ERTMS in Holland: Overview of human factors issues in a pilot with dual signalling

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Abstract
This paper gives an overview of the human factors research performed in the pilot with ERTMS (European Railway Traffic Management System) in commercial train service in Holland between March 2014 and June 2015. Main goal of this pilot, commissioned by the Ministry of Transport in Holland, was to gain experience with ERTMS in commercial train service as input for the overall implementation strategy for ERTMS in Holland. The pilot was evaluated with about 140 research items. About 20 items were related to human factors, for train drivers as well as train dispatchers and operational management (traffic management, maintenance management infrastructure and maintenance management train). Research concerned three different conditions: conventional (line side signals and conventional train protection system), Dual Signalling (line side signals, conventional train protection system, ERTMS), and ERTMS-only (only ERTMS in place). Research is performed by a simulator experiment with train drivers, workshops, data-analysis, questionnaires, observations and expert opinion. Results showed that train drivers and dispatchers are able to work with ERTMS and its accompanying procedures, but in situations with failure of the train protection system, it is not convenient that handling of a failure differs per train type or per track. Driving behaviour of train drivers with ETCS (European Train Control System), both in Dual Signalling and in ERTMS-only condition, differs from the conventional driving behaviour, but there are no indications for unsafe driving behaviour, although research performed is not very extensive. Workload of train drivers is higher when passing a transition point of different automatic train protection systems. Probability of human error by train drivers is higher in situations with failure of the train protection system and in special train processes, when ERTMS can be more complex than conventional systems. There are differences in ETCS-DMI’s (DMI, Driver Machine Interface), despite of the ETCS standards, but there are no indications that these differences cause significant increase in workload or higher probability of human error. Workload of train dispatchers is higher in ERTMS-only conditions, compared to Dual Signalling or conventional train protection system. Probability of human error of train dispatchers depends on characteristics of infrastructure systems, including the train protection system. In maintenance processes workload is higher in a Dual Signalling condition, compared to ERTMS-only or conventional systems.

Introduction
In 2014 the Ministry of Transport formulated a strategy for implementation of ERTMS (European Railway Traffic Management System) in Holland. Prior to decision-making a pilot with ERTMS in commercial train service was performed on the track between the cities of Amsterdam and Utrecht. 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 (in Holland: ATB, Automatische Trein Beïnvloeding) and with ETCS level 2 (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 ETS train protection system. Another aspect was the difference in speed limits: ATB 140 km/h and ETCS 160 km/h. When driving with ETCS train drivers weren’t allowed to ignore the line side signals at danger (red aspect). Main goal of the pilot was to gain experience with ERTMS in commercial train service as input for the overall strategy for implementation of ERTMS in Holland. Based on this strategy and learning experience in the pilot, railway undertakings and infrastructure manager will be able to determine how to incorporate ERTMS in their own processes. Strategy and learning experience in the pilot will have an important influence on procurement of the technical implementation of ERTMS in trains and rail infrastructure [1].

Human factors research items
The pilot was evaluated with about 140 research items. About 20 items were related to human factors, for train drivers as well as train dispatchers and operational management (traffic management, maintenance management infrastructure and maintenance management rolling stock). Human factors research items were for example:
• The impact of the DMI (Driver Machine Interface) on driving a train, workload, human error and situation awareness during the transition between Automatic Train Protection systems (ATP systems).
• The impact of the DMI on driving a train, workload, human error and situation awareness during the transition between ATP systems.
• Differences in DMI’s in the train types involved in the pilot, and estimation of what impact these differences will have on driving a train and on train drivers.
• For train dispatchers the questions involved the change in workload and human error in the different conditions.
• The research questions for operational management also discussed the change in workload and human error in different conditions.
• For train drivers, train dispatchers and operational management special attention was paid to the influence of failure of conventional or ETCS equipment on workload and human error.

All human factors items had to be researched for three different conditions: conventional (line side signals and conventional train protection system, so called ATB-only), Dual Signalling (DS) (Dual Signalling is a combination of line side signals, conventional train protection system and ERTMS), ERTMS-only (only ERTMS in place).

