The impact of innovative devices in the train cab on train driver workload and distraction

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Abstract Dutch train drivers have several innovative devices and applications to their disposal when operating trains. These innovations provide opportunities for displaying integrated information. A practical applicable method was developed to assess the impact of innovations on workload and distraction. This provided useful insights in tasks when workload levels were increased, but also showed that strategic use of innovations could decrease workload levels and potential distraction in complex driving tasks. This enables train drivers to actively manage workload during driving.

Keywords innovations in the train cab, train driver performance, workload, distraction.

1. Introduction

Technological advances, the need for time table optimization and the urge to enhance a safe level of operation in one of the most complex rail systems in the world, have led to the development of several innovations in Dutch train cabs. At Netherlands Railways, innovative devices such as smartphones and tablets are introduced in the cab. Applications on these devices are aimed at providing integrated information about route characteristics and timetables. Train drivers can use this information to optimize the driving strategy.

Monitoring these innovative devices during driving requires multiple resources from the train driver. This could interfere with the demands already posed on the driver by the driving task, which in turn increases workload and affects driving performance. Use of devices during driving could also potentially increase the risk of distraction at crucial points on the route.

Following the CSM REA method (European Union Agency for Railways, 2013), Netherlands Railways assesses each modification in the cab to determine its impact on safety. The aim of the current study is to provide an integral insight into the impact of application of innovative devices during driving on train driver workload and potential driver distraction.

2. Models

The main model we used in this study was the PARRC-model (Parnell et.al., 2016). The PARRC-model is suitable to assess driver distraction in the context of the current situation in the train cab because it addresses five key distraction factors on a systems level. The model allows mapping potential distraction for system aspects that are still under development. In addition, the PARRC-model includes aspects of driver workload. To calculate these workload aspects we used the Multiple Resources Theory by Wickens (1984).

Within the driving context, Parnell et al. (2016) have conducted a comprehensive literature review to identify key factors of distraction. Distraction is defined as a “diversion of attention away from activities critical for safe driving towards a competing activity” (Lee et al., 2008).

The review addresses the impact of technologies in vehicles (e.g. smartphone and navigation systems) on distraction. Based on this review, a model has been developed with a systems perspective on distraction that outlines the five key factors contributing to driver distraction. This PARRC-model is shown in Figure 1.

Figure 1: PARRC-model (Parnell et al., 2016)

In summary, the PARRC-model contains the following key factors:

1. Goal Prioritization (P): the extent to which a task goal is considered more important compared to other task goals;
2. Adapt to demands (A): possibilities in situations to adapt behaviour in order to maintain goals in high demand situations;
3. Resource Constraints (R): the limited amount of cognitive resources a person has in order to process relevant information;
4. Behavioural Regulation (R): resources or mechanisms that direct attention back towards the main task;
5. Goal Conflict (C): the extent to which two or more goals require capacity and interfere with each other. These goals cannot be completed simultaneously without disrupting one another.

To determine the workload factors in the PARRC-model (Resource Constraints and Goal Conflict), the Multiple Resources Theory by Wickens (1984) was applied. This theory states that people have different cognitive resources that they can (simultaneously) use to process task relevant information. Wickens makes a connection between the attention that a person uses to focus on one or more concurrent tasks and the amount of demand that it takes to perform one or more tasks at the same time. Wickens has incorporated this relationship into the Multiple Resources Model (Wickens, 2002), as shown in Figure 2. This model can be used to predict the ability of an operator to perform in situations with multiple tasks and increased workload.

