Literature review on cognitive impacts of cab warning systems and train control technologies

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ABSTRACT
Cab warning systems and train control technologies provide alarms to inform train operators of dangerous situations and enforce speed and movement restrictions to avoid or mitigate negative consequences. While these systems can enhance safety as the last resort of safety control, they may have adverse cognitive impacts on train operators. This article reviews publicly published articles and reports that analyzed human factors issues of in-cab technologies. The reviewed technologies include, but are not limited to, cab signaling systems, automatic train control systems, anti-collision devices, train operators' vigilance systems, and train operators' reminder devices. The findings demonstrate that these technologies can cause a variety of human factors issues, including over-load or under-load, over-reliance on the system, complacency, loss of situation awareness, mode confusion, distraction, and automatic responding. To reduce the potential negative impacts related to the design and usability of in-cab technologies on train operators, the authors recommend employing the human reliability analysis and the human-in-the-loop processes to better understand the impacts of in-cab warning systems on train operators, identify the contextual factors influencing the train operators' performance, and develop strategies to mitigate such human-induced risks.

Keywords: In-cab w*arning systems, Train control technologies, Cognitive impacts, Human factors.*

1 INTRODUCTION

Automated control systems are increasingly being adopted in various industries to improve safety and optimize operations. They are changing the nature of work and transitioning the role of human operators from manually operating to passively monitoring. It is assumed that such technologies prevent or reduce known human errors and improve safety, however, past experience in various domains shows that they may cause unexpected impacts on human performance and introduce new sources of human risks. The reported incidents and accidents from high reliability organizations (HRO) such as nuclear power plants and the aviation industry are strong evidence for this claim. Statistics illustrate that that human factors account for over 75% of major railway accidents, marine causalities, or aviation accidents (Cullen & Smith 2004, Evans 2014, Tao et al. 2020). This number reaches over 90% for failures in nuclear plants (French et al. 2011).

Due to the significant role of human operators in the safety aspect of the social-technical systems and the importance of employing strategies to reduce human-caused risks, a large number of studies in diverse industries have been conducted to develop and deploy human reliability analysis (HRA) and identify human factors issues associated with automation. The performed HRA studies differ in their scope, the types and levels of decomposition of the tasks addressed, and the factors considered to influence the human error probability (Mkrtchyan et al. 2015). While some contributions focus on the identification, measurement, and reduction of human-induced risks at the design stage, some others aim at evaluating the effects of performance shaping factors (PSFs) on human performance (Patriarca et al. 2020).

The bibliometric analyses conducted by Tao et al. (2020) and Hou et al. (2021) highlighted the main research areas of the HRA publications including human performance in human-machine systems. Papadimitriou

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et al. (2020) presented a systematic literature review of the effects of human factors on transport automation safety. They reviewed the role of misaligned trust in automation (i.e. mistrust vs overreliance), situation awareness in automated driving, the transition of control between human and machine, and operators' experience and training in the effectiveness of the automated systems in the road, aviation, maritime and rail domains. The literature review studies disclosed that much less research about the influence of automation on human operators' performance has been carried out in the railway domain as compared to the aviation and road sectors. This was a reason that Papadimitriou et al. (2020) recommended transferring some experiences and lessons learned in relation to human-automation interaction from road and air transport to the railway industry.

One of the limited exploratory reviews in the railway sector about the influence of automation on train operators is Bearman & McCusker (2008), which has been later reorganized and updated by Zimmermann (2015). These review studies were respectively performed under the auspices of the Australian and Canadian governments and were published in non-scientific indexed databases. Bearman & McCusker (2008) categorized the potential human factors issues of new in-cab and train control technologies into “fixation on and distraction by the technology”, “disregard or attenuation to warnings”, “errors inputting data into the system Increased attention and knowledge demands Lack of insight into how the technology is functioning”, “poor communication by the technology about its current functioning”, “misplaced trust in the automation”, “mismatches between the driver's understanding of a task and the way this task is performed by the technology”, “changes to the nature of train driving, particularly relating to change in driving technique required by some new technologies”, “difficulties for drivers transitioning in and out of the technology”, “shifts in workload”, “changes to work-roles and coordination requirements for train personnel other than drivers”. Then, Zimmermann (2015) recategorized the factors into design and usability (involving distraction and workload, human-machine communication, ergonomic display design, and assigning final authority), skill retention, the transformation of work, training and mental models, operator expectation and trust, and unanticipated effects and interactions. In 2021, the authors of the current paper prepared a report on the cognitive impacts of in-cab warning systems for Transport Canada (TC) (see Rad et al. (2021)) and this paper is the extension of the report to fill in the research gap.

