ERTMS roll out from a train driver's perspective

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Abstract. The train driver's job in The Netherlands will change significantly during the next 10 years: most importantly by the deployment of ERTMS Level 2, but also by other technological developments. The Dutch ERTMS Program commissioned a study into the impact of these changes on train driver's workload, competences, required experience, and operational consequences of a 'patchwork' or 'inkblot' ERTMS roll out strategy. The study is based on existing knowledge and experience, interviews and workshops, and a survey amongst train drivers.

Keywords. ERTMS, workload, proficiency, strategy

1. Introduction

In The Netherlands ERTMS (European Railway Traffic Management System) Level 2 will be implemented on main rail corridors to replace the legacy ATB (Automatische TreinBeïnvloeding) automatic train protection system. In Figure 1 it is shown which lines will be operational with ERTMS Level 2 only (i.e. without lineside signals) between 2024 and 2028.

Figure 1. Planned ERTMS roll out in The Netherlands from 2024-2028 (translated from: www.ertms-nl.nl, Retrieved August 16, 2017)

Together with existing ERTMS lines – HSL-South (Level 2 only) and freight routes Betuweroute (Level 2 only) and Havenspoorlijn (Level 1), as well as Dual Signalling lines Amsterdam-Utrecht and Hanzelijn (both ERTMS Level 2 and ATB with lineside signals) – this leads to a major part of the Dutch rail infrastructure being equipped with ERTMS. As part of the deployment strategy it was already decided to provide all rolling stock concerned with the necessary equipment first (till 2022) before changing the infrastructure line-by-line.
The Dutch ERTMS Program recognized that introduction of ERTMS on such a large scale may have an impact on train drivers and train operation, which was also a lesson from a 1.5 years pilot with ERTMS on the Dual Signalling track Amsterdam-Utrecht (ERTMS-pilot, 2015). Furthermore, it was acknowledged that recent and forthcoming introduction of new rolling stock and innovative devices/apps for train drivers will also appeal to changes in the driver's task. This led the ERTMS Program to formulate the following research questions:

1. What is the impact of ERTMS and other innovations on the workload of drivers?
2. Will the required competences of drivers change (and if so, how)?
3. How many hours should a driver service on ERTMS sections to become and remain competent?
4. Are there - from an operational perspective - needs towards ERTMS roll out through a 'patchwork' or 'inkblot' strategy? An 'inkblot' strategy is characterized by expanding ERTMS from one starting track towards adjacent areas. In a 'patchwork' strategy ERTMS is rolled out more scattered across the network, e.g. based on technical urgency.

These research questions were to be answered on the basis of existing knowledge and experience from The Netherlands and abroad. This paper focuses on the aspects that have the greatest relation with the roll out strategy: research questions 1, 3, and 4.

2. Methods

Different methods were used to obtain information from as many perspectives as possible.

2.1 Literature

A short literature search was performed with keywords ERTMS, human factors, workload, competences on Pubmed, RSSB/Spark, and in the Proceedings of the Rail Human Conference 2013 and 2015.

2.2 ERTMS-pilot

Results from research done during the ERTMS pilot on the Amsterdam-Utrecht track in 2014/2015 (ERTMS-pilot, 2015; Van der Weide et al., 2017) were reevaluated in sight of the current research questions. This research consisted of simulator studies (ATB vs ERTMS L2 only vs ERTMS L2 in Dual Signalling), data from actual service, workshops etcetera.

2.3 Interviews and workshops

Interviews were conducted with experts on ERTMS deployment, psychological assessment of (aspirant) train drivers, managers of a high-speed train operator experienced with ERTMS, experts on innovative technologies (to be) introduced in the train cab, an air traffic training expert, and experts in rostering (services, training, etc.). Four workshops were held with 5 ERTMS experienced train drivers (freight and passengers), 7 safety officers, 5 rolling stock specialists and 5 train driver’s professional development specialists respectively.