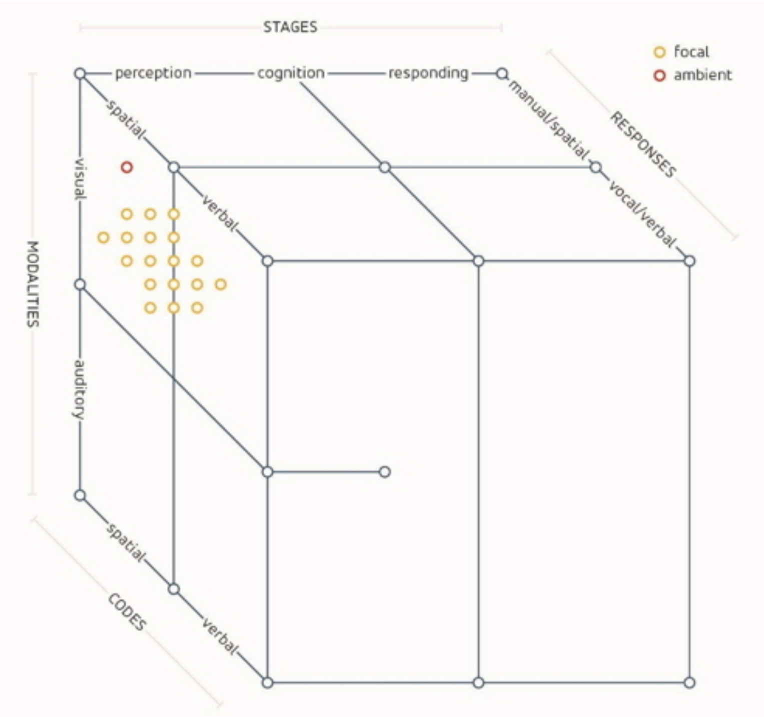

Figure 2: Multiple Resources Model (Wickens, 2002)

Wickens' Multiple Resources Model includes four dimensions of workload:

1. Visual perception: this aspect depicts the visual levels of information processing, distinguishing between focused and ambient perception;
2. Auditory perception: this shows the auditory levels of information processing, with a distinction between spatial and verbal input;
3. Cognitive processing: this concerns the mental processing of spatial and verbal information;
4. Psychomotor responses: the actions that a person performs based on information processing, distinguishing between manual operations and verbal responses.

According to the model, people can divide their attention between different dimensions at the same time. This is easier when attention is divided between components of different dimensions (e.g. listening to a conversation and looking at an object) compared to situations when cognitive capacity has to be shared between components of the same dimension (e.g. reading a text message while monitoring the road ahead). Conflicts arise when multiple tasks demand resources on the same dimension. For example, it is not possible to have two conversations at the same time.
The Multiple Resources Model makes it possible to map workload and potential conflict between specific tasks. Based on the resulting interference, operator performance for various tasks can be predicted. For example, Horrey and Wickens (2003) have used the model to chart the interference between driving performance and the use of navigation technology while driving. The model is applied in the current study because it is suitable to map workload and possible conflicts between the train driving task and the use of particular devices during driving. In addition, the Multiple Resources Model offers the ability to map workload for system aspects that still are under development and have not been introduced in the cab yet. Other measuring instruments or scales such as the SWAT or NASA TLX do not offer this possibility.

3. Methods

3.1 Task analysis and devices overview

To determine workload and possible distraction of current and future devices in the train driver cab, a task analysis of the train driving task was made as well as an overview of the devices used in the train cab. These two steps in the study were conducted together with a focus group of eight train drivers. Also, in-field observations were conducted to experience how devices are used in practice.

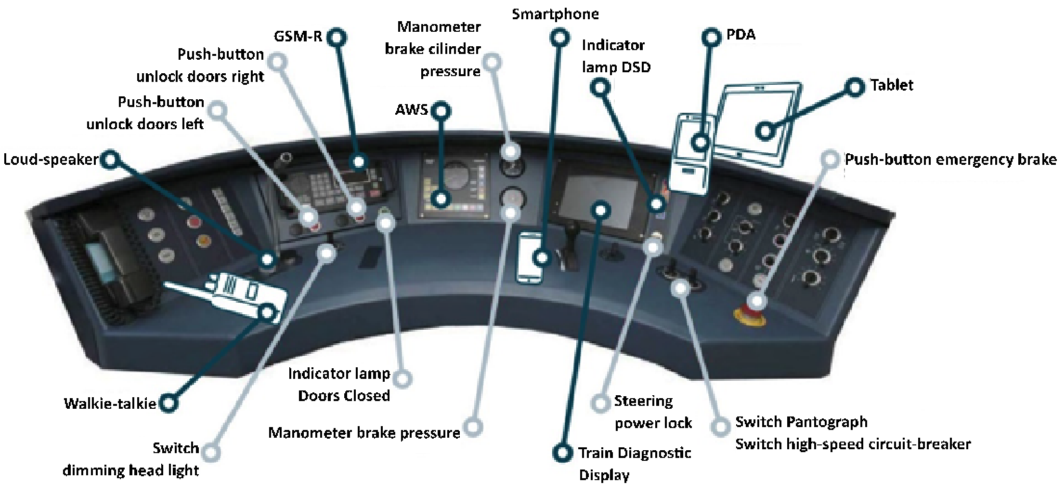

Figure 3: Overview of the current and future devices in the train cab

The task analysis was focused on the actual train driving part of the work and consisted of the following steps: train departures, train driving (on free track or in speed restricted areas), passing a level crossing or station and approaching a (red) signal or station.

