CANADIAN RAIL
RESEARCH LABORATORY

www.carrl.ca

Inadvertently introducing human factors in automated systems control: Train protection systems

Mona A. Rad, Lianne Lefsrud & Michael Hendry

November 9, 2021

INTRODUCTION

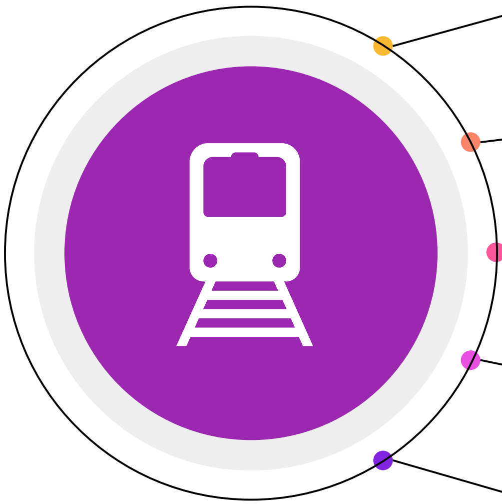
Train protection systems offer great opportunities to improve safety, firmly followed by economic and environmental benefits.

Thus, they play a vital role in sustainable transportation, one of the main pillars of sustainable development.

We reviewed in-cab warning technologies and train protection systems that have been adopted around the world to obtain detailed knowledge about the types of risks they address and the means of interactions they employ.

Furthermore, the nature and sequence of provided alarms, the acknowledgment procedures, and the risk controls were investigated.

The reviewed systems include:



- **Cab signalling 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)
- **Train operators' vigilance devices** — e.g., Driver Vigilance Systems (DVS) and Monitoring Engineer Fatigue (MEFA)

An overview of in cab warning systems

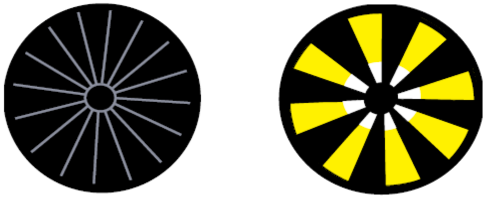
Automatic Warning System (AWS)

AWS provides in cab warnings for the train operator about the aspect of the upcoming signal in the form of an audible alarm as well as a yellow and black visual indicator, known as the 'sunflower'.

When a train is approaching a restrictive signal aspect (i.e., red, single yellow, or double yellow), a warning horn will sound until the train operator presses the AWS acknowledgment button on the train operators' desk within the time limit.

Then, the sunflower indicator changes to yellow and black segmented to remind the train operator they have just received a cautionary warning and acknowledged it.

If the train operator fails to acknowledge the AWS horn within 2 s (high speed trains) or 2.7 s (lower speed trains), an automatic emergency brake is applied (Crick et al., 2004b; McLeod et al., 2005a; Scott and Gibson, 2012; RSSB, 2016; Van Gulijk et al., 2018).



Some problems associated with the AWS system are (McLeod et al., 2005a, 2005b; Halliday et al., 2005).

- The AWS alarm and sunflower display are inherently ambiguous because the AWS does not fully differentiate between different sources of alarms and the same alarms can refer to a variety of risks.
-
- Some warnings of AWS may be activated simultaneously. In such situations, the train operator's memory is the only way to remember how many alarms are current, and the train operator's correct interpretation is required to determine to which of more than one possible condition the alarm refers.

Positive Train Control (PTC)

PTC is adopted to prevent train-to-train collisions and derailments due to excessive train speed, unauthorized incursions into work zones, and unauthorized train movements through misaligned track switches.

Various types of the PTC system has been designed and implemented, including ACSES (Advanced Civil Speed Enforcement System), I-ETMS (Interoperable Electronic Train Management System), and ITCS (Incremental Train Control System).

Figure 1. Example of ITCS in cab display (Roth and Multer, 2009).