This paper reviews the relevant publications in both scientific and non-scientific indexed databases and summarizes the main human factors challenges in relation to using diverse train cab warning systems including cab signaling devices (e.g., Automatic Warning System (AWS)), automatic train control technologies (e.g., Positive Train Control (PTC) and European Train Control System (ETCS)), train-to-train anti-collision systems (e.g., Train Collision Early Warning System (TCEWS)), train operator reminder devices (e.g., Driver's Reminder Appliance (DRA) and In-Cab Signal Reminder Device (ICSRD)), and train operators' vigilance devices (e.g., Driver Vigilance Systems (DVS) and Monitoring Engineer Fatigue (MEFA)). The remainder of our paper is organized as follows: Section 2 summarizes our bibliometric search methodology, and Section 3 provides descriptive analysis. Results and discussion are presented in Section 4. Finally, our conclusions of this review are summarized in Section 5.

2 BIBLIOMETRIC SEARCH METHODOLOGY

We searched academic research databases (i.e., ScienceDirect, Scopus, Web of Science, SpringerLink, and IEEE Xplore), along with non-citation research databases such as FRA, RSSB, and Volpe center libraries for published research in English, up to the date 1 August 2021. We selected several keywords related to human reliability analysis (HRA) in combination with in-cab warning systems and automated train control (ATC) technologies to maximize the number of documents to be analyzed. We also considered references cited by the obtained research as a source for discovering more related scholarly research. This yielded 46 original publications after removing duplicates.

3 DESCRIPTIVE ANALYSIS

This section represents the statistical analysis of the 46 original research publications that have investigated the impacts of railway automation on train operators.

The distribution of the published papers and reports per continent in the years between 2002 and 2020 is illustrated in Figure 1. The year 2017 with the highest share for the European countries, is the most significant period for this research topic.

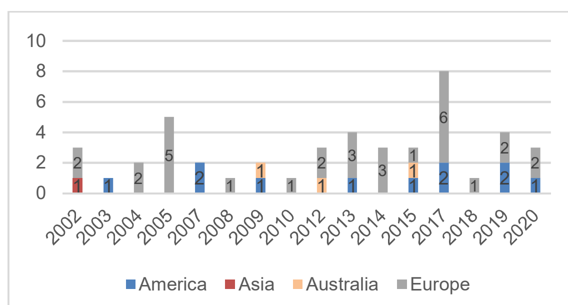

Figure 1. Yearly distribution of the reviewed publications per continent

Detailed analysis discloses that the UK and the US are the leading countries in research on human factors issues of railway automation, with an aggregate share of 65% (see Figure 2).

As shown in Figure 3, the majority of the publicly available studies in the field of research are reports published in non-scientific indexed databases (37%). Among scientific-indexed publications, Journal articles (28%), followed by conference papers (22%) have the main proportions. This result confirms Patriarca et al. (2020)'s claim that some human reliability analysis

(HRA) research and development contributions are publicly available but not recorded in citation databases, and some others are proprietary research.

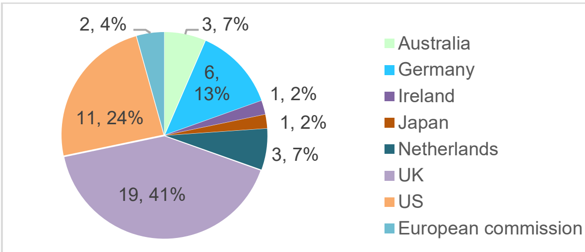

Figure 2. Countries' contributions in the human factors' studies related to railway automation.

