Comparing different types of the track side view in high speed train driving

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Abstract

The introduction of high speed trains featuring an increasing number of automated components raises imperative questions concerning the future tasks and the general role of the train driver. Previous work showed that train protection systems provoke train drivers to relocate their visual attention from the track side towards the displays within the cabin. The introduction of high speed routes allowing automatic train operation (ATO) has major implications that question the importance of the track side view for the train driver: (1) all relevant driving parameters are displayed within the cabin in high speed railway operations. (2) Supervisory tasks based on in-cab display information shift into the train driver´s focus. This study investigated the influence of three differently sized track side views (real size, monitor size, none) on a) the allocation of visual attention towards displays and the track, measured by eyetracking parameters and b) the situation awareness of the train driver supervising a high speed train featuring ATO measured with the SPAM method. Empirical data are presented for both research questions. The implications are discussed in order to identify how the delivery of relevant information in the context of the changing train driver's task can be facilitated.

Introduction

Driving long distance trains is a rather monotonous job (Dunn & Williamson, 2011; Stein & Naumann, 2016), especially with a limited number of stops along the route as in high speed passenger transport.

We are continuously looking at increasing the efficiency of track utilisation and energy consumption as well as punctuality (European Commission, 2011) and after decades of technical development and debate automating high speed passenger operations is today seen as one valid way to achieve these efficiency gains. At the moment automatic train operation (ATO) is restricted to either urban transport operated as closed systems or certain track segments of low complexity. To ensure efficiency gains throughout the whole railway industry, ATO is likely to be introduced to more complex segments containing e.g. railroad switches, platforms, level crossings. As high speed tracks can be considered to be of moderate complexity because these infrastructure elements are less frequent, we choose to start our investigation on the train driver´s tasks in this operational context.

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Additionally, the high speed operational context is most suitable for our research questions, because in-cabin signalling already is the norm today, in contrast to e.g. freight train operations where train drivers still heavily rely on real world cues found along the track to verify their driving behaviour (Rose & Bearman, 2012). The key question obviously is where the main sources of relevant information are located within the working environment of the train driver and whether the drivers allocate their attention to these areas.