2.4 Survey

In the last years, several groups of train drivers have been trained for driving in ERTMS. Some of these drivers regularly drive in ERTMS (freight, work and high-speed trains), while others never drove in ERTMS again after the pilot on the Amsterdam-Utrecht track had finished. All these drivers have been assigned a (digital) questionnaire; 139 unique responses were used for analysis. Age distribution was <35yr, n=11; 35-44yr, n=37; 45-54yr, n=64 ; ≥55yr, n=27. Train driver experience was 0-5yr, n=24; 5-15yr, n=42; 15-25yr, n=40; >25yr, n=33. Their last experience with driving in ERTMS was for the majority in the last month (n=97); for another 22 drivers this was during the last 6 month; for the remaining drivers this was over 6 months (n=4) or even over a year before (n=16). All questionnaires were treated anonymously. In this questionnaire, among other things, drivers were asked about their perceived proficiency, confidence, and safety when driving in ERTMS and ATB. Thus, we were for instance able to calculate changes in them as a function of time since the last ERTMS run.

3. Results

In the next 3 subparagraphs results regarding train driver workload, training, and experience are presented. For legibility reasons results are discussed immediately in these subparagraphs. Consequences related to the roll out strategy are discussed in paragraphs 4, as well as general conclusions drawn from the results.

3.1 Workload

In Table 1 the aggregated results for the expected effect of ERTMS Level 2 on driver workload is presented. Note that the main source of information when driving in ERTMS Level 2 only is presented to the driver on the Driver Machine Interface (DMI) of ETCS, the train control part of ERTMS. The visual focus of the train driver will thus shift from primarily looking outside (lineside signs and signals, braking points, etc.) to more inside directed at the DMI ETCS (Naghiyev et al., 2014; Van der Weide et al., 2017). Apart from information about the current situation (speed, braking curve) it also presents the driver with a form of electronic sight on the planning area. Up to 32 km ahead the driver can see his movement authority, speed profile, and other route specific objects (depending on national regulations and specific implementation). The DMI ETCS was developed to guide attention of the driver to the information and/or action required (Metzger & Vorderegger, 2012).

From Table 1 it is clear that preparation of a journey is somewhat more time consuming in ERTMS. Data entry may be error prone, which is exacerbated by the fact that the data entry procedure is mostly manual and differs from supplier to supplier. Entry of a faulty braking percentage can be dangerous because ETCS may present a wrong braking curve.

For the net ‘train driving’ task – which forms the longest task of a train driver - the processing of information is supported by the ETCS system to a much greater extent than ATB does. ETCS - other than ATB - continuously checks and, if necessary, supports the driver to meet a required speed reduction at a certain location. The location and time at which the driver has to brake is clearly announced by the DMI ETCS, and the braking action itself is monitored continuously. A driver's error in this task is always corrected by ETCS: by a warning first, and eventually by an emergency brake when the driver does not react adequately. As a result, the driver's workload in ERTMS (running in the regular mode Full Supervision) is lower compared to ATB. This was also the result of workshops with drivers in the current study and during the pilot, and substantiated by results of simulator studies during the pilot (ERTMS-pilot, 2015; Van der Weide et al., 2017). Drivers mentioned in these occasions that it is even a challenge to stay alert on some routes that do not require many speed changes and are low on external stimuli, as is the case with Betuweroute and HSL-South. The issue of mental underload is also reported by Buksh et al. (2013) as a risk in the UK. Nevertheless, because ERTMS has a high level of safety, driving will not be unsafe in these circumstances.

Table 1. Indication of the effect of ERTMS Level 2 en DMI ETCS on train driver workload and human error ("+" means extra workload/chance of error; "-" indicates less workload/chance of error due to ERTMS); "0" is no significant difference expected; n.a. = not applicable)

