ERTMS pilot in the Netherlands – impact on the train driver

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Abstract. In 2014 the Ministry of Transport decided for implementation of ERTMS (European Railway Traffic Management System) on the main corridors in Holland. A pilot with ERTMS was performed between the cities of Amsterdam and Utrecht. This paper describes effects of ERTMS on workload and human error of the train driver by comparing driving in conventional (ATB), in ERTMS with Dual Signalling and in ERTMS L2-only train protection. This was done using driving performance data, a simulator experiment, workshops and surveys.

Keywords: ERTMS, driver, workload, human error

1. Introduction

In 2014 the Ministry of Transport decided for implementation of ERTMS (European Railway Traffic Management System) on the main corridors in Holland. A pilot with ERTMS was performed between the cities of Amsterdam and Utrecht for learning and experiencing purposes. The pilot started March 2014 and ended June 2015. The track from Amsterdam to Utrecht is a track with a high train density. The pilot was performed with so called Dual Signalling. This means that the track was provided with both conventional signals and conventional train protection system (ATB) and with ETCS L2 (European Train Control System level 2) as part of the ERTMS-system. Train service was performed with a mixture of trains with ATB and trains with the ETCS train protection system. Another aspect was the difference in speed limits: ATB 140 km/h and ETCS 160 km/h. When driving in ETCS train drivers were instructed to adhere to instructions on the in-cab driver machine interface (DMI ETCS), but due to regulations they weren't allowed to ignore the line side signals at danger (red aspect). Drivers in trains with ERTMS were all trained (ERTMS-pilot, 2015a).
As the future situation with ERTMS L2-only differs from the pilot situation with Dual Signalling the following research question was raised: To what extent do driving in ATB (the current situation, further referred to as 'ATB'), in ERTMS L2 with Dual Signalling (the pilot situation, further referred to as 'ERTMS-DS') and in ERTMS L2-only (the future situation, also present on HSL-South and Betuweroute, further referred to as 'ERTMS-Only') differ with respect to train driver's workload and human error?

2. Method

To answer the research questions related to train drivers a simulator experiment was conducted, in which the different conditions were simulated: ATB versus ERTMS-DS versus ERTMS-Only. Experience of train drivers in daily practice with ERTMS-DS and L2 was explored with questionnaires and in several workshops. Not all research items could be simulated in a valid way, so triangulation of questionnaires, workshops, expert opinion and objective infrastructure data was performed to answer research items like habituation of a train driver to the active train protection system (outside of the scope of this paper). This paper will only address one of seven sub-questions (ERTMS-pilot, 2015b).

2.1 Simulator

The pilot lasted for a little more than one year. Long-term effects of driving in a particular signalling system could not be studied due to the small number of journeys for each train driver, and effects are coloured by daily variations. The reason to perform a simulator experiment is that every subject makes the same journeys under the same circumstances. Any differences can then be attributed to the experimental conditions.
The use of simulation had some restrictions as well:

- Sighting distances for signals were shorter than in reality. This may have limited anticipation in the ATB condition.
- The track layout was represented realistically but buildings or landscape were not simulated. So drivers could not fully rely on their route knowledge.
- Most drivers had limited experience with ERTMS. They may have been in a learning curve that causes them to behave differently.
- The simulator could not log all desired parameters (e.g. changes on the DMI). Some questions therefore had to be answered in a different manner.