Previous work shows a shift of visual attention onto the displays within the cabin away from the track side view once a train protection system is at work (Naumann, Wörle, & Dietsch, 2016). These results are based on the train protection system PZB 90 (for a description see Naumann, Grippenkoven, & Lemmer, 2016), a German train protection system mainly relying on signal aspects and speed indicators located along the track, while the display offers information concerning the status of the train protection system. Therefore the shift of visual attention in the PZB 90 condition compared to a condition without train protection in a simulation study described by Naumann, Wörle, & Dietsch (2016) is in fact a shift away from the information source delivering the major parameters for deriving driver instructions. Even more so because train drivers driving under PZB 90 supervision do have the explicit order to monitor the track ahead for obstacle detection. In contrast, in current high speed passenger operations relevant information is being displayed within the cabin so that is where the visual attention is supposed to focus on. Technically, visual obstacle detection is still a task of legal relevance to the high speed train driver as well, but due to breaking distances which exceed the train driver´s field of view by far, the need for technical obstacle detection and physically enclosing high speed tracks is undisputed. Even more so if ATO is to be implemented, thus emphasizing the critical need to monitor the driving parameters within the cabin, which are likely to be displayed using the ETCS - DMI (European Train Control System - Driver Machine Interface) display layout (European Railway Agency, 2007). This major shift of attentional resources into the cabin (Naweed, 2013) inevitably calls for continuous display monitoring as a key characteristic of automated high speed passenger operation out of two reasons. On the one hand the display information shows what kind of driving behaviour is required in accordance with the track environment and on the other hand the current modus operandi of the automated train components is displayed within the cabin as well. Therefore the continuous comparison between required and automatically executed driving behaviour is essentially based on display information. Previous research (Brandenburger & Naumann, 2016) has identified a lack of clarity in the understanding of the role the track side view is playing in such an operational scenario. Additionally, experienced train drivers claim that the track view is to stay a central part of the train driver´s job in ATO in order to integrate e.g. track conditions or geographic orientation into driving behaviour. Therefore, the first research question aimed to assess (a) to what extend the track side view out of the cabin windows is actually used under ATO conditions in contrast to a non-automated condition and whether the size of the track side view alters the extend of usage. Given the characteristics of the continuous display monitoring task to be executed by the train driver supervising an ATO, there is already a sound body of scientific knowledge applicable to the task at hand. Dunn and Williamson (2011) provide insights on monotony as a consequence of repetitive task characteristics in railway passenger operations and Edkins and Pollock (1997) identify sustained attention and especially inattentiveness to railway signals as the major factor present in all types of railway accidents in a review of train accidents over a 3-year period. Spring et al. (2008) indicate poorer vigilance under ATO in comparison to manual driving with in-cabin signalling and over speed intervention. The authors also report an additional vigilance decrement only present in the ATO group over the course of their experiment. Warm, Parasuraman and Matthews (2008) also characterize cockpit monitoring as a vigilance task hinting at the differentiation between simultaneous and successive vigilance to clarify under which tasks vigilance decrements are more likely to be found. They proclaim successive vigilance tasks to be more vulnerable as the ”observers need to compare current input with a standard retained in working memory to separate critical signals from nonsignal stimulus events” (Warm, Parasuraman & Matthews, 2008; p.435) in contrast to simultaneous vigilance task where ”all the information needed to distinguish signals from nonsignals is present in the stimuli themselves” (Warm, Parasuraman & Matthews, 2008; p.435). While manual driving under in-cabin signalling is mainly relying on verifying manual traction input visualized by means of the speedometer needle against a visually presented speed limit representing a simultaneous vigilance task, monitoring and supervising ATO does include upholding a complex mental model of the automatic components resulting in a certain traction adjustment. Therefore, it can be argued that this task is more successive in nature. Kaber and Endsley (2004) argue that monitoring automated systems is associated with poor vigilance and a failure to build up and maintain an accurate mental model. This model contains an adequate understanding of the underlying automatic components, their functionalities and how these functionalities translate into real world in this specific case traction adjustment matching trackside train protection system´s requirements. Thus, is argued to result in loss of situation awareness (Kaber & Endsley, 2004). Building on a large body of empirical evidence it is undisputed that the perception of relevant information is the key to develop and maintain situation awareness, eventually anticipating future action of the monitored system (Endsley, 1988; Endsley, 1995; Parasuraman, Sheridan & Wickens, 2008). Therefore, the second research question arises (b) whether the size of the track side view (displaying irrelevant information) influences measures of situation awareness in ATO. If so, this has implications in terms of unnecessary distraction of the train driver, who´s central task is to monitor the in-cabin displays.

Hypotheses

Based on Naumann, Wörle, & Dietsch (2016) we hypothesised a shift of visual attention from the trackside view to the display (DMI) in a more automated driving condition compared to a manual driving condition.

> H1) *We expect the number of fixations on the DMI to be higher in the ATO condition than in the manual condition* (figure 1).

As the salience of the track side view is thought to decreases with smaller size

H2) *We expect the number of fixations on the DMI to increase with decreasing size of the track side view* (figure 1).

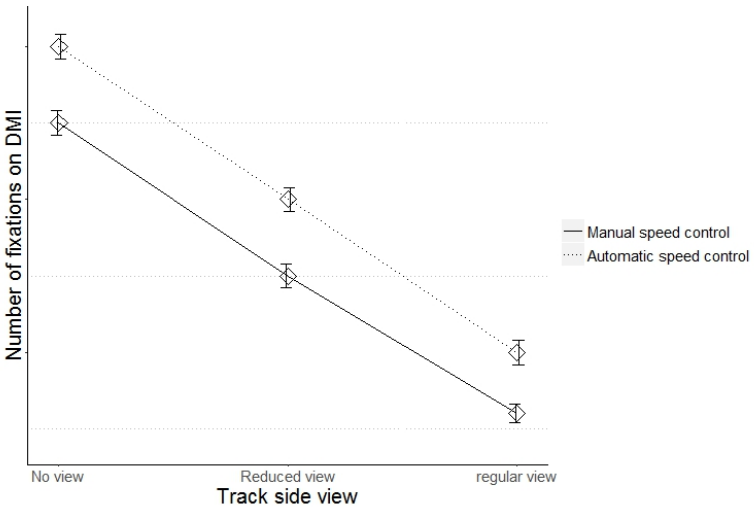

Figure 1. Hypothesized relationship of Number of fixations on DMI and size of Track side view for driving conditions