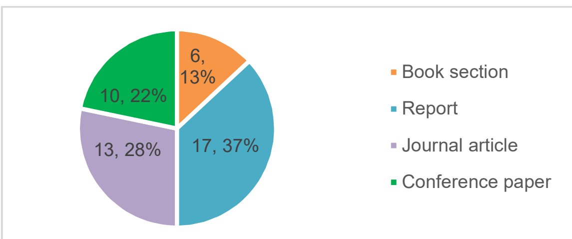

Figure 3. Type of publications

The existing literature is also classified according to the type of data sources (see Figure 4). Like what was reported by Mkrtchyan et al. (2015), three main sources of data, i.e., theoretical data, empirical data, and expert judgment data, were used in the reviewed publications. The theoretical data is excluded from Figure 4 since it was utilized in almost all papers. Moreover, the empirical data is categorized into real-world data (i.e., data obtained through in-cab observations, on-train-data-recorder (OTDR), or occurrence databases) and simulator/simulation tests data.

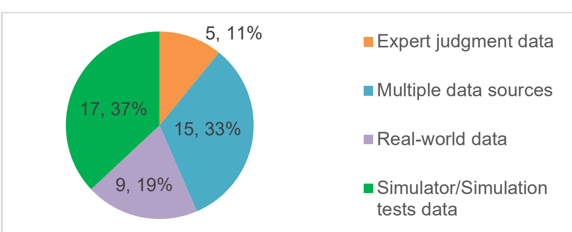

Figure 4. Type of data sources

According to Figure 4, 33% of the researchers combined diverse sources of data to get a better understanding of the ironies of automation. For example, in situations that were a lack of empirical information, they used expert knowledge along with the empirical and/or theoretical information (see e.g., Wreathall et al. (2007a), Rose & Bearman (2012), Nneji et al. (2019)).

4 RESULTS AND DISCUSSION

In this section, we review human factors challenges associated with the introduction and use of a wide range of in-cab warning systems and automated train control technologies.

4.1 Workload

Workload may be characterized as the reaction to demand or stress, with either positive or negative consequences (Oppenheim et al. 2010b). 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 workload to performance relationship is illustrated in Figure 5. 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 (Oppenheim et al. 2010b, FRA 2014). Under-load can result in loss of situational awareness, boredom, fatigue, frustration, over-confidence, and increased reaction times while over-load causes irrational problem solving, loss of situational awareness, exhaustion, and low self-esteem (FRA 2014, Robinson et al. 2015).

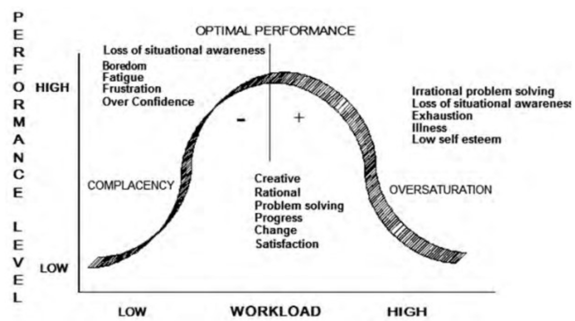

Figure 5. Workload versus performance (FRA 2014)

It is argued in the literature that the integration of any new technology into a system can, on the one hand, cause an overload of mental workload but can, on the other hand, lead to underload because of the increased automation (Robinson et al. 2015). Therefore, several research studies have been conducted to investigate the impacts of a new device on the workload levels of train operators. For example, the RSSB assessed the effectiveness of an In-cab Signal Reminder Device (ICSRD) and concluded it has the potential to increase workload by requiring additional cognitive and physical tasks. This can increase train operator stress and thus response time (Halliday et al. 2005).

The RSSB (2002) compared the imposed workload level of the two types of Driver's Reminder Appliance (DRA) systems on train operators and concluded that the Automatic Warning System (AWS) activated DRA, in which the system is automatically set with regards to the tasks related to AWS, poses a lower workload to the train operator compared to the train operator set DRA.