Intergo, together with research partners, was appointed to answer these human factors research items.

**Train drivers**

**Approach**

To answer the research questions related to train drivers a simulator experiment was conducted, in which the different conditions were simulated: conventional (ATB only) versus Dual Signalling versus ERTMS-only. 60 Train drivers participated in the experiment and each train driver performed 8 runs. Eye tracking data was collected during the runs and after each run the train drivers filled out a questionnaire. Experience of train drivers in daily practice with Dual Signalling and ERTMS-only was explored with questionnaires and in several workshops. Not all research items could be simulated in a valid way, so triangulation of 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 [3]. The Driver Machine Interfaces (DMI’s) of the trains involved in the pilot are assessed by expert opinion together with interviews with train divers [4].

**Driving behaviour and situation awareness of a train driver**

In the simulator experiment driving behaviour of train drivers in the conventional system and driving behaviour with Dual Signalling ERTMS with planning area (ERTMS DS+) and without planning area (ERTMS DS-), has been subject of research. When driving with the conventional train protection system together with line side signals, train drivers brake less (Figure 1) and coast more compared to driving with Dual Signalling ERTMS with or without planning area) [2], so in the conventional condition, train drivers drove more anticipating than in other conditions. The experiment also showed that when driving with the planning area of ERTMS the percentage of time train drivers increased speed was less than driving without planning area [2].

![Figure 1: Percentage of time braking](image)

Results of the experiments were surprisingly different than expected. Goal of the planning area of ERTMS is to gain better situation awareness, and therefore being able to drive a train in a more anticipating way, compared to driving without any planning area, like in the conventional condition. To gain better situation awareness using the planning area, first train drivers have to look at the planning area. Results of eye tracking during the simulator experiment showed that train drivers really were looking at the area on the driver desk showing the planning area of ERTMS [2]. Train drivers also reported a better situation awareness for the condition of ERTMS with planning area, compared to ERTMS without planning area and the condition of conventional systems (Figure 2, [2]). Possible reasons for not showing an anticipating driving behaviour using the planning area of ERTMS can be the limited experience of train drivers.
drivers driving with ERTMS or characteristics of the track and train service between Amsterdam and Utrecht. Another explanation can be that the way the braking curve is presented in the ERTMS-DMI doesn’t support an anticipating way of driving. Further research on this can possibly clarify the obtained results of the experiments performed.

![Situation awareness (SASHA)](image)

**Figure 2:** Situation awareness conventional (ATB), Dual Signalling ERTMS with (DS+) and without planning area (DS-)

### Evaluation of the ETCS-Driver Machine Interface

A questionnaire was distributed under train drivers participating in the simulator experiment about the added value of the ERTMS-DMI. Train drivers reported most frequently that the ERTMS-DMI supports them in energy efficient driving [8]. Results of the questionnaire distributed under train drivers in commercial train service during the pilot showed comparable results about added value of the ERTMS-DMI [2]. Surprisingly energy efficient driving, less often increasing speed and less braking, was not confirmed in the simulator experiment.

Despite of the standards about the Driver Machine Interface (DMI) of ETCS, we found several differences in details of the DMI’s of ETCS in the train types involved in the pilot. The differences found are such that there is no indication for uncertainties or mistakes in control of the DMI when a train driver alternately drives with different train types provided with ETCS [4, 13]. Differences in ETCS-DMI’s can cause some slight increase in mental workload [13]. But differences in cabin characteristics and differences in interfaces of systems other than ETCS will have more impact on the train driver than differences in the ETCS-DMI [13].