ITCS continuously displays the allowed speed limit to the train operator and warns the train operator when a speed reduction is needed.

If the train operator violates the speed limit or required speed reduction, a warning is displayed followed by a penalty brake application (Hann, 2010).

ITCS shows TTB countdown 30 s prior to applying the brakes. If the locomotive engineer does not obey the braking curve in the first 20 s of the TTB, the system sounds an audio alarm.

When the countdown reaches zero, the brakes are activated.

The TTB is adjustable with the train speed and increases when the speed decreases (Roth and Multer, 2009).

European Train Control System (ETCS)

The ETCS refers to the train signalling and control component of the European Rail Traffic Management System (ERTMS).

It is a replacement for legacy train protection systems in European railways including EBI cab, ASFA, ATB, KVB, and TTBL (Figure 2 illustrates the diverse train control systems in Europe), with the main aim of improving interoperability.

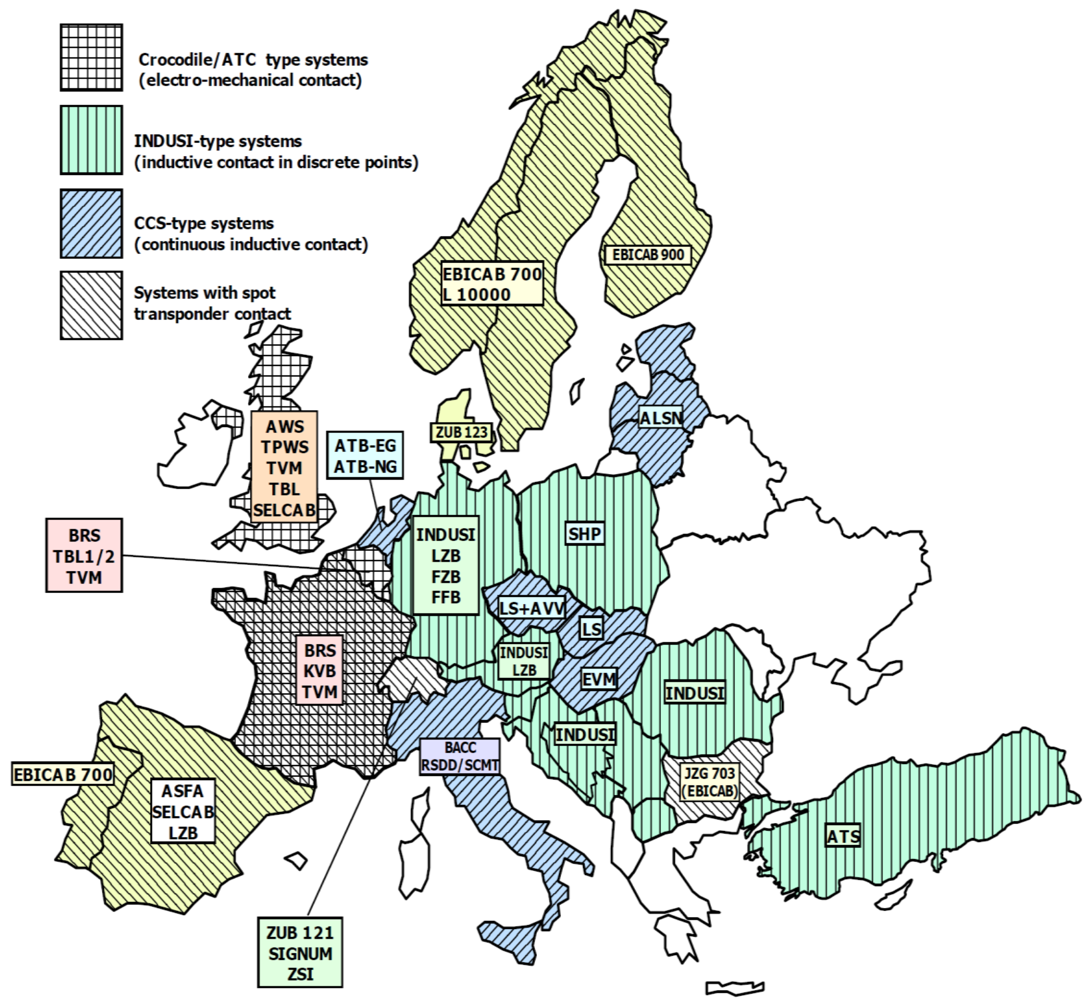


Figure 2. Train control systems in Europe (Vincze and Tarnai, 2006).