Based on the findings by Kaber and Endsley (2004) concerning level of automation and situation awareness

H3) *We expect the situation awareness measures to be smaller in the ATO condition in contrast to the manual condition.*

As the information contained in the track side view in our experimental setting representing future high speed track infrastructure is irrelevant to the monitoring task

H4) *We expect the situation awareness measures to increase with decreasing size of the track side view.*

Method

Participants

26 male German train drivers aged from 21 to 56 (M = 36.53, SD = 10.92) were recruited out of a pool of previous participants. Participants worked in freight (4 out of 26) and passenger transport (22 out of 26). Their occupational experience was ranging from 1 to 37 years (M = 14.07, SD =10.85). All were unfamiliar with the ETCS system featuring automatic speed control. Train drivers with glasses and train drivers following regular medical treatment were excluded from participation. The sample was randomly assigned to the experimental conditions and participants were compensated with € 30.

Experimental Design and Measures

Figure 2. High fidelity railway simulator while driving. In this case with regular sized track side view and the ETCS-DMI giving permission to drive up to 400 km/h.

The study was designed in a 2x3 mixed design including both the variable "speed control" with two between subject levels "manual speed control" / "automatic speed control" and the variable "track side view" with three within subject levels "regular view", "reduced view" and "no view". Participants drove in the high fidelity railway simulator "RailSET" (figure 2), which is presented and explained in detail by Stein and Naumann (2016). The simulator incorporates a cabin (BR 424 manufactured by Alstom/Siemens), a projector (SONY VPL-FH500L), two monitors as side windows (100 cm screen diagonal) and three monitors (30 cm screen diagonal) in the desk as instruments, from which only the center monitor was used during the experiment to display the ETCS-DMI (European Railway Agency, 2007). For experimental manipulation, the simulator was equipped with automatic speed control functionality and three ways of displaying the track side view. The regular track side view includes full frontal presentation of the 3D simulation environment and additional side windows. A reduced track side view consisted of a reduced frontal presentation and no side windows and in the third option no frontal or side view of the 3d simulation was present. The DMI was visible in all conditions. Furthermore, measurement of the dependent variables made the following apparatus and materials necessary. Eyetracking data was obtained using a head mounted Dikablis Essential system in combination with the software DLAB Version 3.0 both supplied by

Ergoneers. Subjective data was assessed using paper and pencil questionnaires of the following kinds. The Situation Awareness rating technique (SART) by Taylor (1990) was first translated to German and adapted to the high speed railway context and then used to assess subjective situation awareness. The adapted SART comprised 10 questions assessing three areas on a 4-point Likert scale (Demand from Attentional Resources (D), Supply of Attentional resources (S), Understanding of the Situation (U)). The SART score was the sum of U and S minus D (Taylor, 1990), with a theoretical range from -5 to 27. Additionally, the situation present assessment method (SPAM) proposed by Durso et al. (1998) was implemented using 12 questions targeting current and future understanding of the driving situation. The SPAM scores were the answering times for correct answers. Further paper and pencil materials were a demographic questionnaire, an informed consent, a short explanatory handout of ETCS and the underlying functionalities of the simulator and a debriefing form. The explanatory handout was used in two versions, one of which incorporated information about the automatic speed control function used in one of the experimental conditions. Lastly, a voice recorder was present to record the answers to the SPAM questions and for post hoc artefact detection.