Then an overview was made of all devices in the train cab, see Figure 3. Also the implementation and phasing out of all devices was made transparent, because not all devices are present in the cab at the same time. For example, the introduction of the smartphone was preceded by the removal of the normal GSM. This overview showed logical transition phases: the current situation (with a PDA showing separated route and timetable information) and the future situation (with a tablet with integrated route and timetable information). These logical phases were used throughout this study to show the effect of the introduction and phasing out of devices on workload and possible distraction.

Next, the way in which train drivers use a device and the specific moments a device is used were made explicit for all devices for regular, delayed, disrupted, and calamity conditions. This was necessary to see if and how specific devices are used in each step of the driving task. In some cases devices are used differently in different steps of the driving task, and dependent on the condition in which the train driver was driving the train. For example, in case of delays different information is checked compared to situations when everything goes according to plan.

3.2 Determining workload and possible driver distraction

For this study the five key factors of the PARRC model were assessed in a specific order to first determine workload and, in the end, the effect on driver distraction. The specific order is explained below.

1. Resource constraints (R)
   The first factor that was determined was the Resource factor (R), which gives insight in the workload a train driver experiences when driving a train and using a device at the same time. This factor describes the limited or restricted access to resources a person has to perform the driving task effectively. We determined the amount of workload for the different dimensions of the Multiple Resource Model by Wickens (2002): visual (V), auditory (A), cognitive (C) and/ or physical (P). First the 'baseline-workload' of the basic train-driving task was determined, without the use of devices. For each step of the train-driving task the demands on each of the VACP components were scored (0: no demand on the component, 1: low demand on the component, 2: medium demand on the component, 3: high demand on the component). Also, the workload accompanied with the use of a device was determined the same way with the VACP model. In addition, the possible benefit of the use of a device on driver workload was estimated, by determining the potential decrease on the cognitive aspect of the basic train driving task. For example, by applying route information, train drivers can anticipate more complex situations on the route ahead. This can lower driver workload, because the train driver has more insight in the situation in front of the train. Combining the workload scores of the baseline workload and the workload of the devices showed the total workload of driving a train with the use of devices.
2. Goal Conflict (C)
   The second factor was the Goal Conflict (C). This factor showed the amount of conflict between the driving task and the use of a device and actually gave a first insight into possible train driver distraction. The degree of conflict depends on the level of shared resources required by the goals. For this factor the conflict matrix of the Multiple Resources Model by Wickens (2002) was used, in which the amount of conflict between resource pairs across tasks is determined. The conflict score for each realistic combination of parts of the driving task and use of a device was calculated.
3. Adapt to demands (A)
   Third, the factor Adapt to demands (A) was explored to determine which possibilities the train driver has to adapt to the demands of a certain situation or to adapt the demands of a situation itself. If the train driver has the possibility to adjust behaviour to manage the situation, it means there is some sort of safety margin when engaging in risky situations. The possible adaptations and the situations in which train drivers applied the adaptations were determined in the focus groups together with train drivers. When there was a possibility to adapt to demands, a positive score (i.e. a lower potential for distraction) was given, when there was no adaptation to demands possible it resulted in a negative influence on distraction (i.e. a higher potential for distraction).
4. Goal Priority (P)
   Next, Goal Priority was assessed for both driving task and use of devices. For each step of the driving task a safety component was determined, based on the degree to which safety is a priority for this step. Then for each device it was assessed in the focus group with train drivers to what extent the devices contributed to task goals (e.g. safety, punctuality). When the safety component of the task is high, but devices contribute mainly to non-safety goals, then the risk for a potential negative effect of distraction is higher compared to situations when the safety component of the task is lower or when devices contribute to the safety goal.
5. Regulate Behaviour (R)
   The last factor that was determined was Behavioural Regulation. This indicates if there are devices or warning systems that actively direct the attention of the train driver back to the safety critical train driving task in case a train driver is engaged in a secondary task.