### Habituation of a train driver to the active train protection system

When driving on a track with different train protection systems, like in a Dual Signalling condition, it is crucial that a train driver is aware which train protection system is active at that moment and that his driving behaviour fits the characteristics of that train protection system. Research on this topic is performed in the simulator experiment [3, 10], by use of a questionnaire for train drivers in commercial train service during the pilot and in workshops, and by the use of data about train speeds during commercial service of the pilot [3, 11]. Most train drivers, as well in commercial train service as in the simulator experiment, report that they are always aware which train protection system is active at that moment [10]. According to train drivers there are enough indications in the cabin and in the infrastructure of the track, which point out which train protection system is active at that moment. Nevertheless 10% to 18% of all train drivers report that during a short period of time it is possible to make a mistake in the awareness about the train protection system active at that moment [10]. Correct driving behaviour related to awareness about the train protection system active at that moment is evaluated in the simulator experiment, by workshops and data-analysis [3, 11]. It can be concluded that there are barely objective indications for changes in driving behaviour due to habituation to driving in a Dual Signalling condition compared to driving in the conventional condition (only conventional systems) [3]. In the simulator experiment and in the commercial train service train drivers showed a more careful driving behaviour in situations with a speed restriction when driving with conventional systems after driving with ERTMS in the Dual Signalling condition. However the research as performed is limited, because habituation in daily practice is a long-term effect [11]. During the pilot there were too little possibilities to monitor this effect with the required detail and the required amount of train drivers.

### Workload and human error of a train driver

Differences in workload and human error of a train driver when alternately driving with different train protection systems is evaluated in the simulator experiment together with workshops, a questionnaire and special experiments in commercial train service [9]. When alternately driving with different train protection systems (Dual Signalling condition), workload of train drivers increases a little compared to driving with only the conventional systems. Workload in the condition of ERTMS-only is higher than in other conditions ([Figure 3](image), left graph, [9]), but this possibly can be clarified by the fact that train drivers participating in the experiment had very little experience with driving in an ERTMS-only condition. There were no statistical differences in workload in special events like authorisation of passing a signal at danger or authorisation for driving on sight ([Figure 3](image), right graph, [9]). Transition between train protection systems caused an increase of workload, especially when these transitions come together with other
demanding events like entering a track yard or a station [9]. Based on the simulator experiment it can be concluded that there is a slightly increased chance on human error, when driving alternately with different train protection systems [9]. Most probable is when a train drivers thinks he is driving with ERTMS, but is really driving with the conventional train protection system. In most situations this mistake will lead to a full brake (based on the characteristics of the conventional train protection system in Holland), initiated by the train protection system. Probability of human error by train drivers is somewhat higher in situations with failure of train protection system equipment and in special train processes, when ERTMS can be more complex than conventional systems.

![Figure 3: Workload of train drivers when driving conventional (ATB), Dual Signalling (ERTMS DS) and ERTMS-only [9]](image)

**Train dispatchers**

**Approach**

For train dispatchers first a task analysis was made based on the documents about special so called user processes related to conventional condition, Dual Signalling and ERTMS-only, regulation and handbooks for train dispatchers [5]. Multiple workshops with train dispatchers were organised. Goal of these workshops was to explore the influence of Dual Signalling on daily task performance. In this exploration daily practice with conventional train protection system with conventional line side signals was compared with daily practice with Dual Signalling. Workshops covered normal train service, disturbed train service due to deviation in driving schedules and disrupted train service due to failure of train equipment (conventional or ERTMS) and failure of infrastructure equipment (conventional line side signals or ERTMS). Also a comparison of formal user processes and regulation and daily practice was made in these workshops. For all research conditions observations of the work of train dispatchers were performed. Observations of Dual Signalling took place for the track Amsterdam-Utrecht. Observations of ERTMS-only took place for the high-speed line HSL-South between Amsterdam and the Belgian border. Workload was calculated for the different research conditions by using the TaskWeighing™ instrument (TaskWeighing™ calculates the workload of train dispatchers, based on objective criteria and computer loggings of real time train dispatching during the pilot [6]). Human error in train dispatching was assessed by expert opinion and in workshops and observations.