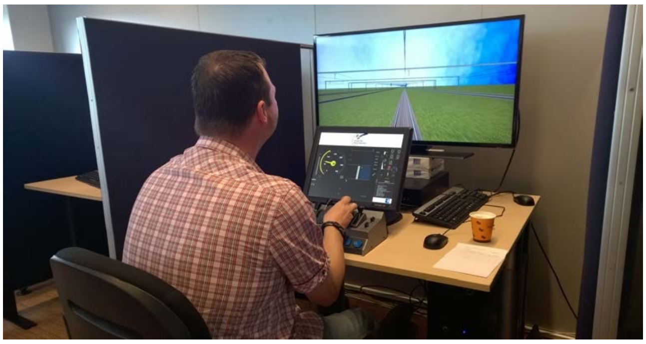

Figure 1. The set-up of the simulator

Forty drivers participated in the ATB versus ERTMS-DS simulation. Another twenty train drivers drove under all three conditions. So in total: 60 drivers. This paper will focus on the twenty drivers experiencing all three conditions. The simulator used was produced by ERSA, and is a slightly adapted version of the training stimulator for ERTMS. The Driver Machine Interface (DMI ETCS), including the STM ATB, is compliant with Baseline 2.3.0d specification. For the research simulator a larger 89 cm display was used with HD resolution to display the view on the track. The driver’s desk was a RailDriver® console, instead of the usual mouse and keyboard, to make actuation of traction and brake controller more realistic.

The track simulated was the Amsterdam-Utrecht track. The experiment focussed on the part of the track between the level transition points (the transition from conventional track to Dual Signalling track and vice versa). Every driver made three similar journeys with conditions ATB,

ERTMS-DS (including signals along the track) and with ERTMS-Only (no lineside signals[1]). A planning area was presented in ERTMS. Driving in ATB was actually in STM-ATB in the simulator, i.e. the graphical representation of ATB cab signals on the DMI ETCS. Journeys started and ended always in ATB, which is in accordance with reality (yards are not equipped with ERTMS). In all runs a certain hindrance was generated in the sense that other traffic on the track lead to speed restrictions for the driver, presented on the DMI or lineside signals and urging him to brake. This hindrance caused by other traffic was the same for every driver.
During the runs drivers were also confronted with several events:

- A normal end of set route (and/or equivalent end of movement authority in ERTMS conditions) followed soon by a permission to proceed (situation: a slow cargo train ahead)
- A signal at danger (and/or equivalent end of movement authority in ERTMS conditions), at which the driver contacted the train dispatcher to receive an order for passing this signal
- Being presented with driving on sight.

The runs were presented in varying order to minimize effects on the outcome.
Behaviours of the driver and the train were registered. These included braking, accelerating, train speed, signals and light signals passed, actual speed, movement authorities visible on the DMI etcetera. The experiment was carried out at the ERTMS academy institute. Four identical simulator set-ups were installed side by side, separated by boards. One of them was equipped with an eye tracking device (Ergoneers).

Subjects had an average driving experience of 15 years, with a standard deviation of 11 years. Experience varied from 36 years of service to 2,5 years. All were employed from the same company. Most of them were used to driving a commuter passenger train SLT type (that has a combined brake/accelerate handle as used in the simulator), some had experience with Traxx locomotives. Preceding the experiment drivers followed ERTMS training (on average 10 months before, some drivers 3 years before the experiment). On average the drivers had made 4 journeys in ERTMS on a Dual Signalling track. Two drivers were experienced with ERTMS-Only, the others were not.
On arrival at the Academy drivers were given a presentation on goal of the experiment and program of the day. Before, between and after the sessions questionnaires were administered. At the end of the experiment the drivers were given a debriefing in which they could report their experiences and provide some context to the outcomes.

Dependent variables were:

- Objective: Number of brake interventions in ERTMS and ATB
- Objective: Number of SPADs in ATB
- Subjective: Dwell time outside as fraction of total dwell time (indicative measure)
- Subjective: Mental workload and debriefing impressions.

2.2 Questionnaires

Drivers were administered several different questionnaires during the simulator study:

- A list at the start of the day on biographical data and experience with ERTMS
- After each run a questionnaire dedicated to workload, an estimation of the chance of error following new information, course of that run, handling of the simulator etcetera.

[1] The ERTMS-Only condition does not exist in reality on this track.

Workload was scored on a RSMI scale (0-150), as was experienced during an event and the run in general.