This factor was determined by experts together with the focus group with train drivers. A system or device that has a fail-safe effect by redirecting the attention to the driving task resulted in a strong reduction in potential distraction. A non fail-safe system resulted in a smaller decrease in potential distraction. And an absent system does not increase the potential distraction, but has a neutral effect.

The first two factors (resource constraints and goal conflict) indicated the amount of workload and the amount of conflict between the driving task and the use of a device. The last three factors (adapt tot demands, goal priority and regulate behaviour) gave an indication of the amount of mitigation of the potential distraction. All five factors together gave an indication of the workload and potential train driver distraction from using devices in the cab (as shown in the results section).

4. Results

Based on the mixed method approach for task analysis, an overview of critical steps in the driving task was identified. For each step in the driving task workload was determined, following the method developed by Wickens (2002). This represents the 'baseline' of workload for the driving task, depicted in Figure 4. The overall analysis of the current study included devices in the cab that are part of the driving task, such as the Drivers' Safety Device (DSD) and Automatic Warning System (AWS), as well as information and communication devices. Due to the complexity of the study and limited space, the result section of the current paper is limited to the innovative (information) devices used in a regular situation in order to provide an image of the impact on workload and driver distraction.

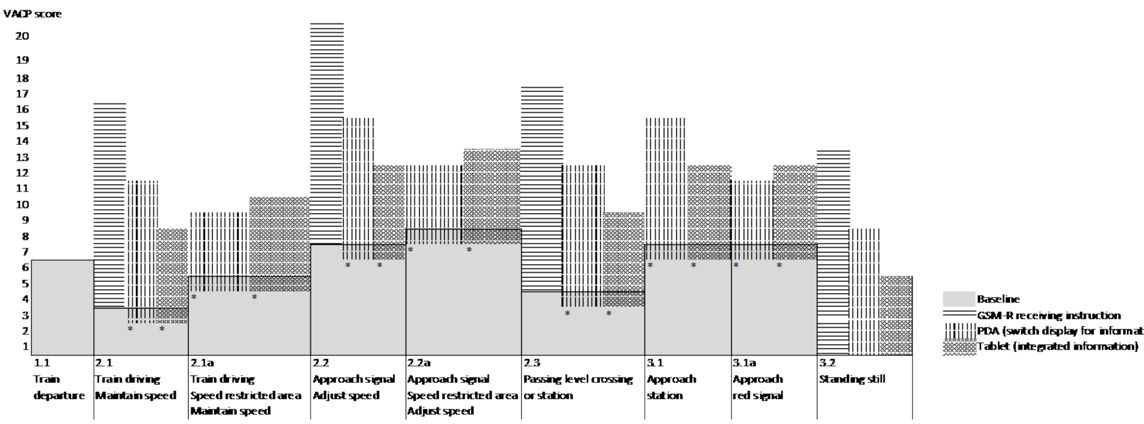

Figure 4: Baseline workload and workload caused by devices in regular condition

4.1 Resource constraints

Figure 4 shows an example of the VACP scores for baseline workload and workload caused by the use of certain devices (GSM-R, a PDA with separated information and a tablet with integrated information). Analysis shows that in particular aspects of the driving task such as the approach of a signal (in speed restricted areas) pose a higher demand on the train driver because of a high visual and manual resource demand. This step requires more visual effort in order to locate signals and observe signal aspects correctly and it requires motor capacity in order to adjust the train speed accordingly. In the focus group, train drivers indicated that these situations cause them to be 'on the edge of your seat'. In comparison, maintaining speed on the open track requires the least amount of resource demand because it requires less visual effort and actions to maintain speed. Figure 4 also shows that certain devices (as GSM-R) are not used in certain parts of the driving task (for example when approaching a red signal). It also shows that devices are used differently during the driving task. For example, when approaching a signal the timetable information on the PDA is not checked, therefore this device does not add onto the workload score for certain parts of the driving task.

For both the current and future situation in the train cab regarding devices, out of all the devices in the cab the GSM-R requires the greatest resource demand of train drivers. Receiving an instruction from the signaller requires the train driver to operate the GSM-R, conduct a conversation with the signaller and write down the specifics of the assignment. The design of the train cab system allows the train driver to operate the GSM-R during driving which could cause conflict with the driving task, especially for visual and manual resources.