Crick et al. (2004a)'s research demonstrated that the visual information provided by the automatic train protection (ATP) system is too much for some train operators to handle, causing increased workload and distractions. Verstappen et al. (2017) found that monitoring innovative devices in train cabs during driving requires multiple resources (e.g., visual and cognitive resources), which can conflict with the primary driving task. This can cause an increase in workload and influence driving performance. Van Der Weide et al. (2017) realized that train operators experienced notably lower workload when driving with European Rail Traffic Management System (ERTMS) compared to driving with ATB (i.e., the legacy system in Netherland), and very experienced train operators even reported boredom. Spring et al. (2009) also reported a reduction in the mental workload of train operators, even to a sub-optimal level, because of an increase in the levels of automation (LOAs). Historical data related to head-up displays revealed a substantial decrease in train operator workload (Davies et al. 2012).

Analyses performed by Foulkes (2004) and Buksh et al. (2013) showed the Level 2 ERTMS, in which all signaling indications are shown in the cab and there are no lineside signals, contributes to a lower workload than the current train driving task. However, according to studies conducted, a variety of factors including the level of ERTMS implemented, train operator strategy, type of traction, and transitions into and out of ERTMS could impact workload under ERTMS (Robinson et al. 2015). An increase in workload because of transition in/out of a train protection system, particularly in complex areas such as stations and level crossings was also reported by Foulkes (2004) and Monk et al. (2017). A series of studies about the workload level of the Positive Train Control (PTC) system revealed that frequent, often non-informative audio alarms of the PTC systems and the required data entry during initialization and/or operation are sources of workload (Wreathall et al. 2007a, Roth & Multer 2009, Roth et al. 2013). Wreathall et al. (2003) emphasized that train automation systems usually automate the easy parts of a task, reducing workload during times when the workload is already minimal while requiring extensive human involvement in challenging situations when the workload is high. Therefore, during high-paced high-risk situations where the workload is already very high, there is an increase in workload demands (Wreathall et al. 2003).

During Wreathall et al. (2007a)'s interviews with train operators who have had experience driving with the PTC system, they expressed concerns regarding high numbers of audio warnings that require to be acknowledged. These can create distractions and high workloads for the train operators. The train operators recommended that audible alarms should be restricted to alert them to potential issues (e.g., an upcoming speed restriction that might be missed) and should be avoided for positive circumstances (e.g., when a speed restriction is no longer in effect) (Wreathall et al. 2007a). Brandenburger and their colleagues performed a series of studies and experiments at the German Aerospace Centre about the effects of railway automation on the train operators (Brandenburger et al. 2017a, Brandenburger & Jipp 2017, Brandenburger et al. 2017b, Brandenburger et al. 2018, Brandenburger & Naumann 2019, Brandenburger et al. 2019). Their experiments illustrated that the higher grades of automation (GOAs) do not always mean a lower workload level. While the transition from GOA-1 to GOA-2 reduced the workload level and kept it at the sub-optimal level (Brandenburger et al. 2018, Brandenburger & Naumann 2019), the transition from GOA-2 to GOA-3 increased workload and made it closer to an intermediate, optimal level of workload (Brandenburger et al. 2019).

In summary, the effect of automation on workload is mixed and automation may increase or decrease the workload level. Nneji et al. (2019), at Duke University, developed the Simulator of Human Operator Workload (SHOW) based on the empirical data from the U.S. railroad industry to quantitatively model freight rail operator workload.

4.2 Distraction

Verstappen et al. (2017) conducted a study about the effects of innovative devices in Dutch train cabs on train operators and highlighted that conflicts between the use of these devices (e.g., communication devices or information devices) and train driving tasks, particularly in critical situations, can be a source of distraction for the train operator. Safar et al. (2020)'s interviews with the US train operators revealed that non-integrated in-cab displays and alarms can be a contributory factor for distraction. The train operators indicated that there are often non-safety/ non-critical alarms that may be distracting. These alarms may sound continuously when activated despite being acknowledged, causing annoyance and distraction to the train operator. Furthermore, a frequent false alarm also raises the risk of ignoring safety-critical alarms by the train operator (Safar et al. 2015, Safar et al. 2020). Frequent, often non-informative audio alarms created by PTC systems can also be a source of distraction (Wreathall et al. 2007a, Roth & Multer 2009, Roth et al. 2013). Using devices such as ICSRD and DRA, which need to be used on the move, may distract train operators' attention away from signals ahead while using the device (Halliday et al. 2005).