The ETCS system was introduced at different levels of technological development (levels 0 to 3), ranging from overlaid equipment on conventional signalling to the full ATC implementation (AG, 2018).

Regarding the ETCS level and the situation, various combinations of visual and audible signals are used to convey useful information to the train operator.

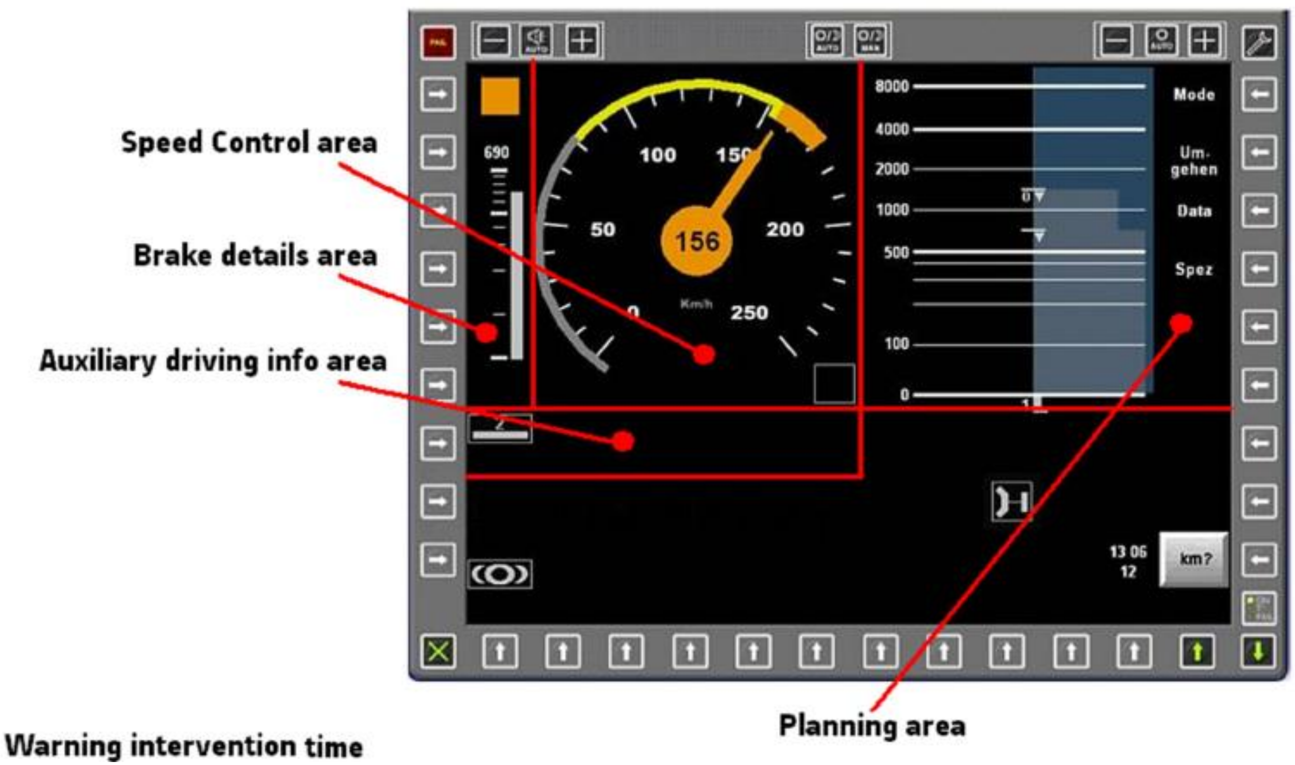


Figure 3. Sample of the ETCS DMI (Railwaysignalling.eu, 2014)

Vigilance Driver Device (VDD)

VDDs were developed to ensure that train operators are vigilant during train journeys. They address the risks associated with train operator sleepiness, fatigue, faintness, and death.

