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The use of human senses by train drivers to detect abnormalities

Emil Jansson[a,*], Oskar Fröidh[a], Nils O. E. Olsson[b]

[a]*KTH Royal Institute of Technology, Div. of Transport Planning, Brinellvägen 23, SE-100 44 Stockholm, Sweden*
[b]*Norwegian University of Science and Technology, Department of Mechanical and Industrial Engineering, NO-7491 Trondheim, Norway*

Abstract

Driverless and unattended train operation is a foreseeable future. While many functions of the driver can be automatized and replaced but detecting abnormalities is more difficult to automate. This study investigates how train drivers detect abnormalities. The objective is to prepare the way for unattended train operation also for remote areas. Using disruption descriptions, written by train dispatchers, we have identified which senses are used by the train drivers and in which situations. Four of the human senses are used by train drivers to detect abnormalities: the visual, the auditory, the somatosensory, and the olfactory systems. The most used sense by the train drivers to detect abnormalities is the visual system. Before introducing driverless and unattended train operation, alternative tools for detecting abnormalities should be included based on the human senses.

Keywords: automation; abnormalities; railway; train driver; human senses; driverless

1. Introduction

The development of automated road vehicles in the transport sector is moving forward rapidly. However, the development of automated rail vehicles for medium- and long-distance passenger and freight services is not going as fast. The main arena for the development of automation in railways comes from the European research programs Shift2Rail and the continuation, Europe's Rail (European Commission, 2021). One of the goals of these programs is to make the railway more competitive through automation by reducing operation costs. One way of doing so is to introduce driverless or unattended train systems. However, it will bring new challenges to train operation as for remote lines there is a lack of monitoring other than driver/train crew and fixed detectors. Assistance from external personnel can also be assumed to be time-consuming, unlike in metro systems where the physical distances are short. The

* Corresponding author. Tel.: +46-72-148-6321
E-mail address: emiljans@kth.se

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concept of automated railway vehicles is called automatic train operation (ATO). ATO is divided into four grades of automation (GoA), see table 1. GoA 1 contains an automatic train protection system that monitors the speed of the train and movement authority, however, the train driver is responsible for driving the train. GoA 2 has automated starting, driving, and stopping, while the train driver does the other tasks. With GoA 3 there is no longer a train driver in the cabin, but there is a train attendant onboard. A GoA 4 system does not have any personnel on board.

To maintain or increase the safety and reliability of the railway system in GoA 3 or 4 systems, several strategies can be applied, in isolation or in combination. These include at least the following, (1) finding ways to detect and manage abnormalities without relying on the driver, (2) reducing the occurrence and/or consequence of such abnormalities. This study is focused on the detection part of the first strategy but does not imply that this is the only one.

Table 1 Definition of grades of automation, based on The International Electrotechnical Commission (2014) and Shift2Rail (2019).

Grade of automation	**Train operation**	**Setting the train in motion**	**Driving and stopping the train**	**Opening and closing the doors**	**Operation in the event of disruptions**
1	Automatic train protection with driver	Driver	Driver	Driver	Driver
2	Automatic train protection and automatic train operation with driver	Driver/Automatic	Automatic	Driver	Driver
3	Driverless	Automatic	Automatic	Automatic/Attendant	Attendant
4	Unattended	Automatic	Automatic	Automatic	Automatic

With a higher grade of automation, GoA 3 or 4, there will no longer be a driver in the train cab and thus that role needs to be fulfilled in other ways. Karvonen et al. (2011) state that metro drivers have many critical roles besides driving and that it is important that all the roles are taken into account in an automated metro system. In 2018 there were more than 60 fully automated metro systems in the world (UITP, 2019) and thus the different roles of the driver in the metro system seem to have been replaced. In mainline operation, the introduction of GoA 3 and 4 will be more complex as it is more open, covers larger areas, and is more heterogeneous than a metro system (Yin et al., 2017). The safety aspects of a mainline system regarding unauthorized people in the track area is another concern identified by Powell et al. (2016).

Brandenburger and Naumann (2018) highlight that in a GoA 3 or 4 system there will be a new role, known as the train operator, who replaces the train driver. The train operator would not be in the train cabin but would remotely monitor the trains and also remotely control them in case of an unplanned event. However, the train operator would have difficulties detecting abnormalities using the five human sensory systems: visual, auditory, olfactory, gustatory, and, somatosensory. In the present study, abnormalities are defined as irregularities around the track area such as obstacles or damages. The definition also includes potential vehicle faults.

