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

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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.

Introduction

Analyzing automation-related incident and accident data and learning from the past events are useful tools to understand issues associated with using automated systems.

This equips us to formulate and implement effective strategies and to mitigate the negative impacts of such systems on human operators.

Although there are relatively high numbers of research studies on human-automation accident analysis in the aviation and process industries (e.g., Gawron (2019), Read et al. (2020), and Goel et al. (2017)), the number of publications in the railway domain is limited.

Introduction

To fill this research gap, we reviews several accidents and incidents that occurred in relation to in-cab warning systems or train automated technologies around the world and extracts the important lessons that can be learned.

An overview of automation-related railway incidents and accidents

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Chlorine rail car accident

Accident	Country	Year	Fatalities/Injuries
Chlorine rail car accident	US	2004	3/43

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.

Source: NTSB (2006)

Chlorine rail car accident

The crew of the UP train 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.

The train operator had manipulated the throttle and horn, which prevented the Alerter alarm, and also inputted data into the control system. However, 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).

Washington Metropolitan Area accident

Accident	Country	Year	Fatalities/Injuries
Washington Metropolitan Area accident	US	2009	9/80

A train-to-train collision occurred in the Washington Metropolitan Area in 2009.

Source: NTSB (2010)

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Washington Metropolitan Area accident

The track circuit malfunction made the automatic train control (ATC) 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).

NTSB (2010) pointed out that contributing factors to the accident were lack of a safety culture, lack of a good maintenance plan, and ineffective safety oversight.

Ladbroke Grove accident

Accident	Country	Year	Fatalities/Injuries
Ladbroke Grove accident	UK	1999	31/400

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.


Source: BBC (1999)

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Ladbroke Grove accident

Lawton and Ward (2005) carried out a systematic accident analysis and categorized five contributing factors to the accident:

1. active failures (i.e., the train operator passed the red signal after acknowledging the Automatic Warning System (AWS) alarm and the signaller did not show a timely reaction to the SPAD event)
2. local working conditions (e.g., inexperience, expectation, distraction, strong motor programs, false perceptions, confirmation bias, and situational unawareness)
3. situational and task factors (e.g., track layout, poor human-system interface, poor feedback from the system, and poor communications)
4. inadequate defences (e.g., poorly engineered safety devices, poor signalling, poor policies and standards, and the lack of awareness of hazards)
5. (latent) organizational failures (e.g., no safety improvement measures for SPAD events, no official standards for train operator training)