They give audio and visual indications to train operators, and if they fail to respond to the alarms within a certain time then an automatic brake is applied (Multer et al., 1998).

Note that the time intervals between alerts (usually between 25 and 120 s) as well as time to acknowledgment (usually 3-15 s) are sometimes functions of speed and required braking distance.

Furthermore, visual and auditory indications can be synchronous or asynchronous.

Vigilance Driver Device (VDD)

Although the existing VDD systems play an important role in keeping train operators conscious, they are deficient in terms of revealing a lack of mental engagement of the train operator in the case that the person is physically able to press the acknowledgment button.

When a train operator is neither fully asleep nor fully awake, it is probable to interact with the system while suffering from a lack of situational awareness.

Thus, Monitoring Engineer Fatigue (MEFA), a modified version of Aurora’s Aircrew Labor In cockpit Automation System (ALIAS), is being developed by FRA to fill this gap.

EDVTCS is a wrist and/or finger worn VDD system and is used by Russian, Australian, and UK railways (Dorrian et al., 2008; Stein et al., 2019).

ExPL is a current R&D project being undertaken by the FRA with the cooperation of Aurora Flight Sciences and the MIT Human Systems Laboratory.

It is a real time, automated second set of eyes based on machine vision/machine learning technologies. ExPL detects railway signal lights, detects and reads railway signs, observes rail track and merging conditions, and detects long-distance objects in day/night conditions.

It provides visual alerts and improves crew situational awareness. The feasibility and proof of concept of ExPL were confirmed in the Volpe Centre Cab Technology Integration Laboratory (FRA, 2020).

Figure 4. An overview of ExPL (FRA, 2020).