**Differences in task performance of train dispatchers**

Train dispatching tasks are influenced by the train protection system of trains in different ways. During the pilot, train dispatchers were not able to recognize which train protection system was active for which trains on the track. In case of failure of the train protection system without major logistic impact, communication between train dispatchers and train drivers will be tuned to the train protection system active at that moment. In practice processes defined for the pilot for a situation with failure of the conventional system appeared to be more extensive than for a situation with failure of the ETCS-system. Knowledge about the train protection system, available at as well the train dispatcher as the train driver, is important for the amount of communication and quality of communication between train dispatcher and train driver [5]: during the pilot especially train dispatchers had less knowledge about the ETCS-systems compared to knowledge about the conventional system.

In case of failure of the train protection system with major logistic impact, there are less recognizable differences in train dispatching tasks to be performed and the way these tasks are performed, depending on the train protection system involved [5]. Most important differences arise due to differences in frequency of occurrence of failure of a train protection system with major logistic impact.

The maxim speed of a train can be dependent on the train protection system. In Holland during the pilot a train with ERTMS was allowed to drive with a maximum speed of 160 km/h, with conventional train protection system the maximum speed was 140 km/h. But the plan for train service was based on the maximum speed for conventional system. So there was no need for train dispatchers to act because of less homogeneity in speeds of trains on the track involved in the pilot.

**Workload and human error of a train dispatcher**

Differences in workload of train dispatchers due to differences between conventional systems and ERTMS-systems depend on the logistic impact of a failure in the train protection system, which is active at that moment. Therefore the
frequency of failure of both conventional train protection system and ERTMS has been analyzed. This analysis showed that frequency of occurrence of failure of any type of train protection system without major logistic impact (disturbance) is that low that there will not be any difference in workload [5]. But in the condition of Dual Signalling the chance on major logistic impact in case of failure of ERTMS is less than in the condition with only conventional systems or the ERTMS-only condition, because train drivers have the ability to switch quickly from ERTMS to conventional train protection system. So workload of a train dispatcher in Dual Signalling condition will be less than in other conditions.

Workload of a train dispatcher in case of failure of the train protection system that causes major logistic impact will be higher in the ERTMS-only condition compared to the Dual Signalling condition or the condition with conventional systems [5]. In case of a failure of the conventional train protection system in Holland a train driver is allowed to drive with limited speed, thus limiting logistic impact. In case of a failure in the ERTMS system in the condition of ERTMS-only, this is technically impossible, creating longer lasting logistic impact on train service.

Figure 4 shows results of qualitative comparison of all distinguished conditions.

<table>
<thead>
<tr>
<th>Workload train dispatcher</th>
<th>ATB-only (conventional)</th>
<th>Dual Signalling (ERTMS-only)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure without disturbance</td>
<td>-</td>
<td>Less than ATB-only (conventional)</td>
</tr>
<tr>
<td>Failure with disturbance</td>
<td>-</td>
<td>Equal to ATB-only (conventional)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Higher than ATB-only* (conventional)</td>
</tr>
</tbody>
</table>

*- ERTMS-only: no fall back, bigger chance on greater impact on train service
- Dual Signalling: fall back to ATB
- ATB-only/conventional: allowed to drive with limited speed

Figure 4: Workload of train dispatchers conventional (ATB-only), Dual Signalling and ERTMS-only [5]

In workshops with train dispatchers so called safety critical activities are assessed on possible differences in (the chance) on human error related to the train protection system with which a train is driving. For following safety critical activities relevant differences were determined [5]:

- Problem with a movement authority (conventional, Dual Signalling, ERTMS-only)
- Failure of GSM-R (conventional, Dual Signalling, ERTMS-only)
- Failure of a Radio Block Centre (Dual Signalling, ERTMS-only)
- Failure of a ERTMS balise (Dual Signalling, ERTMS-only)
- Differences between aspect of a signal in conventional system and the permitted speed with ERTMS (Dual Signalling)

The chance on human error due to differences in the train protection system active at that moment increases in a number of situations [5]:

- Giving movement authorisation by communication between train dispatcher and train driver. Limited knowledge or limited experience with special characteristics of the train protection system involved can possibly cause confusion between train dispatcher and train driver, especially relevant for the Dual Signalling condition ([5], [12], [14]). Mostly confusion will not result in mistakes with impact on safety [5].
- Temporary Speed Restriction: when trains differ in maximum speed because of differences in train protection system, there should be different procedures for implementation of a Temporary Speed Restriction. During the pilot train dispatchers couldn’t recognize with which train protection system a train was driving at that moment, so it was difficult for them to implement a Temporary Speed Restriction in time in a correct way.