Tasks	Current situation ATB-EG	Future situation ERTMS L2 with DMI ETCS	Indication of the effect of ERTMS on workload and human error
Preparation (start of mission)			
• personnel number	via GSM-R	via DMI ETCS	0
• train number	via GSM-R	via DMI ETCS	0
• train protection level/mode	n.a.	via DMI ETCS	+ extra action
• train data (brake, length)	n.a.	via DMI ETCS	+ extra action, error prone
Train driving			
• perception of signalling	Lineside signals (supported by cab signalling)	DMI ETCS	0 differs only in focus (outside versus inside) - actively "searching" for signals (route knowledge) becomes less demanding
• react to signal aspects	Timely and sufficiently braking based on craftsmanship	Timely and sufficiently braking supported by DMI ETCS	- DMI guides braking
• sight on track ahead	Set route is deducted from the last lineside signal(s) aspect; there may be sight on the next lineside signal	Movement authority (MA) visible via electronic sight in planning area on DMI, up to 32 km ahead	- better situation awareness
• shunting, driving on sight, etc.	Speed restricted, unprotected	Speed restricted, no planning in modes like SH, SR, NL	0 comparable
Special situations			
• level transition	n.a.	Acknowledgement	+ extra action with the purpose of raising situation awareness
• temporary speed restriction (TSR)	Via lineside signals, not always protected	Part of protection (MA) if entered/transmitted via RBC	- / 0 comparable but safer
• failure infrastructure incl. procedures to enable to proceed	Signal failure	Loss of contact with RBC Balise failure	+ extra actions (assuming harmonized procedures for all lines) ++ extra actions and error prone when procedures are dependent on location (line)

From Sweden it is known that a "retrofit" line - in which ERTMS has replaced the existing lineside signaling retaining the exact speed profile - can lead to a higher workload of the train driver. This seems to be caused by a route with many changes in permitted speed at a short distance. The DMI ETCS then gives many announcements and the planning area shows sometimes confusing information (Kecklund & Nordlöf, 2015). The Swedish authors argue for driveability analysis before (retro)fitting a line with ERTMS. In The Netherlands the lines equipped with ERTMS do not have complex speed profiles or level crossings, which may explain the contradictory findings.

For the deployment of ERTMS attention is needed for special situations, like level transitions (e.g. the transition between ERTMS Level 2 and Level STM ATB) and technical failures. Transitions between ERTMS and the legacy ATB occur when part of the tracks in the Netherlands are provided with ERTMS Level 2. Such a level transition is announced to the driver on the DMI ETCS and the driver must timely acknowledge the transition by pushing a button to prevent a brake intervention of the ETCS system. This requires an extra action of the operator, which in this case is considered as simple and not stressful, as confirmed in the workshops with drivers. The questionnaire included the question "Indicate how much effort it takes to alternate between driving in ATB and ERTMS within a duty on one day". The answer shows that this alternation is experienced by 89% of drivers as taking no (65%) to a little (24%) effort (see Figure 2). As reasons for perceived effort were mentioned (n=139; multiple answers were possible): Mentally switch to another system (18%), Various regulations (13%), Location of the transitions (12%), Making (executing) the transitions themselves (8%).

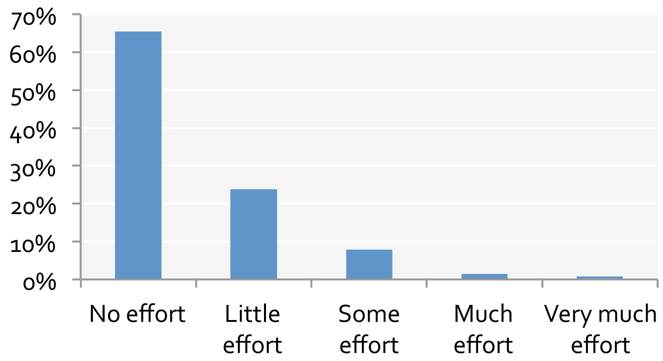

Figure 2. Perceived effort to alternate between ATB and ERTMS within a duty on a day (n=139)

The DMI will change due to the level transition (see Figure 3). The display shows clear differences between both situations, so it is easy to see in which system one drives. As a result, the likelihood of errors caused by an insufficient driver's awareness of the active system, is judged negligible by experts and train drivers.

Much more important than the change on the DMI ETCS before and after a level transition is the driver's need to shift focus of attention from the inside to the outside or vice versa, to be aware of the change in system and protection level, and the degree to which the driver is supported in reacting to signals / speed commands (Naghiyev et al., 2014). With a transition from ATB to ERTMS, as soon as the driver has acknowledged the transition, the DMI ETCS provides a lot of information that will allow the driver to quickly build an up-to-date image of the route situation (situational awareness). Around the transition from ERTMS to ATB, the driver must build an up-to-date image of the situation by looking outward. He must observe signs and signals, determine the position of the train relative to stations or other key points, check for track workers, etc. The mental image of the route situation - that the driver usually develops and updates while driving - must now be created in short time, because the driver loses some of the information that was presented on the DMI ETCS after the transition, so he needs to obtain comparable information from the outside world.