The role of the train driver has been the subject of previous studies (Jansson, Olsson and Erlandsson, 2006; Karvonen et al., 2011; Andreasson, Jansson and Lindblom, 2019), however, the human senses used by train drivers to detect abnormalities have not been investigated in these studies. Previous studies of perception with automated vehicles have focused on the visual aspects as shown in the review made by Van Brummelen et al. (2018). The use of sound to identify road vehicle engine failures has been studied by Suman, Kumar and Suman (2022) using an algorithm with acoustic signals. Hodge et al. (2015) state that accelerometers can measure vibrations and motion detectors can detect movement in wagons. Svechtarova et al. (2016) reviewed the literature about sensor devices that were inspired by the human senses and found several devices for all five senses.

The purpose of this paper is to support increased levels of automation on trains in medium- and long-distance services and to prepare the way for Automated Train Operation (ATO) also for remote areas with unattended train operation.

One objective of the study is to identify which of the five human sensory systems are used by train drivers to detect abnormalities and which types of abnormalities are detected. A second objective is to identify possible methods to detect abnormalities in driverless or unattended trains by use of new technology, which could be applied in GoA 3 and 4 systems.

2. Method

In this study we use disruption descriptions from the Swedish railway network, written by train dispatchers operating in centralized traffic control (CTC), to identify the senses that the train drivers use to identify abnormalities. The data source is provided by the infrastructure manager, the Swedish Transport Administration (Trafikverket), and contains information for all trains, delayed more than three minutes (Trafikverket, 2019). The time period for the data was one year, 2019, and the dataset consisted of 250,000 disruptions of which 140,000 had a manually written description. Only the disruptions with a written description were used.

A qualitative approach based on thematic analysis (Willig and Rogers, 2017) was used. We connected keywords to each sensory system, see Table 2. As an example, the words “saw” and “see” were connected to the visual sensory system. We conducted queries with the keyword on the 140,000 disruption descriptions. After the queries, the descriptions containing the keywords were analyzed and the descriptions in which the driver had not used a human sensory system to detect an abnormality were excluded. Train dispatchers have written the descriptions and thus they can only write what the train drivers have reported to them, which is a limitation as it is not first-hand information. As only 56% of all disruptions have a description many situations are not described.

Table 2 Keywords connected to a sensory system used for the queries.

Keyword	Sensory system
Discover	All
Noise; Sound	Auditory
Taste	Gustatory
Smell	Olfactory
Felt; Shake	Somatosensory
Saw; See	Visual

3. Results

From the disruption descriptions, we have found that four human senses are used to identify abnormalities by the train drivers, the visual, the auditory, the somatosensory, and the olfactory systems. The results from the queries are shown in Table 3 and the visual sensory system had the most number of descriptions, over 70 descriptions. Followed by the auditory, olfactory, and somatosensory systems.

Table 3 Number of descriptions by keyword from disruption descriptions in the Swedish railway network in 2019.

Keyword	Number of descriptions with use of a sensory system	Sensory system
Saw; See	73	Visual
Noise; Sound	9	Auditory
Smell	4	Olfactory
Felt; Shake	3	Somatosensory

3.1. The visual system

The visual system is used by the train driver to identify abnormalities around the track area and also on other trains. Detecting persons around the track area is done visually and the train drivers also sometimes evaluate the specific situation. Examples we found of this in the descriptions are: "… saw children dangerously close to the track…" In other situations, they specify what type of persons are around the track: "Driver saw a child that put things on the track…", "…saw a teenage girl walked on the track.", "train X saw several young [persons] close to the track". Train drivers also visually detect animals: "5 cows are right at the track at km…but the train did not see any faults [with the pasture]…". The train drivers can visually detect abnormalities on other trains: "Train X saw that train Y had a log hanging outside the last wagon", "Driver on train X reports sparks on the wheels on train Y".

Observations by train drivers are also important for train dispatchers, as it allows them to control the track area for obstacles: "Train X saw nothing. Traffic control wants another train with sight speed". There are numerous examples of train drivers controlling for obstacles with reduced speed on the order of the traffic control. After nothing has been observed by the train drivers, normal operation recommences: "Neither train X nor train Y did see any children, normal speed again".

3.2. The auditory system

Train drivers use their hearing abilities to detect abnormalities. There are reports of train drivers hearing noises from wagons, wheels, or locomotives. After hearing the noises the train driver controls it: "Train X heard a noise from a wheel, stops at the next station and controls it" or "The train driver controlled a wagon after he heard a noise". The exact type of noise that the train driver has heard in these situations is unclear. Other types of noise are clearer as the situation when the horn was stuck continuously sounding and the train driver stopped and tried to adjust it.

3.3. The somatosensory system

The somatosensory system has been used by train drivers to detect and control abnormalities. Train drivers have used their sense of temperature to control hot wheel alarms: "…smelled burnt, but nothing was hot". The somatosensory system has been used to detect wheel damage ("The driver felt a wheel flat…"), and damaged tracks ("The driver felt a subsidence in the track at km…").