- A debriefing: an extensive questionnaire at the end of the day about drivers' opinion on ERTMS, the simulator, their personal experience.
- A (translated) SASHA questionnaire on Situation Awareness.

2.3 Workshop
Several workshops were held with a separate group of drivers, each addressed to a particular subjects such as design and setup of the simulator experiment, workload and human error, workload and habituation in the three train protection conditions or operation constraints and disturbances. Examples of the latter: starting / turning the train, orders, GSM-R malfunction, balise malfunction, difference between lineside signals and Movement Authority on the DMI. The workshop was focussed on workload and human error in these situations.

2.4 Survey
In a survey, drivers were asked to rate their workload in daily practice when driving with ATB, ERTMS-DS and ERTMS-Only under several sight conditions (daytime, good sight; daytime, reduced sight; night time, good sight). They were also asked their opinion on some aspects of ERMTS in a number of daily scenarios. The survey was completed 107 times, of which 70 surveys could be used for analysis. Driver experience ranged from 3 till 40 years (mean 18,7 years; standard deviation 10,6 years). Drivers drove passenger trains (NS Reizigers, ICE) and freight or work trains (DB Schenker, Shunter a.o.). The time past since their training on ERTMS was on average 5 years. Their ERTMS driving experience was on average 2 years and 7 months.

3. Results

3.1 Driver workload - Simulator
When asked about their workload during the previous run, drivers scored a mean RSME rating of 25.5 for ATB, 27.8 for ERTMS-DS, and 36.7 for ERTMS-only (on a 0–150 scale). The difference is significant ($F(1.32)= 7.430$, $p < 0.05$). Workload with ERTMS was significantly higher than with Dual Signalling ($p=0.032$) or ATB ($p=0.028$). See figure 2.

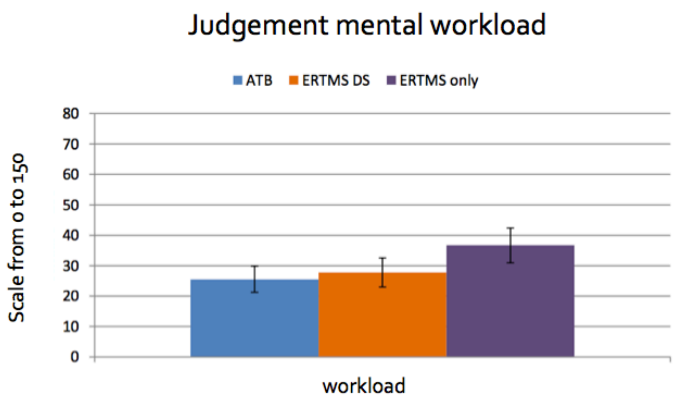

Figure 2. Judged mental workload for the three conditions.

In the debriefing, drivers commented on their workload for the three conditions in general. Many drivers could get along well without the signals in the ERTMS-Only condition (‘ERTMS is more clear and orderly”). Most of them prefer ERTMS and find there is not much difference in workload overall; this is despite their judgements after each separate run.

3.1.1 Events

Other judgments of workload were related to three different events during the runs.
There was no significant difference between ATB, ERTMS-DS and ERTMS-Only in workload for each of the events. Figure 3 illustrates this. When asked if the driver knew what was going on in an event (to be answered with ‘yes’ or ‘no’) they responded 19 times ‘no’ in ATB condition, 21 times in ERTMS-DS and 23 times in ERTMS-Only. When asked if one knew how to handle the event, almost all drivers responded ‘yes’. Apparently, obeying signals does not always require full understanding of the situation.
During the debriefing some drivers remarked that, due to their limited experience with ERTMS, it takes more mental effort remembering the procedures when one is forced by the DMI to stop for unknown reasons (which is the equivalent of a signal at danger).