Figure 5 shows results of qualitative comparison of all distinguished conditions [5, 12].

<table>
<thead>
<tr>
<th>Train dispatcher</th>
<th>ATB-only (conventional)</th>
<th>Dual Signalling</th>
<th>ERTMS-only</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human error</td>
<td>*</td>
<td>Higher than ATB-only (conventional)</td>
<td>Equal to or higher than ATB-only (conventional) *</td>
</tr>
</tbody>
</table>

* ETCS terminology differs from traditional terminology for ATB/conventional.
** Possibly different speed restriction procedure for trains, dependent on ATP-system active, train dispatcher has no information about ATP-system of the train involved.

Figure 5: Human error of train dispatchers, conventional, Dual Signalling and ERTMS-only [5,12]
Operational management

Approach
Operational management is a broad term for traffic management of the railway undertaking (logistic control of trains due to delay and failure of technical equipment), maintenance of trains related to small technical failures, and monitoring and maintenance of infrastructure equipment. To answer the research items for operational management first a task analysis was made based on the documents about the so called user processes related to conventional systems, Dual Signalling and ERTMS-only, and regulation and handbooks for all distinguished forms of operational management. Multiple interviews with representatives of operational management were held. Goal of these interviews was to explore the differences in daily task performance in situations with failure in conventional systems, Dual Signalling and ERTMS-only [7].

Differences in task performance of operational management
For operational management failure of technical equipment in trains and infrastructure is trigger for their work. Figure 6 shows the occurrence of failure of technical equipment during the pilot in the period of October 2014 to February 2015 [7]. Frequency of occurrence of failure of technical equipment is very low for both conventional systems and ERTMS-equipment, however anno 2014/2015 ERTMS failures with small impact on train service occur more often than failures in conventional systems (ATB-failures and line side signal failures).

<table>
<thead>
<tr>
<th>Failure type</th>
<th>Great impact on train service</th>
<th>Small impact on train service</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATB-failure train (conventional system)</td>
<td>0</td>
<td>5</td>
</tr>
<tr>
<td>ATB-failure track (conventional system)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ATB-failure other (conventional system)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Lineside signal failure (conventional system)</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ERTMS failure</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

Figure 6: Occurrence of failure of technical equipment in trains and infrastructure, conventional systems and ERTMS [7]

Important to know is that in the ERTMS-only condition there is no fall-back scenario for a train driver, which means the train comes to a longer lasting stop when an ERTMS failure occurs. When in the Dual Signalling condition an ERTMS failure occurs the train driver can switch from ERTMS to conventional systems and after a short stop the train will drive again. A failure in conventional systems also only causes a short stop of the train, and the train driver is allowed to drive to the next station with limited speed (in Holland: 80 km/h or less, depending on the type of failure). In order to limit logistic impact of a failure in a train protection system only an ERTMS-failure in the ERTMS-only condition is reason for operational management to act in a short notice. For the conventional condition or Dual Signalling condition there is less reason for operational management to act immediately.

For comparison of the several conditions (conventional, Dual Signalling, ERTMS-only) a brief assessment of processes of operational management in practice was made. Of course operational management processes for conventional systems differ from operational management processes for ERTMS-systems, especially related to maintenance management of rolling stock and maintenance management of the infrastructure.

In Holland there are several lines equipped with ERTMS Level 2, but operational management for as well infrastructure as rolling stock differ from each other per line. Prescribed processes for operational management and required detailed knowledge about the characteristics of the technical system differ per line. This is caused by technical differences related to the supplier of the ERTMS-systems and is also related to project decisions during specification and implementation of the ERTMS-systems.