The impact of vigilance devices on distraction is different. Vigilance devices, on the one hand, are argued to reduce distraction through an increase in levels of vigilance, arousal, and attention (Halliday et al. 2005). However, on the other hand, they can divert the train operator's attention away from the primary task of driving (Wilde & Stinson 1983, Rose & Bearman 2012).

4.3 Loss of Situation Awareness

Endsley (1996) defined situation awareness (SA) as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future". They categorized SA into three levels: level 1 (perception), level 2 (integration and comprehension), and level 3 (projection).

SA is reflected in a train operator's actions and response time (Halliday et al. 2005, Park et al. 2020). According to the conscious thinking processes that are needed to attain SA, longer response times are expected in decision making with good SA. When the levels of train operator vigilance or arousal decrease, their attention may deviate from the task of checking signals and thus increase the risks of making skill-based errors. An operator may automatically respond during low arousal despite the loss of SA (Halliday et al. 2005). SA is commonly assumed to be improved with experience; thus, novices have low SA and are more dependent on displays of information (Halliday et al. 2005). Crick et al. (2004a) found that more experienced train operators had considerably longer response times to the AWS, possibly reflecting the greater understanding by these individuals of the need to be aware of the signal before responding. According to information available, expert judgment, and the simulator experiment, Thomas & Davies (2008) and Davies et al. (2012) proposed that head-up display of speed and brake information can help the train operator to maintain situational awareness. In-cab Signal Reminder Device (ICSRD) and a moving map display are other recommendations for enhancing situation awareness of train operators (Halliday et al. 2005, Liu et al. 2017).

4.4 Mode Confusion

Mode confusion (mode error) happens when the user is confused about the system's current mode (i.e., errors in SA) or is unable to recall how the system reacts in the current mode (i.e., slips of action) (Wreathall et al. 2007b). There is a risk that the train operator does not understand or forgets that the mode change has occurred due to distraction and workload, which can result in mode errors (Sebok et al. 2015, Sebok et al. 2017). Safar et al. (2020) clarified that train operators accustomed to driving within cab signal territory may forget they are within no cab signal territory and wait for the speed reduction alarm to adjust the speed.

Two types of mode transitions and their related mode confusion are considered for the PTC system. One type of mode transition is when a train is equipped with a PTC system, but depending on the circumstances, the system could be operating or not. For example, on a PTC-equipped train, the system may not be operational because the train is outside of PTC territory or because the PTC system is malfunctioning. The second type of mode transition is related to the situation in which a train operator works on both PTC territory and non-PTC territory. The potential issue allied with the first type of mode transition is that the train operator may not recognize that the PTC system is not operating or may notice but fail to adequately enhance vigilance to compensate for the lack of PTC protection. When a train is moving between PTC equipped and unequipped areas, i.e., the second type of mode transition, factors including complacency and skill loss could contribute to the train operator errors. If the train operator has become over-reliant on the PTC system and, due to temporary workload or distraction, fails to notice or forgets protection provided by PTC is not available at the moment, it can result in complacency and therefore human errors. (Wreathall et al. 2007a, Wreathall et al. 2007b, Roth et al. 2013).

Changes in operating conditions can be the main cause of mode confusion. These kinds of problems may be triggered by frequent switching between trains that have the DRA and those that do not, or switching between trains with train operator set DRA and AWS activated DRA (RSSB 2002). This means that the increase in the number of transitions in a route/work shift can raise the probability of error (Monk et al. 2017). Hence, an inkblot strategy for rolling out ERTMS imposes less workload on train operators than a patchwork strategy when there are fewer transitions. Notably, in an inkblot strategy, ERTMS is rolled out from one starting track towards adjacent areas, while in a patchwork strategy, the development of ERTMS is distributed across the network, e.g., based on technical urgency (Van Der Weide 2017).