Procedure

The study took place in the research facilities of the German Aerospace Center in Braunschweig, Germany. Upon arrival the participants gave their informed consent before filling in the demographic questionnaire and reading the information on the simulator. Then the eyetracking device was attached and calibrated. Afterwards, the participants started driving the first of three experimental blocks for approximately 35 minutes. During the driving block the experimenter shortly joint the participants two times in the cabin (after approximately 10 and 20 minutes of driving) to ask two questions at a time related to the SPAM method. The driving block ended with an ordered standstill of the train conveyed through the DMI. In the pause between the first and the second driving block the participant filled in the adapted SART questionnaire. The second and third driving block as well as the pause between them followed the routine described for the first driving block and the first pause. After finishing the third driving block the participants once more filled in the SART questionnaire. Afterwards all recording equipment was shut off and detached before participants got a debriefing along with their monetary compensation and were dismissed.

Results

Attention allocation

Based on findings of Naumann, Wörle, & Dietsch (2016), we formulated our first hypothesis that we expect the number of fixations on the DMI to be higher in the ATO condition compared to the manual driving condition. Nevertheless the between-subject effect for the driving condition was not found significant ($F(1,24) = .486$; $p > .05$) employing a repeated measures ANOVA including both factors track side view (three levels) and driving condition (two levels) as independent variables and the number of fixations on the DMI as a dependent variable. Therefore we could not reject the null hypothesis based on sample data. Inspecting figure 3 added additional evidence to the fact that the difference between the group means, although showing larger numbers of fixations for the ATO condition, is not of significant size in relation to the within group variations in both driving conditions, also reflected by a small to moderate effect size (η^2 =.20).

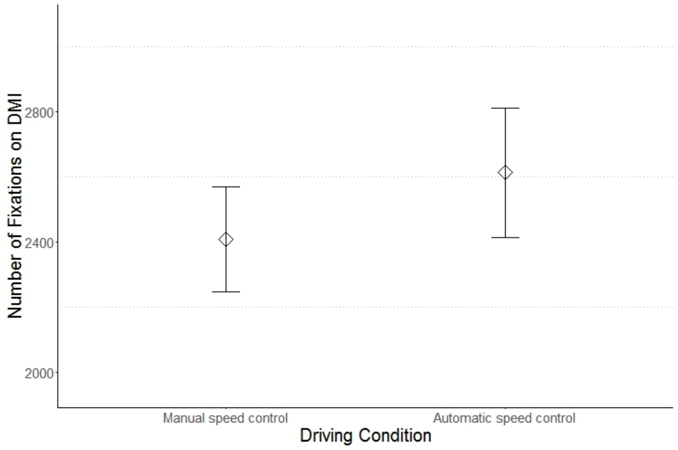

Figure 3. Absolute Number of Fixations on the Driver- Machine- Interface in our sample by driving conditions. Error bars represent the standard error of the mean (SE).

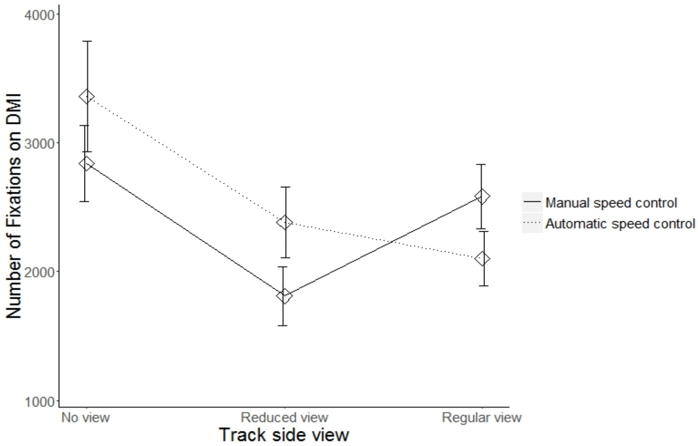

Figure 4. Absolute Number of Fixations on the Driver-Machine-Interface for three different sizes of Track side view by speed driving conditions. Error bars represent the standard error of the mean (SE).