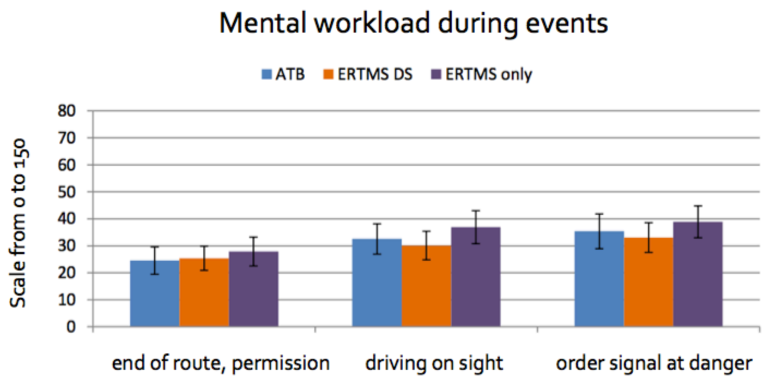

Figure 3. Mental workload during events for the three conditions. Be aware that the y-axis (RSME) runs from 0 to 150; the graph exaggerates differences.

3.1.2 Level transitions

In the debriefing it became clear that transitions, from ERTMS to ATB of vice versa, constitute a special situation. Such a transition may impose a varying workload, depending on the remainder of the infrastructure. Especially the transition from ERTMS (ERTMS-DS or Only) to ATB urges the driver to notice the actual situation, any signs present, other traffic, stations to be stopped at. Meanwhile, ERTMS is still the active system. So the ETCS DMI is still active and is the information source to consult and the basis of any decisions. The transition imposes workload. This workload will be lower when there is little other infrastructure to consider, compared to transitions in a crowded, complex environment. Because the workload at a transition lasts only a short time it is of little effect on the total workload of a run.

3.1.3 Attention (eye-tracking)

As a related measure of workload, distribution of attention was also investigated between the three conditions ATB, ERTMS-DS and ERTMS-Only. This was done by measuring the percentage of glances directed at different sources of information with the aid of eye-tracking.

Time spent looking at an information source is supposed to be related to attention focussed and thus, to using and processing information from that information source. (Johnson and Proctor, 2008; Styles, 1997; Zelinsky, 2008).
Figure 4 shows the percentage of time spent looking at several sources.

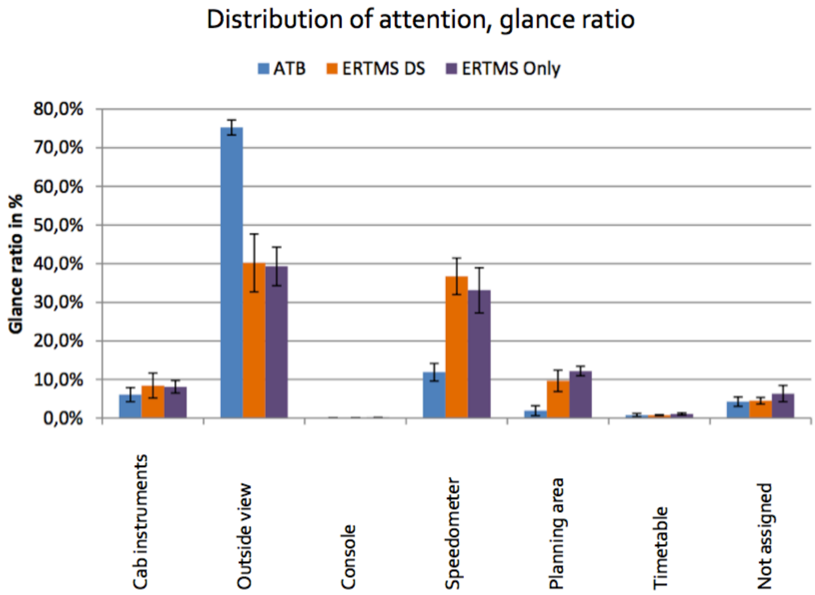

Figure 4. Distribution of attention, percentage of time looking at sources.