Workload and human error of operational management
Differences in workload and human error of the traffic management operators of a railway undertaking depend on the logistic impact of a failure of the train protection system. Workload of the traffic management operator of the railway undertaking is higher in the ERTMS-only condition because there is no fall back for ERTMS-only and there is a bigger change on a disturbance due to train protection system failure with impact on train service (Figure 7).
Differences in workload and human error of the maintenance management operators of a railway undertaking depend on number and kind of failures of the train protection system.

<table>
<thead>
<tr>
<th>Maintenance management train RU</th>
<th>ATB-only (conventional)</th>
<th>Dual Signalling</th>
<th>ERTMS-only</th>
</tr>
</thead>
<tbody>
<tr>
<td>workload</td>
<td>-</td>
<td>Equal to ATB-only (conventional)</td>
<td>Higher than ATB-only* (conventional)</td>
</tr>
<tr>
<td>human error</td>
<td>-</td>
<td>Equal to ATB-only (conventional)</td>
<td>Equal to ATB-only (conventional)</td>
</tr>
</tbody>
</table>

** Special failures related to ERTMS in Dual Signalling

** More information about ATP-failure available.

** More accurate detection of location of ATP-failure

Acknowledgements

We especially thank our research partners NLR - Netherlands Aerospace Centre and ErgoS Human Factors Engineering for their contribution to this project.
References

Monotony, Fatigue and Microsleeps - train drivers’ daily routine: a simulator study.

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Abstract:
The train drivers’ profession has undergone significant changes in the last years. Information-processing and controlling functions have increased substantially while physical demand has decreased. However, because of the shift work, physical and mental strain is still high. Fatigue and monotony seem to be issues related to normal operation conditions. Also, train drivers’ ability to react to unpredictable events deteriorates when exposed to highly predictable and uneventful driving tasks.

A driving simulator study was conducted in order to evaluate the impact of monotony to the train drivers’ driving performance. Eleven male train drivers took part at the experimental study in the RailSET train simulation environment - a realistic replica of a real train drivers’ cabin and its surrounding. While driving under a normal and monotonous condition, driving tasks were given to the participants in order to measure reaction times and driving performance. Participants were divided into two groups: morning and afternoon.

The results of the study show a significant difference in reaction times between the normal and the monotonous condition, with higher reaction times in the monotonous condition. The self-rated sleepiness on basis of the Karolinska Sleepiness Scale shows a considerable increase in the course of the test drive. Five from eleven participants were experiencing microsleep episodes. Six out of eleven test persons showed signals passed at danger (SPADs), i.e. they slipped past a signal showing a red aspect (stop). Almost all train drivers participating in the simulator study pointed out the importance of the monotony and fatigue study, based on their own experience of occurrence and probability of microsleep in the daily routine of the train drivers’ work.

Introduction
The modern railway drivers’ profession has been experiencing significant changes in the last period of time. Performing heavy physical work is no longer the central task of the train drivers, but taking the information from the environment, controlling, monitoring and tracking tasks. The train driver moves along a fixed track and does not „steer” the train, yet among other things his input consists of a continuous and often rapid stream of signals. The ability of being concentrated is very important in order to perceive abnormal, unexpected events and contingencies on the track. The problem is that fatigue and monotony seem to be issues related to normal operation conditions [1] and it deteriorates train drivers’ ability to react to unpredictable and uneventful driving events [2].

Welford [3] shows that fatigue occurred not only as a consequence of information overload, but also can be caused by underload, by a too low level of arousal and monotony of the environment. Myers [4] reported that mental fatigue and monotony can affect performance. Train drivers do not expend much physical energy during normal duty runs. Information-processing and controlling functions in monotonous environment lead to sensory adaptation and to reduced absorption of information [5]. Neurophysiological investigations showed that experiencing of monotony and mental fatigue can lead to microsleep episodes, which are not noticed by the person concerned [6].

Preliminary researches and interviews with the train drivers showed, that experiencing the microsleep episodes are almost daily routine of train drivers’ profession. Also, because of the shift work, physical and mental strain is still high [7].