Concerning the second hypothesis, a highly significant within-subject effect for the size of the track view on the number of visual fixations was found again using repeated measures ANOVA while relying on Greenhouse-Geyser corrected degrees of freedom ($F (1.817, 43.613) = 8.86$, $p < .01$). The size of this partial effect was moderate (η^2 = .270). Accordingly, the data displayed in figure 4 indicated an increasing number of fixations on the DMI with decreasing size of the track side view, which is in line with hypothesis 2. Nevertheless, figure 4 showed an interesting deviation from this pattern in the regular track side view condition, where the number of fixations was actually higher for manual speed control condition, raising questions concerning a possible interaction effect. Nevertheless, there was only a trend for an interaction effect in a repeated measures ANOVA model ($F(1.817, 43.613) = 2.859$, $p = .073$) failing to reach significance. In the absence of a significant interaction effect figure 4 once more shows that indeed the number of fixations on the DMI steadily increased with smaller track side view irregardless of speed control. Although, the curve for the manual driving condition deviated somewhat from our expectations voiced in hypothesis 2 in the sense that regular size track side view resulted in more fixations of the DMI in the manual condition than expected, we accepted hypothesis 2 after having ruled out an interaction effect undermining main effect relevance.

Situation Awareness

To test hypotheses 3 and 4, both SART and SPAM scores were evaluated. Concerning hypothesis 3, claiming situation awareness ratings to be smaller in the ATO condition, a repeated measures ANOVA testing for differences in the dependent SART scores did not reveal a group mean difference between driving conditions ($F(1,19) = 1.104$, $p > .05$). Similarly, no between-group effect was found for the SPAM scores ($F(1,22) = .267$, $p > .05$), which is also visible in the small sizes of the effects for SART (η^2 = .055) and SPAM (η^2 = .012) measures. Interestingly, the Pearson correlation between the SART and the SPAM scores was small ($r = .340$). Therefore, hypothesis 3 was not validated.

The fourth hypothesis claimed that an increased situation awareness rating would go along with decreased size of the track side view. Nevertheless repeated measures ANOVAs for SART ($F(1.945, 36.964) = 3.553$, $p > .05$) and SPAM ($F(1.727, 37.989) = .679$, $p > .05$) did not show a significant within subject effect of the track side view factor. These results did not validate hypothesis 4. Even more so figure 5, depicting subjective SART scores for different track side views driving conditions, did show a trend opposite to hypothesis 4, showing slightly better situation awareness ratings for an increasing size of the track side view. Objective SPAM scores remained mostly unchanged over the track side view conditions (figure 6).

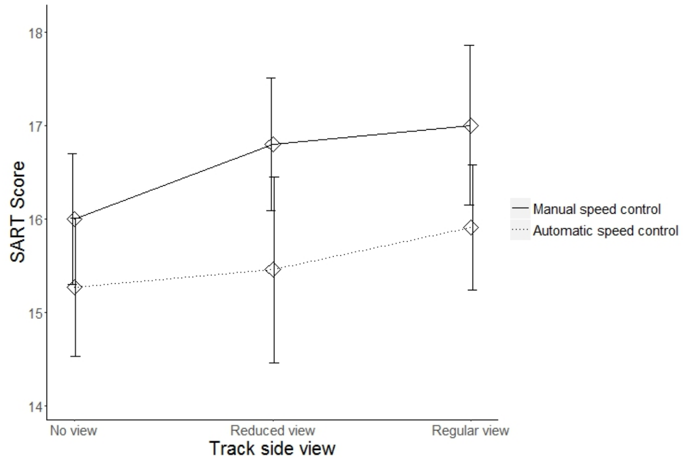

Figure 5. Subjective SART Score for three different sizes of Track side view by driving conditions. The depicted SART Scores theoretically range from -5 to 27. Error bars represent the standard error of the mean (SE)

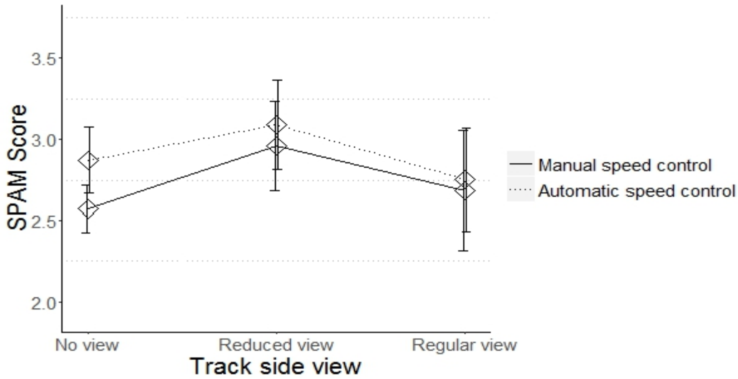

Figure 6. Objective SPAM Scores in seconds for three different sizes of Track side view by speed driving conditions.