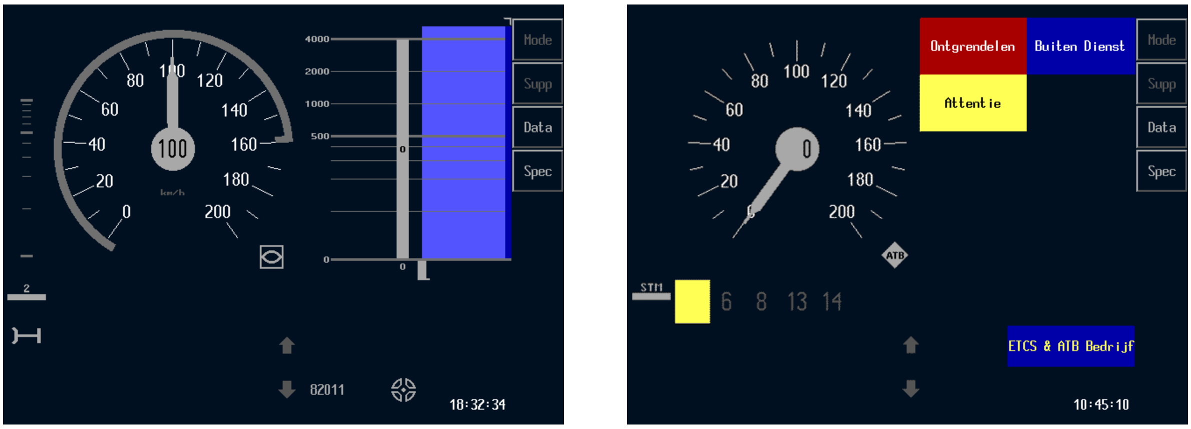

Figure 3. DMI ETCS in SLT trains during ERTMS pilot. Left: ETCS level 2. Right: STM ATB.

The more complicated the infrastructural situation around the transition point, the more demanding this task becomes. During workshops and during the ERTMS pilot Amsterdam - Utrecht (ERTMS-pilot, 2015) drivers mentioned a number of transitions that they considered as challenging. For example, a level transition on a slope is very burdensome for a freight train driver, when accompanied by a low speed or speed limitation. During the ERTMS pilot Amsterdam-Utrecht (ERTMS-pilot, 2015), some drivers noted that extra effort is needed in a transition from ERTMS to ATB if a braking curve is currently active. In that case, the DMI ETCS may not yet demand for a braking action, but ATB requires the driver to brake directly after the transition e.g. because of a yellow signal aspect. The driver then may need to choose a brake mode *before* the transition to meet the ATB brake criterion after the transition.

In the current situation with ATB, technical failures include signal failures and ATB malfunctions. Similar failures in the future ERTMS situation are loss of contact with the RBC (radio block center), balise failures and malfunctions of the ETCS onboard equipment. Technical failures increase mental workload. Correcting malfunctions requires following procedures, the so-called user processes. Because these malfunctions rarely occur, these procedures are not performed on a regular basis and the operator's experience is limited. From the workshops and the pilot (ERTMS-pilot, 2015) it became clear that the handling of ERTMS failures generally requires more operations by the driver compared to ATB. The procedures in ERTMS may, due to regulations, differ from ATB tracks. In addition, the current ERTMS tracks in the Netherlands (HSL-South, Hanzelijn, Betuweroute) have different user processes. During the workshops drivers mentioned this as being confusing, which means that it may take more time to solve problems. It is therefore recommended to harmonize procedures and regulations.

Related to the introduction of new rolling stock some lessons can be learnt from recent introductions:

- New Traxx locomotives for service in passenger trains on HSL-South led to bad performance on mainly the ERTMS part of the route. During workshops some drivers blamed ERTMS for this; however, this could not explain differences with performance of Thalys on the same track. It appears that simultaneous learning of new rolling stock and a new train protection system may impose a too high demand on train drivers.
- From the ERTMS-pilot (2015) it became clear that layout of the DMI ETCS and design

of the Start of Mission procedure should be harmonized. Although it was concluded that the differences in layout between suppliers are not safety critical and many of them will disappear when baseline 3 of the DMI specifications is adopted, the need for standardization of especially the STM ATB mode of the DMI and of the Start of Mission procedure remains evident.