Discussion

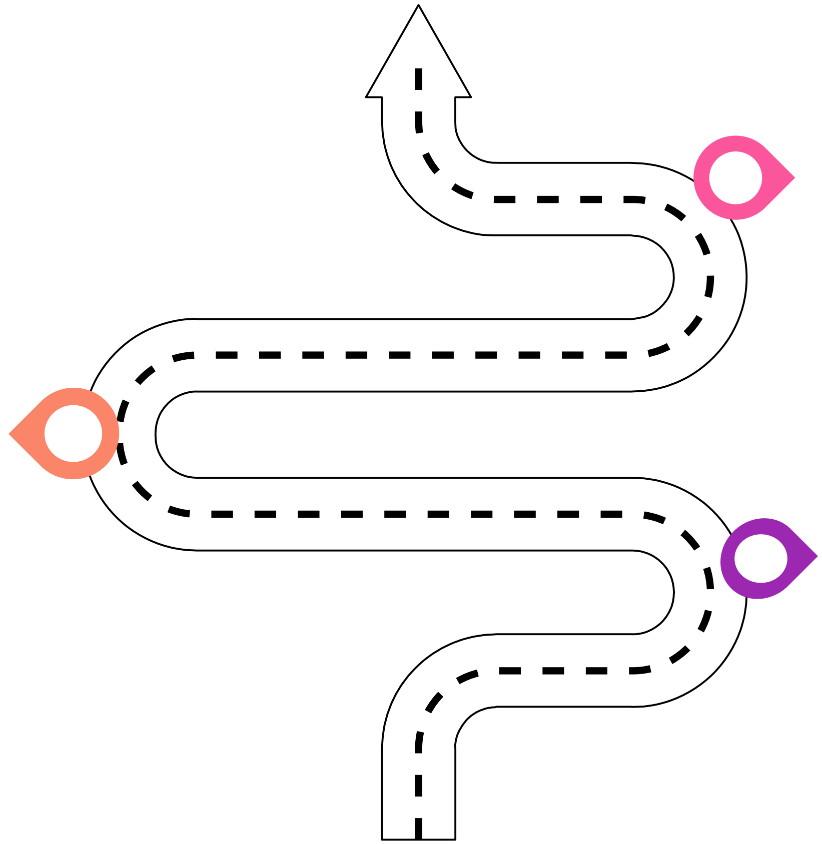
Types and sequences of warnings

Visible and audible signals are the two common types of driver system interactions in train cabs.

Visual warnings are used in situations with a lower degree of danger while auditory warnings in conjunction with visual warnings are usually employed when there is a higher urgency.

In urgent situations, visual alarms are sequentially or concurrently followed by auditory ones because sounds have a higher probability of generating a response with a faster reaction time compared to visual displays.

Types and sequences of warnings



Visual warnings

More visual signals to provide the train operator with relevant and advisory information (e.g., advisory braking profile and sunflower indicator in AWS).

Auditory warnings

If the train operator does not react to them, then an auditory warning is activated to accompany the visual alarm.

Visual warnings

(e.g., a flashing red light, speed reduction message, and/or TTB application countdown) to inform the train operator of a hazardous situation.

Warnings according to the types of risks

The overview of in cab warning systems indicates that although warnings related to different types of risks (e.g., SPAD, overspeed, and collision) are usually designed in a way to be distinguishable by the train operator, there is no direct relationship between the type of risk and type of warning (e.g., visual or audible warnings).

The appropriate types of warnings and their characteristics are chosen based on factors including the required perceived urgency, alarm states (e.g., normal, unacknowledged alarm, and acknowledged alarm), and the environment.

Systems can be categorized into three generations:

1st generation

- They only alerts the train operator of an upcoming hazardous condition.
- They need no train operator acknowledgment and have no automatic brake intervention.

2nd generation

- The train operator must acknowledge the warning, usually by pressing an acknowledgment button.
- If the train operator fails to do so, the emergency brake will be applied to bring the train to stop.

3rd generation

- The train speed is continuously checked with the dynamic speed profile, and warnings, service brakes, and emergency brakes are activated whenever needed.
- Emergency brakes are triggered in the situation when the train operator takes no action after the warnings and the brake curve speed is violated.

The literature review showed that human factors issues associated with the introduction and use of in-cab warning systems and automated train control technologies are:

- Workload
- Distraction
- Loss of Situation Awareness
- Mode Confusion
- Complacency and Over-reliance
- Visual Attention Allocation
- Automatic Responding
- Memory Failures

Conclusions

CONCLUSIONS

The prevention of signal passed at danger, overspeed, collisions, and train operators' vigilance are the primary focus of in-cab warning systems.

These systems commonly use visual and auditory alarms sequentially or concurrently to warn the train operators of a hazardous situation.

Systems can be categorized into three generations:

- first generation, consists of a warning only system without the requirement for train operator acknowledgment or automatic brake intervention;
- second generation, consists of a warning system which requires the train operator to acknowledge warnings and an automated application of brakes to stop the train upon failure to acknowledge;
- and third generation, which enhances second generation capabilities with monitoring of train speed and an application of brakes in the event of over speed.

CONCLUSIONS

Within the reviewed literature concerns were raised that upgrading of systems through generations has resulted in the confusing array of controls and displays, and recommend a consolidated control system and interface when possible.

The literature review showed limitations of train operators to handle and cope with alarms were primarily related to workload, and that their response differs greatly between individuals and situations.

- with an under-load of the train operator resulting in boredom, fatigue, over confidence and complacency;
- and, an over load resulting in irrational reactions, confusion, exhaustion and low self-esteem.

Due to the potential for negative cognitive impacts, automated braking should be a result of the emergence of an unsafe situation not reliant on a failure of the train operator to acknowledge.