In this paper the result of the experimental study about the monotony effects and performance impact during train driving will be shown and discussed.
Methods

The experimental study was conducted in RailSET- Railway Simulation Environment for Train Drivers and Operators (Figure 1) - a realistic replica of a real train drivers’ cabin and its surrounding at the Institute of Transportation Systems at the German Aerospace Center (DLR e.V.) in Braunschweig.

![Image of RailSET- Railway Simulation Environment for Train Drivers and Operators.]

Eleven male train drivers took part in the study. They were on average 39.36 years old (SD = 7.35) and had three to 27 years train driving experience (M= 17.18; SD =6.90). The participants worked for different rail operators, in passenger as well as freight train operation. They worked both in regional and intercity rail traffic.

Each train driver had to perform a driving task for four hours. The independent variables in the mixed factorial experimental design (Table 1) were:

1) driving under normal or monotonous condition, and
2) time slot of the experiment, specified in morning (8:00-12:00) or afternoon (12:30-16:30).

The time slot in the afternoon was chosen according to Horne & Reyner [8] as one time period of the day with most vehicle accidents happening regarding sleep and fatigue (13:00-16:00). Thus, it represents the ‘midafternoon slump’-condition, compared to the normal condition in the morning, since least sleep related vehicle accidents happen between 8:00 and 10:00.

<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
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<tbody>
<tr>
<td>Morning (8:00 - 12:00)</td>
<td>Afternoon (12:30 – 16:30)</td>
</tr>
<tr>
<td>Drive 1: normal</td>
<td>Drive 2: monotonous</td>
</tr>
<tr>
<td>Drive 1: normal</td>
<td>Drive 1: normal</td>
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</table>

In the normal drive condition, participants had to drive for 20min with max 160 km/h according to the electronic timetable (EBuLa) presented on the display on the driver’s-cab control panel. During the drive, movement commands were sent to the participants, presented also on the driver’s-cab control panel display. The commands had to be read by the participants immediately and to be confirmed via touch input.

In the monotonous condition, participants had to drive for ca. 65min in one direction (outward bound) and 65min in the other direction (return). In order to induce monotony, they had to drive ‘on sight’ with max 40km/h because of an imaginary ‘assumed overhead contact line dysfunction’. In addition, the drive implied difficult lighting conditions.
(100% fog and 80% darkness) in order to simulate a long and monotonous night drive. As in the normal driving condition, the drivers got movement commands they had to follow.

Dependent variables were:

a) performance measures (reaction times), stops in front of a signal showing a red aspect, and Signals passed at danger (SPADs = slipped past a signal showing a red aspect meaning stop) behaviour

b) subjective (sleepiness Karolinska Sleepiness Scale KSS, [9]) and objective (microsleep episodes) measures of fatigue; objective measures of vigilance (Mackworth Clock-Test; [10]),

c) additional physiological measures: heart rate (HR), and heart rate variability (HRV)).

The participants were instructed to drive normal duty run. They were given driving tasks (to stop at the insufficient secured level crossing and to stop at the stop signals) in order to make performance measures. Signals passed at danger (SPADs) behavior of the participants and microsleep episodes were also under special attention.

The Mackworth Clock-Test was applied in the beginning of the second section of the session (after the normal drive, before the monotonous drive) in order to measure the effects of long term vigilance and also to induce monotony and sleepiness. The subjective sleepiness was measured at six times via the KSS: in the very beginning of the session, after a short training session, after the normal drive, after the Mackworth Clock-Test, after the first half of the monotonous drive (outward), and after the second half of the monotonous drive (return).

Results

In general, the results of the study show that both monotony condition and “midafternoon slump”-condition showed effects on the train driver’s performance.

Performance measures

Figure 2 shows that in the monotonous condition six out of eleven participants had signals passed at danger (SPADs), i.e. they did not stop at a signal showing a red aspect, five train drivers stopped at the signal.

