannot identify automation errors and failures. The Shady Grove accident, Southall train collision, Washington Metropolitan Area accident, and Ladbroke Grove accident are examples where overreliance on the systems and complacency were significant contributory factors.
3) The warning system should provide unambiguous feedback and convey the degree of risk and urgency. In the Ladbroke Grove accident, the train was only equipped with the AWS system which activates the same horn for all restrictive signal aspects (i.e., yellow, double yellow, and red signal aspects), the result was that the train operator misinterpreted the alarm related to the red signal (stop) for the yellow signal aspect.
4) In accidents such as the Ladbroke Grove accident, Korean accident, and Australian incident, the automation systems did not stop the trains as a result of habitual response to warnings by the train operator which overrode the automatic brake system. Thus, automated braking should be a result of the emergence of an unsafe situation not on a failure of the train operator to respond.
5) Most negative cognitive impacts of in-cab warning and train protection systems on train operators are a result of workload levels. An under-load of the train operator results in boredom, fatigue, overconfidence and complacency. An overload results in irrational reactions, confusion, distraction, overtrust in the system, and loss of situation awareness.
6) Train operators should be trained in procedures to follow when the in-cab warning system malfunctions and unexpected events occur. They also should also be trained as to higher risk portions of routes and appropriate mitigation measures.
7) Alarm and automated systems should be analyzed not only from the technical point of view but also in connection with the safety management system.

## 4. Conclusion

This paper reviews automation-involved railway incidents and accidents, summarizes the main contributing human factors, and infers important lessons learned. The results show that automation is not a perfect solution for all human error modes and it can pose new human factors issues related to design and usability. Automation-related incidents and accidents in the railway industry demonstrate that automated system failure, the complacency of the train operator, inconsistency of alarm performance with user expectations, and poor alarm design and management were common reasons for most of these occurrences. Furthermore, research indicates that the limitations of train operators to handle alarms are primarily related to workload, with their response varying greatly across individuals and situations.

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