The partly parallel introduction of ERTMS and other innovative devices/apps may have divergent effects. Details about new devices/apps in Dutch train cabs and their relation with the current ATB system can be found in another paper (Verstappen et al., 2017), but in respect to ERTMS the following was found:

- Some innovations are directed at improving safety in ATB (ORBIT; Van der Weide et al., 2016): these should not interfere with the higher level of safety provided by ERTMS because this may lead to confusion and thus impact trust in both systems.
- Other innovations provide information not present in ERTMS like timetable information, traffic situation (other trains ahead, behind, crossing), and energy efficiency. This information is appreciated, but during workshops drivers and experts were divided or inconclusive about possible interference with ERTMS information. For instance, the app presenting route information (RouteLint) also gives insight into the set route, which basically mirrors the movement authority presented on the planning area of the DMI ETCS while driving in ERTMS, but with a lower degree of reliability. Further study should be done into added value and risks of the use of this app in ERTMS. The same holds for an app directed at driving on time and energy efficiency: in its current state of development no speed is advised, but in the future it could function as a true driver advisory system with speed advise. A risk analysis should give insight into the chance and effect of contradictory information, i.e. a recommended speed that is higher than permitted speed according to ERTMS.

3.2 Training

During roll out of ERTMS an increasing amount of train drivers will be needed with ERTMS certification (basic training) and proficiency (basic experience). From workshops and interviews with drivers and experts a consensus appeared that drivers after basic ERTMS training should drive for a period of six months, three times a week, to become truly proficient for ERTMS. A quantitative substantiation for this ‘rule of thumb’ was not found. Also, it has not become clear which requirements have to be set for these ERTMS runs: simulators may be an efficient way for gaining proficiency in infrequent tasks. Assessment of the quality of ERTMS training was not within the scope of this study.

3.3 Retaining proficiency, confidence, and safety

Depending on the roll out strategy the number and location of trained ERTMS drivers will vary, but also the aspect of keeping these drivers experienced needs attention. Due to agreements between employers and employees Dutch train drivers are entitled to a certain number of unique track kilometers. During early stages of ERTMS roll out it therefore may become a challenge to develop work schedules with a certain minimum amount of ERTMS track included. To get an insight into the required experience, drivers were asked in the questionnaire to self-assess their proficiency, confidence, and safety (on a scale 1-10) during their last run in ERTMS Level 2 and if they were to drive in ERTMS at the time they filled in the questionnaire. By dividing these two ratings, and plotting them against the numbers of days since each driver's last run in ERTMS, time dependency of self-assessed proficiency, confidence, and safety were investigated. The results show that all these aspects decrease as time passes. This decrease is slightly sharper in perceived proficiency and safety than with perceived confidence (see Figure 4). Table 2 shows the calculated time in which these scores have decreased to 95%, 90%, 85%, and 80% (last run in ERTMS = 100%) respectively. No significant differences between age groups were present in these outcomes. This could however be caused by the small numbers in each age group. Also, the skewed distribution of time since last run in ERTMS – with the majority having very recent experiences – may have influenced the reliability of these results.

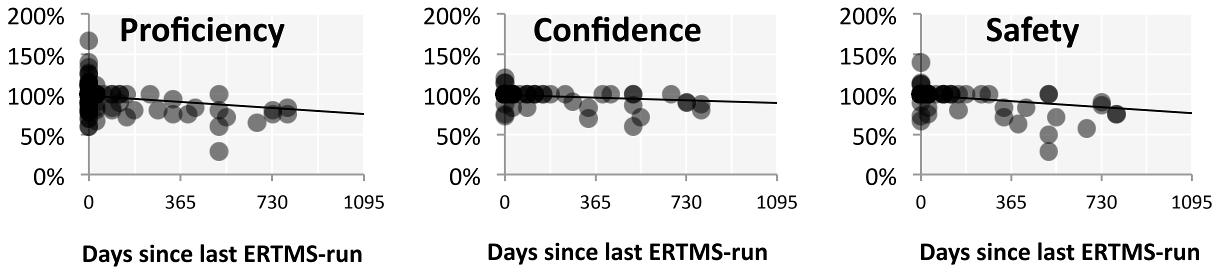

Figure 4. Self-assessed proficiency, safety, and confidence in driving in ERTMS as a function of time since the last run in ERTMS (last run=100%; n=139; every dot is 1 respondent).