Currently, train drivers have a PDA at their disposal in the train cab, which displays timetable information and dynamic route information. To access this information the train driver has to switch between displays, which requires manual resources in addition to the visual and cognitive resources needed. In the near future, this PDA will be replaced with a tablet, which integrates the information of both displays and will give a more clear overview of the information. In effect, the tablet requires less manual, visual and cognitive effort to process information and as a result poses a lower resource demand on the train driver. In addition, discussions in the focus group with train drivers show that train drivers strategically consult the route information when the driving task requires less resources (e.g. on the open track). They use this information to adjust their driving strategy in situations when resource demand is higher (e.g. approach of a restrictive signal). In this way train drivers are able to decrease the demand of the driving task (and limit potential conflicts between the use of devices and the driving task) in more critical situations further along the route (see Figure 4, indicated with the * below the baseline workload).

4.3 Goal conflict

Following this baseline workload, the demand of each device applied in the cab during driving and its conflict with the driving task were determined, using the conflict matrix devised by Wickens (2002). The use of GSM-R showed the highest conflict scores if used when approaching a signal. The conflict scores for the tablet with integrated information were lower than scores for the current situation with separated information on the PDA.

4.2 Adapt to demands

Following the identification of resource demands and potential conflicts between devices and the driving task, possibilities were identified for train drivers to adapt to the demands of both driving task and application of devices.

The system provides several possibilities to adapt to demands or avoid conflicts between tasks. Some of the devices demand immediate resources during driving, such as reaction to signals of the Driver’s Safety Device or the Automatic Warning System. Other devices require less immediate action, with room for the train driver to decide to postpone the use of a device (e.g. ignore a smartphone call). The application of other devices such as the tablet is optional, allowing the train driver to consult the device at a more convenient moment on the route. Train drivers indicated in the focus groups that they have possibilities to adapt their behaviour to the demands of the primary driving task or secondary tasks. They apply a more defensive driving style while engaging in a secondary task. For instance, reduce train speed to be able to answer a GSM-R call from the signaller. On the other hand, other train drivers interrupt conversations with the signaller in order to focus on the driving task when the resource demands of the primary driving task increase.

The PARRC-model focuses on identifying behavioural changes aimed to protect the main task goal in high task demand situations. Interestingly, the current study found that train drivers not only adapt their behaviour to the demands of complex situations, but the application of route information allows train drivers to actively influence the demand of the driving task. By applying route information, train drivers can anticipate more complex situations on the route ahead, which allows them to adjust the driving strategy accordingly (see also, Buksh et al., 2013). For instance, the application that provides route information (called 'Routelint') helps train drivers to anticipate unplanned red signals. By adjusting the driving strategy, train drivers might even be able to prevent these situations from occurring altogether (Van Luipen et al., 2013). As a result, the strategic application of devices during driving limits the demand of complex situations further on the route.

Compared to the current situation in the train cab, the capabilities of train drivers to adapt to demands are similar in the future cab design. In the future situation, train drivers might use the integrated information on the tablet to determine a more convenient moment on the route to engage in secondary tasks. This is particularly useful to anticipate and manage demand of critical aspects of the route such as driving in an area with restricted speed.

4.3 Goal priority

Next, the effect of distraction was assessed based on goal priority. The safety component is more critical in case of an approach of a signal at danger compared to maintaining speed on the open track. If a train driver engages in a secondary task when the safety component is critical, the potential negative effect of distraction is more severe compared to other steps in the driving task when the safety component is less critical.

Other goals such as punctuality, energy efficiency and customer service were also taken into account for the devices. For example, devices with a clear safety priority are the AWS, DSD, ORBIT and GSM-R (depending on the obtained information from the signaller). ORBIT is a warning system that issues an auditory warning signal in case the brake curve is exceeded when approaching a signal at danger. This way, the train driver receives a verbal warning signal when the train approaches a signal at danger at too high speed. Other devices such as the PDA and tablet are especially aimed at punctuality, but the implementation of the information obtained from these devices also contributes to the safety task goal.

4.4 Behavioural regulation

For the final key factor of the PARRC-model, behavioural regulation, it was determined to what extent system factors assist train drivers to redirect attention towards the driving task in case of interference between the primary and secondary task. Two aspects were identified to regulate behaviour: the AWS and the recently introduced ORBIT system. ORBIT, in contrast to the AWS, does not actively intervene to reduce train speed. Nevertheless ORBIT is an aid that supports the train driver to focus attention towards the train driving task at crucial moments on the route which require higher resource demand (i.e. driving in 40 km/h areas, approach of signal at danger). It should be noted however that despite the introduction of ORBIT, the amount of system aspects that could mitigate the potential for distraction at critical driving steps are limited.