3.4. The olfactory system

The ability to smell has been used in different situations by train drivers. Train drivers have on several occasions smelt smoke or other smells from the train: "The driver of train X smelt something burnt and suspected the brake", "Driver smells something from the engine".

4. Discussion

The results show that four of the human senses are used by train drivers to detect abnormalities. Even though the number of descriptions of the auditory, olfactory, and somatosensory systems was fewer than 10, we can say that these senses are used by train drivers. A factor to consider is that the results are based on the descriptions of disruptions written by train dispatchers. This means that not all situations in which the train drivers use the human senses are included in the data set. Thus the actual number of uses is most probably much higher than the descriptions found in this study.

From the results, we can see different abnormalities that are detected by the train driver not only on their own train but also on other trains or in the track area. If the train driver is removed in a GoA 3 or 4 system, it is desirable to find other ways to detect such abnormalities in other ways by using different kinds of sensors.

With a GoA 3 or 4 system, the detection of abnormalities should be automated as it would not be feasible for a train operator to continuously monitor the train. This will require automated detection systems that process the sensor data and alert when a certain threshold is reached. The thresholds might vary and be very complex thus there could be a need for artificial equivalent senses together with machine learning algorithms to detect abnormalities.

According to the review by Van Brummelen *et al.* (2018) there are numerous tools available to visually detect obstacles and they all have advantages and disadvantages. Single-camera, stereovision, and lidar do not work well in poor weather conditions. As trains run all year long in all types of weather conditions, the possibility to detect obstacles must work even in poor conditions. Radar works well in poor weather conditions but is not good at detecting pedestrians or static objects. Sonar works well in fog and snow, but only works well on very close range, up to 2 meters. The review shows that car manufacturers combine different visual technologies such as single-camera, radar, and sonar. Combining different technologies is also beneficial for driverless or unattended railway vehicles as trains pass different conditions throughout their service.

From the results, we can see that the train drivers control the track area for obstacles on the order by the traffic control. This visual task might need to be done by a train operator (Brandenburger and Naumann, 2018) that remotely connects to the train and uses visual sensors to control the area. In order for train operators to be able to perform this task, the right information must be available to them.

For the auditory system, one possible tool would be to install an audio recording device inside the train cabin to capture what the train drivers are hearing today but also other locations could be relevant. The challenge would be to automatize the type of sounds that would indicate an abnormality. Suman, Kumar and Suman, (2022) proposed an algorithm to detect mechanical failures that would be necessary also for driverless or unattended trains. The algorithm should be able to detect noise that indicates a mechanical failure and also sounds at a high volume.

To replicate the somatosensory system, tactile sensors can be used to sense temperature and vibrations according to Svechtarova et al. (2016). Accelerometers, gap sensors, gyroscopes, and magnetostrictive displacement sensors could all be used to measure the wheels (Hodge *et al.*, 2015). The somatosensory system is used by train drivers to detect abnormalities such as wheel failures, track failures or to control hot wheel alarms. The somatosensory system is subjective and thus different train drivers might interpret the same situation in different ways. One train driver might report it while another might not and it will be a challenge to set a threshold for the alarm. This would be an area in which artificial intelligence could play a vital role.

Smoke detectors are already used to detect smoke onboard passenger trains, while other types of smells could be more difficult to detect. As smoke detectors are in use for many years the technology and the ability to detect smoke is proven. However, it might be a challenge to detect other types of smells as with the example of the train driver smelling “something” from the engine. Several of the mentioned senses are subjective and different drivers might experience the same smell in different ways.

Automated systems have the potential to monitor these issues more uniformly, being less dependent on the attention and experience of individual train drivers. To detect all the abnormalities there will probably be a need to develop artificial intelligence applications. A risk could be that the system will alarm too often resulting in false alarms and especially with a GoA 4 system, without any personnel onboard the train, the possibilities to control the alarm will be limited. This risk should be minimized for example with developed algorithms and remote monitoring with cameras.

5. Conclusion

New approaches are needed to support increased levels of automation on trains. A contribution to such development, this study has identified which human sensory systems are applied by train drivers to detect abnormalities and the type of such abnormalities. We find that train drivers in Sweden use four of the human perception systems to detect abnormalities:

- The visual system to detect different obstacles along the tracks and on other trains. It was the most used sense in the dataset.
- The olfactory system to detect different kinds of smells.
- The somatosensory system to detect damaged tracks or wheels.
- The auditory system to detect noise and sounds from the vehicle.

Based on our results, we see that it is important that this type of detection is represented in future driverless or unattended systems. There will be a need for an automated detection system based on the sensor data. The railway sector can utilise experiences from the development of techniques such as artificial intelligence and monitoring systems in other types of vehicles. In addition to detection, further work can address how the detected abnormalities can be managed remotely.

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