The amount of attention spent looking outside by drivers was analysed in further detail. Statistical analysis reveals that drivers significantly look more outside when driving in ATB (75.3 %) compared to ERTMS-DS (40.2 %) or ERTMS-Only (39.3 %) ($F(2) = 31.105$, $p < 0.01$). This is congruent with experience in the UK (Buksh et al., 2013). There is no significant difference between ERTMS-DS and ERTMS-Only.

3.2 Driver workload - survey

Workload measures were also derived from the survey. Figure 5 shows mean workload in the conditions ATB, ERTMS-DS and ERTMS-Only that was calculated for the responses of 42 drivers. Judgements were made for different sighting conditions.
Overall, workload was judged as (rather) low in all conditions. Workload experienced in driving with ERTMS was significantly lower than with ATB ($F(1.585) = 8.119$, $p < 0.01$). As the figure shows, the difference is caused mainly by the higher workload under ATB with reduced sight. With good sight (at daytime as well as at night) there were no significant differences between the three conditions. Differences between ERTMS-DS and ERTMS-Only and differences between ATB and ERTMS-DS were not significant. Furthermore, experienced workload with reduced sight was significantly higher than with good sight ($F(1.171) = 50.584$, $p < 0.01$). This holds for daytime and night.
Drivers who gave the response ‘moderate’ (3), ‘rather high’ (4) or ‘high’ were asked for a motivation of their answer. Their motivations can be summarized as follows:

- Reduced sight requires higher concentration (3)
- Heavy fog makes looking ahead difficult (1)

- Procedures for ERTMS-DS urge the driver to pay twice the amount of attention (1)
- The driver still feels ill at ease with ERTMS-DS so has to be more alert (2).

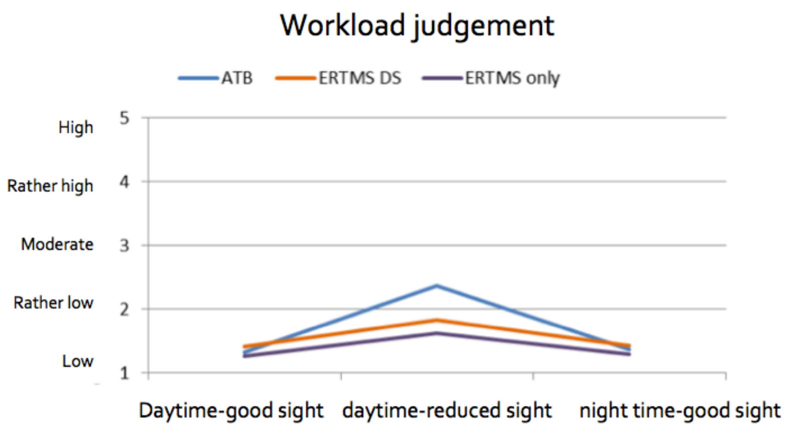

Figure 5. Judgements of mental workload for different sighting conditions.

3.3 Driver workload – workshop

All drivers reported that workload is low in all conditions, if the train service is not disrupted. They say they look at the ERTMS-DMI less often and more outside because they have so much experience. Very experienced drivers on the Betuweroute (ERTMS-Only) even report boredom. It must be noted that the BetuweRoute is a 158.5 km freight-only route, containing no level crossings, only few connections, and many kilometres with sound screens along the route, which makes it low on stimuli.

Small differences between conditions arise when taking an order from the train signaller but this does not influence workload overall. Reversing a train requires somewhat more actions but will not lead to differences.

It is not the signs or planning area that increase the workload, but the transitions. If only ERTMS-L2 is available behind the transition it may increase workload if the transition fails: as opposed to Dual Signalling there is no fall-back to ATB available. Also, one level transition to ATB on the pilot track was located just before a yard, a station, a bridge and a signal. Drivers indicated that there was a lot of information to be processed to obtain full situation awareness.