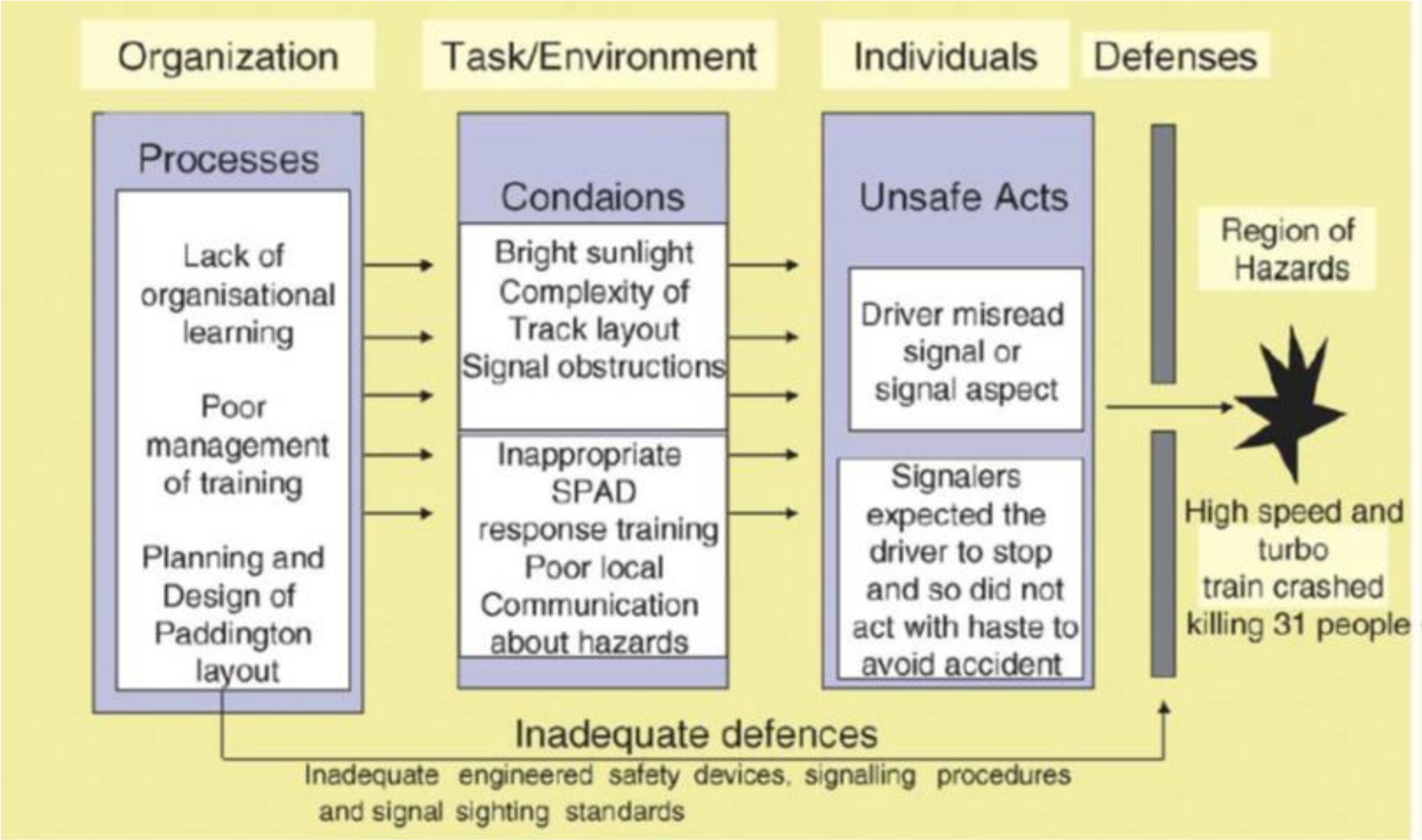

Figure 1. Systematic accident analysis of the Ladbroke Grove crash (Lawton and Ward, 2005).

Llanbadarn incident

Accident	Country	Year	Fatalities/Injuries
Llanbadarn incident	UK	2011	0/0

A passenger train ran onto the level crossing with the barriers raised at Llanbadarn. Fortunately, there were no road vehicles or pedestrians on the crossing at the time.

The line was equipped with the European Train Control System (ETCS) Level-2, in which traditional trackside signals and signs are replaced with speed and movement authorities displayed on the driver-machine interface (DMI).

Llanbadarn incident

So that, the train operator had to check a signal and a movement authority on the DMI 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.

Yong-Wen collision in China

Accident	Country	Year	Fatalities/Injuries
Yong-Wen collision	China	2011	40/172

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.

Source: The world (2011)

Yong-Wen collision in China

The signalling and train control system used on the accident line was the Chinese Train Control System (CTCS).

Approximately one hour before the accident, severe lightning at this location resulted in a flaw in the control system.

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.

Yong-Wen collision in China

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.

Yong-Wen collision in China

This accident has been analyzed with a range of accident causation models including:

- 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),
- HFACS-RA (Zhan and Zheng 2016; Zhan et al. 2017),
- HFACS-STAMP (Li et al. 2019),
- FRAM (Liu and Tian 2017).

Yong-Wen collision in China

For example, Zhan et al. (2017) adopted the HFACS-RA method in combination with the ANP and the Fuzzy DEMATEL techniques to identify the leading causes of this accident.

The ranked causal factors were considered as:

- “Unsafe Acts” (showed by “A”),
- “Preconditions for Unsafe Acts” (showed by “P”),
- “Unsafe Supervision” (showed by “S”),
- and “Organizational Influence” (showed by “O”) categories.

Yong-Wen collision in China

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

Haft-Khan accident in Iran

Accident	Country	Year	Fatalities/Injuries
Haft-Khan accident	Iran	2016	47/103

Two passenger trains collided in a rear-end collision followed by fire.

Haft-Khan accident in Iran

The first train stopped due to technical problems in its brake system associated with cold weather.

Then, the second train controlled by the automatic train control (ATC) system stopped after seeing the red signal of the block.

Meanwhile, the shift for the Centralized Traffic Control (CTC) operator changed and the new CTC operator permitted the second train to resume their journey.

Haft-Khan accident in Iran

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 faulty performance of the ATC system and its frequent incorrect warnings in the past caused the CTC operators 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 (Sameni et al., 2018; Eftekhari et al., 2020).

Korea (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).

Australia (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 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 2021).

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

Incident/Accident	Country	Year	Type of system	Immediate cause	Human Factors					
					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- Level2	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					♦	

Lessons learned from accidents

Lessons learned from accidents

- 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.

- Highly reliable systems can cause complacency and over-reliance. A train operator loses situational awareness and cannot identify automation errors and failures. The Washington Metropolitan Area accident and Ladbroke Grove accident are examples where overreliance on the systems and complacency were significant contributory factors.

Lessons learned from accidents

- 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.

Lessons learned from accidents

- 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 operators 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.

Lessons learned from accidents

- 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, over-confidence and complacency.
    - ❖ An overload results in irrational reactions, confusion, distraction, over-trust in the system, and loss of situation awareness.

Lessons learned from accidents

- Train operators should be trained in procedures to follow when the in-cab warning system malfunctions and unexpected events occur. They also should be trained in higher risk portions of routes and appropriate mitigation measures.

- Alarm and automated systems should be analyzed not only from the technical point of view but also in connection with the safety management system.

Conclusions

Conclusions

- 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.

Thank you! Questions?

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