5. Discussion and Conclusion

This study is an initial effort to explore the impact of innovations in Dutch train cabs on workload and train driver distraction. In summary, based on the five key factors of the PARRC-model (Parnell et al., 2015) we determined potential conflicts between use of devices and the primary driving task, possibilities to adapt to the demands of these various tasks and their implications for potential distraction. This study provides an integral perspective on the impact of Netherlands Railways train cab innovations on workload and potential distraction.

Resource constraints and goal conflicts for the driving task and the application of devices during driving were determined by applying the Multiple Resources Model (Wickens, 2002). Results showed that in particular driving in a speed restricted area and approaching signals with a restricting aspect increased resource demands. For the application of devices it was found that in particular existing standard communication devices such as the GSM-R pose an increased demand on the train driver. However, the use of GSM-R during driving is incidental, whereas the innovative devices that provide route information are monitored more frequently during driving. These innovative devices require visual and cognitive resources. Conflicts between communication devices or information devices and the train driving task at critical aspects of the route create a risk for distraction. Train drivers apply defensive driving strategies to adapt to these demands and to prevent conflicts between tasks to occur.

Interestingly, the application of the route information obtained from the tablet or PDA, if used on the right moment, allows the train driver to actively manage the demand of the primary driving task and secondary tasks by anticipating critical steps on the route ahead. This supports a more proactive driving style as defined by Buksh et al (2013). By implementing the route information, the frequency of situations with a high safety component (i.e. the approach of signals at danger) could be reduced, which might help mitigate the risk of distraction.

Based on the assessment of task goal priorities and in particular the safety component, distraction poses an issue when applying (communication) devices in critical steps such as the approach of a restricted signal aspect. For these instances, the train cab is equipped with several warning systems (e.g. AWS, ORBIT) that could support the train driver in redirecting attention towards the primary task.

When the current situation in the train cab is compared with the future situation when innovative devices such as the tablet with route information and ORBIT are fully implemented, it can be concluded that the future train cab set-up provides the train driver with more possibilities to mitigate the risk of distraction.

The mixed methods approach used in the current study posed a few limitations. For instance, Wickens' Multiple Resources Model, which was applied to provide insight in resource demand and task conflicts, proves less insightful in circumstances with task underload. Regarding the current developments in the train cab, with new innovations introducing more advanced levels of automation, underload is a serious issue that should be addressed.

A second issue regarding resource demands in particular is the 'red-line' of workload which has been discussed in detail (Grier et al., 2008). Since there is no general consensus on the definition of workload itself, and it is regarded as a dynamic construct with many factors influencing experienced workload (Cain, 2007), it seems impossible to define a 'red-line' of workload. Furthermore, it is difficult to assess the 'red-line' of workload for a system which is still under development or which has yet to be implemented. As a result, the discussion whether it is responsible to use innovative devices as an aid during driving remains unresolved.

The PARRC-model assesses distraction on a systems level. However, in the context of innovations in the train cab, it is also important to determine the impact on train driver behaviour through objective measurements such as eye tracking to observe attention allocation. Following the cognitive task analysis and the application of the PARRC-model in the current study, the next step in this research project will be to assess distraction in relation to devices in the train cab with eye-tracking and a simulator setup.

Based on the models of Parnell et al. (2016) and Wickens (2002), the current study provides useful insights in the potential risk and mitigation of train driver distraction on a systems level. Further research in this area should focus on the validation of this method combining aspects of workload and driver distraction. The current study focused on the effects of workload and distraction on the primary task of train driving. However, it could prove insightful to focus on secondary task performance as well, especially in the context of multiple devices and the application of information of driver advisory systems.

Based on the results of this initial study, Netherlands Railways has further clarified the regulations regarding the application of devices in the train cab during driving. This study is a first step for Netherlands Railways in developing a method to systematically assess workload and potential for distraction in the context of train cab innovations. This method puts innovations in the train cab in a systems' perspective. Follow-up research with simulators and eye-tracking will build on this initial exploration so that future developments in the train cab will optimally support the train driver.

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