FUTURE RESEARCH

We aim to identify the impacts of train control systems on performance of train operators, determine potential human error modes and their contributing factors, and formulate strategies to prevent or mitigate the negative impacts associated with the design and usability of ETC on the Canadian train operators.

To achieve these goals, getting full or partial access to any data listed below can be useful.

- Railway incident and accident data
- On-train monitoring and recordings (OTMRs) data
- Simulator data
- Human factors evaluation data

Acknowledgments

CN

Transport Canada / Transports Canada

NSERC
CRSNG

Thank you! Questions?

Mona A. Rad, ahmadira@ualberta.ca
Lianne Lefsrud, lefsrud@ualberta.ca
Michael Hendry, hendry@ualberta.ca

References

AG. (2018). Automated mass transit. Australian Government, Department of Infrastructure, Regional Development and Cities, Canberra, Australia.

Connor, P. & Schmid, F. (2019). Train protection. The Railway Technical Website. www.railway-technical.com/signalling/train-protection.html.

Crick, J., McCorquodale, B., Chissick, C., Diamond, H., Lear , A., Page, H. & McGuffog, A. (2004). Driver error data collection project: final report. Qinetiq, Rail Safety and Standards Board (RSSB), London, UK.

Dorrian, J., Lamond, N., Kozuchowski, K. & Dawson, D. (2008). The driver vigilance telemetric control system (DVTCS): Investigating sensitivity to experimentally induced sleep loss and fatigue. Behavior Research Methods, 40(4), 1016-1025.

FRA. (2020). Rail moving America forward: Current research projects. Federal Railroad Administration (FRA), US Department of Transportation, Washington, DC, USA.

Hann, G. (2010). Incremental train control system. IEEE Vehicular technology magazine 5(4), 50-55.

McLeod, R. W., Walker, G. H. & Mills, A. (2005). Assessing the human factors risks in extending the use of AWS. Rail human factors: supporting the integrated railway. B. N. J. Wilson, T. Clarke, & A. Mills. London, Routledge: 109-119.

Multer, J., Rudich, R. & Yearwood, K. (1998). Human factors guidelines for locomotive cabs. Federal Railroad Administration (FRA), US Department of Transportation, Washington, DC, USA.

Oman, C. M. & Liu, A. M. (2007). Locomotive in-cab alerter technology assessment. Development of alternative locomotive in-cab alerter technology: Final technical report. Volpe Center, US Department of Transportation, Washington, DC, USA.

Railwaysignalling.eu. (2014). The ERTMS/ETCS signalling system: An overview on the standard European interoperable signalling and train control system

Roth, E. & Multer, J. (2009). Technology implications of a cognitive task Analysis for locomotive engineers. Federal Railroad Administration (FRA), US Department of Transportation, Washington, DC, USA.

RSSB. (2016). Coexistent operation of ERTMS and Class B (AWS and TPWS) systems: The development and user testing of an integrated DMI. Rail Safety and Standards Board (RSSB), London, UK.

Scott, A. & Gibson, H. (2012). Red means stop, doesn't it? A human factors trial of a UK train safety system driver-machine interface. Rail human factors around the world: impacts on and of people for successful rail operations. A. M. JR WIlson, T. Clarke, J. Rajan, & N. Dadashi, CRC Press: 457-464.

Stein, C., Liu, A., Brown, D. A. & Porch, A. (2019). Monitoring engineer fatigue (MEFA). Federal Railroad Administration (FRA), US Department of Transportation, Washington, DC.

Van Gulijk, C., Figueres, M., Hughes, P. & El-Rashidy, R. (2018). TAVISON final report: The augmented SPAD BowTie Institute of Railway Research, University of Huddersfield, Huddersfield, UK.

Vincze, B. & Tarnai, G. (2006). Evolution of train control systems 14th International Symposium European Rail Research Network of Excellence. Zilina, Slovakia.