4.5 Complacency and Over-reliance

Roth & Multer (2009) referred to complacency as a general term that reflects the incapability of a train operator to act as well without a system as they could before the system was installed. Complacency can have various negative consequences, such as train operators not detecting the system failure (or it being off), experiencing delays in identifying and reacting to a system failure, and losing their driving skills and therefore not being able to perform the driving task as well when the system is not available as they previously could have (Roth & Multer 2009, Roth et al. 2013). Complacency tends to criticize the operator for unreasonably depending on a system and is closely connected to the principles of overreliance and excessive trust (Wreathall et al. 2007a, Roth & Multer 2009, Roth et al. 2013).

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. This could be crucial because anticipation is a required factor for higher-level situation awareness and a lack thereof could detrimentally impact the error management process when the system fails (Giesemann 2013). Over-reliance on the system can highly increase the risk to accept the displayed information even when it is incorrect (Halliday et al. 2005). Abe et al. (2002) reported that over-trust in warning systems can cause substantial delays in responding to hazards when there is a mismatch between what the train operator expects and the actual state of the system.

McBride et al. (2014) highlighted that the reliability of a system can play a role in excessive trust and complacency and is a double-edged sword. On the one hand, the greater the reliability of an automated system, the better the performance when the system is perfectly operating. On the other hand, the reliable automated system increases the tendency to get complacent, which makes the operator less vigilant and less capable of reacting to system errors or failures. With a highly reliable PTC system, train operator performance may decline if the information provided becomes unavailable (Wreathall et al. 2007a). A degree of complacency in checking all alarms was reported by Carey (2015) for cases containing an excess of non-critical alarm messages. Furthermore, the results of Brandenburger & Jipp (2017)'s study showed that train operators perform worse in degraded operations for the higher levels of automation, which can partly be compensated by train operators' experience.

4.6 Visual Attention Allocation

Naweed (2014)'s study disclosed that, in spite of the existence of in-cab devices and signaling systems, the outside area still needs to be searched for danger. It takes time for the eyes to refocus from one viewing distance to another one (i.e., visual accommodation)(Halliday et al. 2005). Hence, the transfer of primary information from outside the cab to inside the cab could negatively affect safety due to the shift in attention and visual accommodation increasing the risk of missing out of cab important events (Wreathall et al. 2007a).

An exploratory eye-tracking field study carried out by Naghiyev et al. (2014a) and Naghiyev et al. (2014b) illustrated that some train operators are more dependent on the system and reactively respond to situations, while others rely less on the alerts and alarms and are more proactive. Overall, when train operators used the ERTMS system, they spent considerably more time monitoring the speedometer rather than seeing the out-of-cab environment in comparison to conventional systems. The results of studies conducted by Brandenburger et al. (2017a), Van Der Weide et al. (2017), and Hely et al. (2015) also confirmed that train operators direct considerably less attention to out of cab than in-cab devices when driving trains equipped with ATP systems (e.g., ERTMS) compared to those with conventional systems. The operators of trains equipped with a PTC system also reported a greater need for focusing on in-cab displays, at least initially, thus limiting their ability to check outside the cab (Roth & Multer 2009, Roth et al. 2013). During an examination of PTC systems, the train operators pointed out that they needed to closely track the in-cab display to remain within the braking curve and prevent a penalty brake application. The train operators emphasized that when the train traveled within a time window that allowed no flexibility in schedule variation or approached territories with speed restrictions, attention allocation emerged as an issue (Wreathall et al. 2007a).

Monk et al. (2017) found that when new signaling systems were first introduced, train operators were more focused on the in-cab signaling display and were distracted by it, reducing the amount of attention paid to monitoring outside of the cab. However, after a while, they could better balance their attention between inside and outside of the cab. Some Incremental Train Control System (ITCS)'s train operators also mentioned that, after 3 weeks to 1 month of working with the system, they spent less time monitoring the in-cab display. However, some train operators indicated no noticeable change in their attention distribution even after they had sufficient experience in running a PTC-equipped train and a remaining inability to have a head-up driving style (Wreathall et al. 2007a).