A RBC malfunction causes more workload for ERTMS-Only than ERTMS-DS because it has to be resolved (no fall-back to ATB). Finally, conflicting commands, as in Dual Signalling where ATB may require an earlier braking or a lower speed than ETCS, e.g. due to a yellow signal aspect, pose higher workload for inexperienced drivers.

3.4 Human error – Simulator

After each run drivers judged the chance of a mistake in reaction to new information (in the cabin or outside) on a scale ranging from 1 (very great) to 7 (very small). The mean judgment for ATB was 6.3, for ERTMS-DS 6.25 en for ERTMS-Only 6.05. The differences are not significant.

In the debriefings they added:

- Switching towards ATB is more error prone (from ERTMS-DS or ERTMS-Only)
- The locations of transition points should be given more consideration
- Workmanship and experience are what matters: transitions should be no problem

- ERTMS is safer: you don't have to work with expectations (that may cause errors) because the screen tells you what is coming up. And width ERTMS you don't have to remember the last signal.

Drivers do not expect a difference for the three conditions in the number of brake interventions (see also table 1).

Judgment of situation awareness on the basis of the SASHA list can be considered to be an indicator of a chance of an error. The mean score (on a scale from 0 to 6) was 4.18 for ATB, 4.33 for ERTMS-DS and 3.92 for ERTMS-Only. See figure 6. This is a significant difference ($F(2) = 3.724$, $p < 0.05$). Situation awareness was higher under ERTMS-DS than under ERTMS-Only ($p=0.021$).

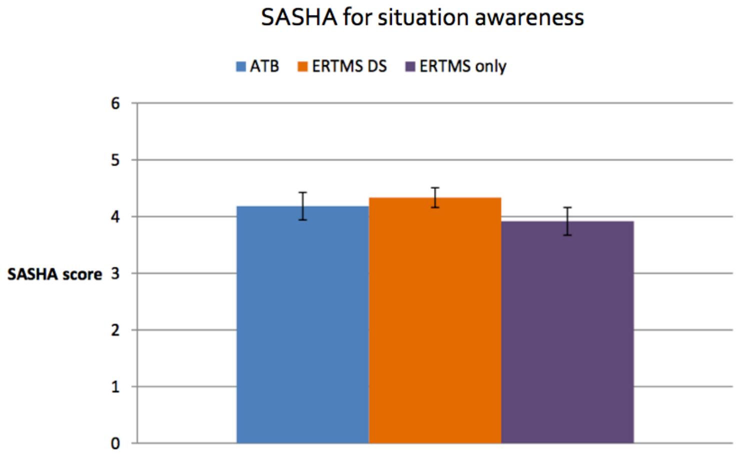

Figure 6. Situation awareness in the three conditions

Awareness of the active train protection system was very high in all three conditions. There are no significant differences. See figure 7.

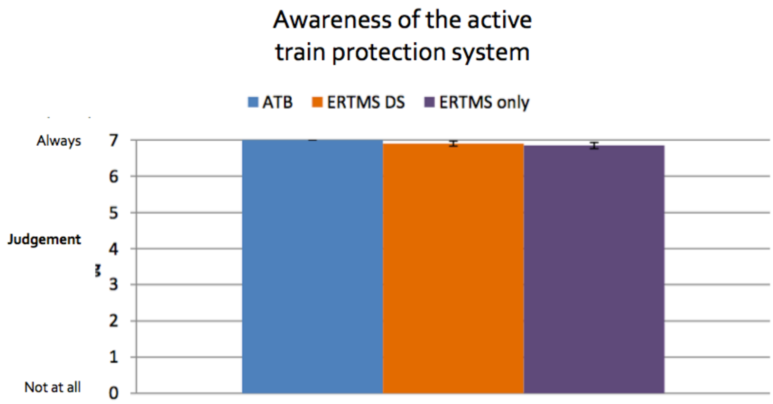

Figure 7. Awareness of the current train protection system

The number of brake interventions during the experiment was analysed as an indicator of error chance. Over all 60 runs (20 times 3) of the experiment there were 6 brake interventions, which is 0.1% of all brake applications. Half of these interventions took place when the driver drove below 40 km/h. The speed was below 40 km/h for a substantial part of the runs because of the events (driving on sight, order passing signal at danger). Table 1 one summarizes the number of brake interventions and the total number of times the brake was applied, for speeds below and above 40 km/h.