![Figure 2: Signals passed at danger (SPADs) in the monotonous condition](image)

The reaction times of the train drivers in the monotonous condition were higher for the insufficiently secured level crossing task and the stop signals (Table 2). Scores regarding the reaction time show a significant difference between the normal and the monotonous condition by the insufficient secured level crossing task (Z= -2.934; p=.003).

A comparison of reaction times between morning and afternoon showed no significant differences.
Table 2 Descriptive analysis of the reaction time in ms

<table>
<thead>
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**Fatigue**

**Microsleep Episodes**

Five out of the eleven train drivers were experiencing microsleep episodes, four of them in the afternoon group (Figure 3). These are the high risk factors that can cause an incident under special circumstances, such as failing of the train protection systems or in the situation of unpredictable and uneventful driving events that needs immediate reaction.

![Figure 3: microsleep episodes](image)

**Sleepiness**

The Karolinska Sleepiness Scale (KSS) measured the self-rated sleepiness at certain points of the ride. Figure 4 shows a considerable increase of the ratings during the test drive. Especially in the afternoon group, the ratings increased strongly over time.

The sleepiness ratings of the KSS after the monotonous drive differed significantly from the ratings after the first (normal) drive ($Z = -2.724; p = .006$). Participants stated to be more tired after the monotonous drive than after the first drive. Also, the KSS ratings after the first half of the monotonous drive are significantly higher than the ratings of KSS after the first drive (normal condition; $Z = -2.871; p = .004$). Furthermore, the ratings were significantly higher after the second half of the monotonous drive (return) than after the first half of the monotonous drive ($Z = -2.684; p = .007$).
Morning:

For the morning group, KSS ratings were significantly higher after the first half of the monotonous drive than after the first drive (normal condition; Z= -2.070; p= .038).

Afternoon:

For the afternoon group, the differences were even more distinct. At all the following measuring points, the KSS sleepiness ratings were significantly higher than the ratings after the first drive (normal condition):
1) after the monotony task: Z= -2.041; p=.041;
2) after the first half of the monotonous drive: Z=-2.060; p=.039;
3) after the second half of the monotonous drive: Z=-2.032; p=.042.

Pearson correlations were subsequently computed to investigate whether there are correlations between reaction time and the self-rated sleepiness (KSS). Significant correlations occurred for the reaction times in the insufficient secured level crossing task ($r= .947; p= .014$). Participants with higher self-rated sleepiness reacted more slowly.

**Physiological measures**

Physiological measures (ECG) showed a decrease of the heart rate (HR) and an increase of the heart rate variability (HRV) after the monotonous ride. Wierwille & Muto [11] pointed out that this tendency can be interpreted as an indicator for monotony and fatigue.

Figure 5 depicts train drivers strategies to avoid getting tired in monotonous situations during the ride. Opening a window was mentioned six times, standing up or moving three times. Talking, checking display, changing seated position or temperature was mentioned two times. Other strategies such as eating, switching the light on and searching for concentration were mentioned one time each. According to this results the train drivers’ wish more physical activity during the ride. The ambient conditions such as light and temperature are very important factors that can be helpful in order to avoid getting tired or even having micro-sleep episodes.
The importance of the monotony and fatigue study in context of train driving was pointed out by almost all the participants of the experimental study.

Discussion

The results of the experimental study show that monotony impacts train driver’s performance, the reaction times and the ability to react to unpredictable events. The data presented in this paper show a good correspondence between subjective measures, reaction times as well as physiological measures for both normal and monotonous ride. All measures indicated a decrease in performance and increase of fatigue. Both monotonous condition and ‘midafternoon slump’-condition effect the drivers’ performance. Microsleep episodes and Signals passed at danger (SPADs) are consequences that can lead to fatal accidents.

Participants of this study mentioned strategies that can be used to avoid or to reduce monotony, for example temperature regulation and more physical activity during the ride (standing up, moving). This can be helpful advices, but not a solution to the problem.

Future studies should be aimed to research of effective potential countermeasures that on the one hand decrease drivers' proneness to the effects of monotonous driving and, on the other hand, support the drivers’ ability to judge his or her state correctly.

References