Operating ICRSD also means a train operator needs to devote more attention to in-cab displays, which can cause head-down driving and constant changes in visual distribution (Halliday et al. 2005). Despite some detrimental effects of in-cab systems on train operators' visual attention distribution, Merat et al. (2002) discovered that AWS can considerably increase the number of looks at signals as great numbers of the first looks at signals of the train operators studied were taken after AWS had sounded.

4.7 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. 2010a, 2010b, Carey 2015). In some cases, the train operator is 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. Therefore, the train operator may trigger automatic responses (Stein et al. 2019). The automatic responding shows the warning system has failed in its primary purpose to alert the train operators and attract their attention to threads (Halliday et al. 2005).

The results of a questionnaire survey of 277 UK train operators illustrated that a considerable number (i.e., 56%) have automatically acknowledged an Extended AWS alarm at least once during their driving experience, although only 2% did it on a daily basis(McLeod et al. 2005). McLeod et al. (2005) also analyzed On-Train Monitoring Recorder (OTMR) data and found that some train operators started pushing the cancellation button before the alarm had started to sound or they responded to the alarm very quickly. These anticipatory and quick responding behaviors may indicate unconscious alarm canceling, with only a physical response and no interpretation (Halliday et al. 2005, Balfe 2020). Because the AWS neither differentiates between caution and stop signal aspects nor has a mechanism to prevent misperceptions, train operators who are confronted with successive cautionary signals (yellow or double yellow) likely respond to the AWS horn without conscious interpretation about the signal aspect (Lawton & Ward 2005).

The existence of warnings related to situations that are less important than restrictive signals (e.g., Temporary Speed Restriction (TSR)), personal factors, the high number of alarms, and signaling issues were reported as the main reasons for automatic responding (McLeod et al. 2005). More analysis revealed that poor alarm management (e.g., excessive, uninformative audible alarms) reinforces a tendency to an automatic response without completely perceiving the alarm's meaning (Wreathall et al. 2007a). To address this problem, a variety of ideas for effective alarm management were recommended. First and foremost, the warnings must be accurate and informative to reduce the risk of automatic responding. Second, if an audible warning is adopted in a situation that the operator requires to monitor somewhere other than the display screen (in this example, they need to check out the window), it is useful to make distinctions between sounds relating to auditory alarms of different conditions (e.g., a different tone for approach versus stop). Third, using different actions (e.g., a different button push for approach versus stop alerts) for acknowledging different alarms is a good method to mitigate the risk of automatic responding (McLeod et al. 2005, Wreathall et al. 2007a).

4.8 Memory Failures

Short-term memory, also known as "working memory", is volatile and easily lost or distorted. Not only the passage of time but also interference between the current contents of working memory and newly arriving information can be a reason for information loss (McLeod et al. 2003). Thus, McLeod et al. (2003) recommended that a train operator should never rely on working memory to maintain vital safety data and suggested that external assistance is necessary.

Crick et al. (2004b) reported that 77.1% of their focus group train operators had at least occasionally forgotten the signal aspect after acknowledging the AWS. The evidence showed a possible risk of the train operator being uncertain about what an active alert corresponds to after around 7 seconds (Moray et al. 1983). A memory failure related to the DRA system may include forgetting to set the DRA, pressing a different button (e.g., AWS alarm reset or door release button) instead of the DRA button, resetting the DRA, and starting the trip based on the platform guard's signal without checking whether the signal aspect is clear (RSSB 2002). Davies et al. (2012) proposed that repeating the AWS warning on the head-up display can reduce the risk of train operators forgetting a cautionary signal was shown on the previous signal.