Table 1. Brake interventions with and without planning area, per total of brake applications.

Condition	**Above 40 km/h**		**Below 40 km/h**		**Total**	
	Brake interventions	Times brake applied	Brake interventions	Times brake applied	Brake interventions	Times brake applied
ATB	0	178	0	1576	0	1754
ERTMS-DS	2	256	0	1551	2	1807
ERTMS-Only	1	238	3	1947	4	2185

Because of the small number of brake interventions to the total, no statistical analysis was possible. However, to the investigators the number of brake interventions seems rather large. The reason may be the limited experience of the drivers participating in the experiment. They drove a mean of 4.1 runs in ERTMS on the Dual Signalling track in 6 months.

3.5 Human error – Workshop

In the workshops with experienced drivers a few points concerning human error were raised.

In ERTMS Only and ERTMS-DS, a driver can increase the speed as soon as the DMI shows this command. In ATB this is not allowed until the tail of the train passes the corresponding point. A possible error is to increase the speed immediately.
In ATB there is a higher chance of error when the driver receives an order from the train signaller because he has to write as well as perceive the signals while driving. In ERTMS it is probably easier to keep an eye on the DMI. Besides, the driver can see his movement authority and in this way look ahead before he starts writing down the order. This also may reduce human error.
Handling ERTMS malfunctions has a higher chance of error in ERTMS-DS, because drivers in general will have less experience with ERTMS and make errors in awareness of the current train protection, or in their choice of the correct procedure. In the workshop especially balise and RBC malfunctions were supposed to have a higher chance of error:

- Balise malfunction. Consequences depend mainly on the knowledge, training and experience of the driver. Human error will be small for an experienced driver. Resolving the malfunction may take longer for a less experienced driver. This will not influence safety directly but being occupied may increase the chances of approaching a signal at danger.
- RBC malfunction. This is not relevant in ATB. In ERTMS-Only there is no fall-back to ATB, so special activities and procedures may be necessary and this increases chance of error.

4. Discussion

Habituation for longer periods is difficult to study on the basis of the simulator experiment or even the pilot because of the small number of journeys: there was a small chance an ERTMS trained driver meeting an ERTMS train.. A first impression is available because the pilot lasted one year and drivers reported from their daily experience with ERTMS.

It may be possible that in the simulator experiment drivers gave desirable answers on their experienced workload or awareness of the current system, being in the presence of colleagues and experimenters. Actual workload may be higher.

Although the focus in the experiment is on periods of high workload, it should be noted that driving in ERTMS ('DS' or 'Only') may impose a low workload and lead to a low activation of the driver. This is already experienced by drivers on the Betuweroute freight track (with ERTMS-Only L2).
Experience seems to be a crucial factor in handling disturbances that by definition do not occur on a daily basis. There is now a difference in train companies with regard to the number of ERTMS training days as well as rostering. Experience reduces the chance of errors. Although in ERTMS this will not influence safety it can have logistic consequences and impose higher workload for train signallers.
Transitions are an important source for malfunctions or a higher workload. Switching from ERTMS to ATB requires the awareness that the driver has more responsibility. However, in this experiment train drivers are constantly aware of the system that is operational. In ERTMS-Only there is no fall-back to ATB and so the experience of the driver is essential in dealing with a malfunction. And the possibility of errors and malfunctions at a transition indicates that the location of a transition should be given consideration so they are not near other items that require attention.

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