Table 2. Average decrease of self-assessed proficiency, safety, and confidence in driving in ERTMS as a function of time since the last run in ERTMS (last run=100%; n=139).

Remaining scores (calculated)	Proficiency	Confidence	Safety
95% remaining	0.4 year	1.2 year	0.5 year
90% remaining	1.1 year	2.7 year	1.2 year
85% remaining	1.8 year	4.3 year	1.9 year
80% remaining	2.5 year	5.8 year	2.6 year

Legal requirements are that train drivers should at least drive on a certain route once every year to retain their route knowledge. From the results in Table 2 it shows that on average drivers feel 10% less safe and proficient if this minimum exposure would be applied. During workshops with drivers and experts consensus was reached that driving on an ERTMS track once a year would be too infrequent. A minimum frequency of once every 6 months (corresponding to maximum 5% decrease in perceived proficiency, confidence, and safety) was considered to be acceptable according to the participants. This would also comply with current practice on HSL-South where a one-day retraining session is offered when a driver has not been driving there for 6 months. Other than these questionnaire results no substantiation for this 'standard' has been found: as it has great impact on rostering, costs for training, and potentially performance further research is recommended.

4. Discussion and Conclusion

Results of this study are based on existing knowledge, workshops and interviews (opinions, experience, and consensus), and a questionnaire (self-assessment, memory). On some points a need for quantitative data is identified – e.g. exact required ERTMS training and experience - but for others most results point in the same direction. When the results of this study are plotted against the two roll out strategies 'inkblot' and 'patchwork' the following can be concluded:

- The study shows that ERTMS driving – as currently deployed in The Netherlands – is generally less demanding than the legacy ATB. However, there is a potential peak load at level transitions between ERTMS and ATB sections when located at an unfavorable position. Also, sources of error are identified by differences in regulation amongst ERTMS sections and by differences in information presentation and data entry by the driver machine interface (DMI). Furthermore, the study shows that some other innovations are complementary to ERTMS, whilst others are highly undesirable in combination with ERTMS because contradictory information from a lower safety level may be presented.
- Regardless of the roll out strategy chosen, when station yards are not (partly) equipped with ERTMS, drivers will often be faced with level transitions ATB <> ERTMS. Therefore, from a workload perspective an inkblot strategy is less demanding than a patchwork strategy only when there are *actually* fewer transitions. Also, it is easier for train drivers to maintain a mental picture of areas where ERTMS is deployed with an inkblot strategy. With each roll out strategy, the location of each level transition must be evaluated with drivers (of different rolling stock), and the user processes must be harmonized. This also applies to existing ERTMS tracks.
- An inkblot strategy may involve a more gradual training of the driver's workforce, because of a more clustered implementation. In a patchwork strategy quite soon during roll out (nearly) all drivers may encounter an ERTMS track, thus requiring a large training capacity. This only applies for large nation-wide (passenger) train companies, because most freight and work train companies already trained their drivers to be able to use the current ERTMS routes, and small passenger train operators are not using tracks that will be ERTMS equipped. Furthermore, it is expected that train service will be more robust in an inkblot strategy: by training all drivers in/around the inkblot a local pool of ERTMS drivers is available when disruptions occur, and drivers gain experience with ERTMS more often. It was shown in this study that not driving in ERTMS for more than 6 months has a negative effect on perceived proficiency, confidence, and safety. A consequence of this may be that drivers (temporarily) are designated to duties in/around the inkblot and thus encounter less variation in routes.

In summary, from an operational perspective, there is a slight preference for an 'inkblot' roll out strategy. This preference is based on a number of advantages of this model: (1) there is a clearer mental picture for the driver; his situation awareness is thus simplified, (2) it puts less burden on training capacity, because the training can take place more gradually, and (3) it appears more robust to disturbances because trained staff is present in and around the 'inkblot'. For most smaller train operating companies only to the first argument applies: for them the preference for an 'inkblot' strategy is less prominent.

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