4.9 Skill Loss

Skill loss (skill degradation) is a probable but unpleasant feature of automation (Bainbridge 1983). As supervisory train control technology increases, train operators have a reduced opportunity to carry out tasks themselves, thus contributing to skill loss. The skill loss issue becomes apparent in a situation that requires the operator to take charge of the train (Wreathall et al. 2003). Therefore, maintaining the required skills of train driving is important and can be achieved either through a frequent application or structured training (Balfe 2010). Giesemann (2013)'s study highlighted the effects of the train protection system on task-related competence and control expectations which can result in poor automation failure management. They believed that the system is not a problem itself, but the reasons for concerns are the lacking feasibility of anticipation and a proactive driving style which might push train operators into passivity, causing loss of situation awareness and thus errors in the event of an automation failure.

4.10 Summary of Automation and Human Factors

A summary of the main human factors issues associated with the use of in-cab warning systems and automated train control technologies is provided in Table 1.

Table 1. Key human factors issues of in-cab warning systems

Author	Workload	Distraction	situation awareness	Mode confusion	Complacency and over-reliance	Visual attention allocation	Automatic responding	Memory failures	Skill loss
Balfe (2020)							♦		
Safar et al. (2020)		♦							
Oppenheim et al. (2010b)							♦		
Brandenburger and Naumann (2019)	♦		♦						
Brandenburger et al. (2019)	♦								
Nneji et al. (2019)	♦		♦						
Stein et al. (2019)			♦						
Brandenburger et al. (2018)	♦								
Brandenburger et al. (2017a)			♦			♦			
Brandenburger & Jipp (2017)					♦				
Sebok et al. (2017)	♦	♦	♦	♦					
Van der Weide et al. (2017)	♦					♦			
Van der Weide (2017)	♦					♦			
Monk et al. (2017)	♦			♦		♦			
Verstappen et al. (2017)	♦	♦							
Liu et al. (2017)			♦						
Hely et al. (2015)	♦					♦			
Robinson et al. (2015)	♦								
Safar et al. (2015)		♦							
Naghiyev et al. (2014a)						♦			
Naghiyev et al. (2014b)		♦				♦			
Naweed (2014)						♦			
Smith et al. (2013)									
Roth et al. (2013)	♦	♦	♦			♦			

Author	Workload	Distraction	situation awareness	Mode confusion	Complacency and over-reliance	Visual attention allocation	Automatic responding	Memory failures	Skill loss
Giesemann (2013)			♦		♦				
Buksh et al. (2013)	♦								
Rose and Bearman (2012)		♦							
Davies et al. (2012)	♦		♦					♦	
Scott & Gibson (2012)	♦								
Oppenheim et al. (2010a)	♦		♦						
Oppenheim et al. (2010b)							♦		
Roth & Multer (2009)	♦	♦		♦	♦	♦			
Spring et al. (2009a)	♦								
Thomas & Davies (2008)	♦		♦					♦	
Wreathall et al. (2007a)		♦			♦	♦	♦		
Wreathall et al. (2007b)			♦	♦	♦	♦			♦
Halliday et al. (2005)	♦	♦	♦		♦	♦	♦		
Crick et al. (2004b)				♦			♦		
McLeod et al. (2005a)				♦			♦		
McLeod et al. (2005b)				♦					
Lawton & Ward (2005)		♦	♦				♦		
Foulkes (2004)	♦		♦			♦			
Crick et al. (2004a)	♦	♦		♦					
Wreathall et al.(2003)	♦	♦	♦		♦				♦
RSSB (2002)				♦				♦	
Abe et al. (2002)					♦				
Merat et al. (2002)						♦			

5 CONCLUSIONS

This paper summarizes the potential negative impacts of in-cab warning devices and automated train protection systems on train crews. Through this review, we have found that most of the publicly published human-automation interaction research has been performed, or at least sponsored, by governments and regulatory bodies. Furthermore, depending on the technology development stage and available facilities, human factors researchers have collected and utilized real-world data, simulator experiments data, and/or expert judgment data in addition to theoretical data.

This literature review reveals that workload (i.e., under-load or over-load), distraction, loss of situation awareness, mode confusion, complacency, off-balance trust in automation (i.e., over-trust or mistrust), head-down driving, automatic responding, and skill loss are the key human-automation challenges.

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