Discussion and Conclusion

Aim of the current line of research is to identify how relevant information about a certain train ride can be delivered effectively to the train driver given the fact that ATO is at work. This does question central assumptions concerning the train driver´s tasks, two of which we stated in the introduction for further investigation. Namely, (1) all relevant driving parameters are displayed within the cabin in high speed railway operations and (2) supervisory tasks based on in-cab display information shift into the train driver´s focus, basically rendering track supervision irrelevant in terms information acquisition of driving parameter. Therefore the study investigates a) whether ATO (hypothesis 1) and decreasing size of the track side view (hypothesis 2) containing irrelevant information lead to an increased focus of visual attention on the in-cabin DMI. Additionally it is investigated b) whether ATO (hypothesis 3) and decreasing size of the track side view (hypothesis 4) result in heightened situation awareness of the train driver. Concerning research question (a), a significantly higher number of fixations on the DMI for train drivers supervising ATO (hypothesis 1) cannot be found. Nevertheless, the observed group differences between the ATO and the manual driving group are in line with hypothesis 1 and findings from Naumann, Wörle, & Dietsch (2016), who reported train protection functionality to result in more visual attention on the DMI. As hypothesized, a decreased size of the track side view is found to result in more visual attention allocation on the DMI (hypothesis 2). This effect is especially prominent in the ATO condition resembling future high speed train operation. Closer inspection of the data (figure 4) revealed unexpectedly high numbers of fixations on the DMI for manually driving train drivers equipped with a regular outside view. Even in the absence of a significant interaction effect this deviation is worth noting as it contradicts the current understanding that modern in-cabin signalling along with automatic train protection forces the train driver´s attention onto the displays (Naumann, Wörle, & Dietsch, 2016; Naweed, 2013). It seems crucial to ensure that in-cabin signalling as e.g. in the ETCS- DMI is side-lined by measures enhancing the attention allocation onto the relevant displays, especially in ATO environments. Ultimately, results on hypothesis 2 lead to the conclusion that the size of the track side view may be employed to redirect visual attention towards in-cabin equipment in an ATO environment. The effects of track side view size on visual attention in manual driving environments need further clarification.

Concerning the train driver´s situation awareness (research question b) in ATO environments, several results are of interest. First of all, reduced situation awareness in the ATO condition as a negative consequence of the higher automation functionality for both of the situation awareness measures was not found (hypothesis 3). Moreover, objective situation awareness (SPAM) tends to be higher in the ATO condition in our data, while subjective situation awareness (SART) tends to be lower in the ATO condition. The correlation between the subjective SART measure and the objective SPAM measure was small in size. One possible explanation for this inconsistence is the moderating effect of time pressure described by Stoller (2013) who reports that correlations between subjective and objective situations awareness measures decrease if time pressure is low. The results concerning the effect of track side view size on situation awareness are statistically inconclusive (hypothesis 4), as the hypothesised effect failed to reach significance. Interestingly, subjective situation awareness tends to grow with size of track side view, while objective Situation Awareness remains constant. The presented results lead to the conclusion that varying the size of the track side view containing mainly irrelevant information to the train driver does not seem to endanger a proper level of situation awareness in automatic high speed passenger operation. Nevertheless, the size of the track side view as a unique source for information on orientation and weather conditions and its impact on situation awareness in current railway operations still needs further investigation.

Future research questions in this line of research will also focus on the effects of part-time supervision in contrast to full time supervision of automatic high speed trains. Likewise facilitating adequate responses to failures in automatic speed control components as well as implementing the insights into a working environment enabling high speed passenger train operation to be supervised remotely are of interest.

References

Brandenburger, N., & Naumann, A. (2016). Determining the allocation of tasks in automated high speed driving. In B. Milius & A. Naumann (Eds.), *Proceedings of the 2nd Workshop on Human Factors* (pp. 112-121). Braunschweig: ITS automotive nord.

Dunn, N., & Williamson, A. (2011). Monotony in the rail industry. In *HFESA Conference* (47th ed.).

Durso, F.T., Hackworth, C.A., Truitt, T.R., Crutchfield, J., Nikolic, D., & Manning, C.A. (1998). Situation Awareness As a Predictor of Performance for en Route Air Taffic Controllers. *Air Traffic Control Quarterly, 6*(1), 1-20.

Edkins, G.D., & Pollock, C.M. (1997). The influence of sustained attention on Railway accidents. *Accident Analysis & Prevention, 29,* 533-539. doi:10.1016/S0001-4575(97)00033-X

Endsley, M. (1988). Situation awareness global assessment technique (SAGAT). In *Proceedings of the IEEE 1988 Aerospace and Electronics Conference.*

Endsley, M. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *Human Factors, 37*, 32–64.

European Commission (2011). Weissbuch: *Fahrplan zu einem einheitlichen europäischen Verkehrsraum – Hin zu einem wettbewerbsorientierten und ressourcenschonenden Verkehrssystem*. Brussels, Belgium.

European Railway Agency (2007). *ERTMS/ ETCS: Functional Requirements Specification FRS.*

Kaber, D.B., & Endsley, M.R. (2004). The effects of level of automation and adaptive automation on human performance, situation awareness and workload in a dynamic control task. *Theoretical Issues in Ergonomics Science, 5*, 113–153. doi:10.1080/1463922021000054335

Naumann, A., Grippenkoven, J., & Lemmer, K. (2016). Future information and assistance systems for train drivers and evaluation of their usability. In: *Proceedings of the 11th World Congress on Railway Research*, Milan, May 29 –June 2, 2016.

Naumann, A., Wörle, J., & Dietsch, S. (2016). The effect of train protection systems on train drivers' visual attention. Poster at the HFES Europe chapter annual meeting, 2016. http://www.hfes-europe.org/posters-2016/

Naweed, A. (2013). Investigations into the skills of modern and traditional train driving. *Applied Ergonomics, 45,* 462–470. doi:10.1016/j.apergo.2013.06.006

Parasuraman, R., Warm, J.S., & Dember, W.N. (1987). Vigilance: Taxonomy and utility. In L.S. Mark, J.S.Warm, & R.L. Huston (Eds.), *Ergonomics and human factors: Recent research* (pp. 11–32). New York: Springer-Verlag.

Parasuraman, R., Sheridan, T.B., & Wickens, C.D. (2008). Situation Awareness, Mental Workload, and Trust in Automation: Viable, Empirically Supported Cognitive Engineering Constructs. *Journal of Cognitive Engineering and Decision Making, 2*, 140–160. doi:10.1518/155534308X284417

Rose, J., & Bearman, C. (2012). Making effective use of task analysis to identify human factors issues in new rail technology. *Applied Ergonomics*, 43, 614–624. doi:10.1016/j.apergo.2011.09.005

Spring, P., McIntosh, A., Caponecchia, C., & Baysari, M. (2008). Level of Automation: Effects on Train Driver Vigilance. *44th Annual Human factors and Ergonomics Society of Australia Conference*, 264–271.

Stein, J., & Naumann, A. (2016). Monotony, Fatigue and Microsleeps - train drivers` daily routine: a simulator study. In B. Milius & A. Naumann (Eds.), *Proceedings of the 2nd Workshop on Human Factors* (pp. 96–102). Braunschweig: ITS automotive nord.

Stoller, N. (2013). *Situation Awareness von Lokführenden während sicherheitskritischer Ereignisse im Bahnverkehr* (Bachelor Thesis). Fachhochschule Nordwestschweiz Olten.

Taylor, R.M. (1990). Situation awareness rating technique (SART): the development of a tool for aircrew systems design. In *Situational Awareness in Aerospace Operations* (Chapter 3). France: Neuilly sur-Seine, NATO-AGARD-CP-478.

Warm, J., Parasuraman, R., & Matthews, G. (2008). Vigilance Requires Hard Mental Work and Is Stressful. *Human Factors, 50*, 433–441.