Signals passed at danger (SPADs) have been one of the most serious kinds of incidents in railways, and they have occurred sporadically due to train driver errors. These incidents usually occur because of drivers’ limited non-technical skills (NTS) rather than a lack of technical skills. In order to improve drivers’ NTS, a new education program has been developed with focuses more on human factors perspectives compared to traditional ones. The framework of the program consists of three steps: (1) learning from experiences with the process by which SPADs occur in a driving simulator, (2) understanding error mechanisms and coping strategies with an educational comic book, and (3) thinking of error-prevention actions on one’s own through discussion with instructors and other drivers. The experiences with the process by which SPADs occur in the first step motivate drivers to learn human factors behind errors and SPAD-prevention strategies, which are addressed in the second and third step. For this purpose, a SPAD-inducing scenario has been developed in simulation. A pilot test of this education program was carried out with 170 drivers at a training center, and it showed positive results in drivers’ responses to this program and understanding of SPAD-prevention strategies. According to the questionnaire survey conducted after the education program, all drivers responded that they became aware of a danger of assumptions through this program. In addition, 77% of drivers answered that they realized the importance of NTS in signal confirmation after receiving this program, which is up from 17% shown in pre-program responses. Based on these educational effects, this education program has been rolled out through JR East.

Keywords: SPAD, Human factors, Non-technical skills, Train driver training, Simulator

1. Introduction

Signals Passed at Danger (SPADs) have been one of the most serious kinds of incidents and should be prevented as much as possible in order to achieve a higher level of safety. To reduce the occurrence of SPADs, train protection systems such as Automatic Train Stop (ATS) have been installed to automatically stop a train before passing a signal at danger. However, SPADs still have occurred sporadically due to drivers’ incorrect handling of the ATS device. There are various kinds of driver training putting emphasis on technical skills such as driving techniques, knowledge of rules and procedures, and correct handling of emergency situations. On the other hand, it has been pointed out in safety-critical industries that safe operations cannot be achieved solely by improving technical skills\(^1\). For instance, even a highly skilled surgeon can make a terrible mistake if s/he failed to have clear communication with nurses and anesthesiologists during an operation. Such “cognitive, social and personal resource skills that complement technical skills and contribute to safe and efficient task performance” are called “non-technical skills (NTS)”\(^2\). Training programs to support NTS improvement have also been developed and implemented in aviation and anesthesiology\(^3\).

The importance of NTS is the same in the field of railway operations. Serious incidents often occur because drivers’ NTS are limited, i.e., they are easily distracted, not fully aware of the situation, make wrong assumptions, etc., rather than as a result of a lack of necessary technical skills. SPADs can occur when a driver was distracted by interrupting events and/or expected that her/his route would soon be cleared and/or misunderstood the activation of train protection system based on wrong assumptions. Therefore, a new education program has been developed that focuses more on human factors perspectives compared to the conventional training in order to improve drivers’ NTS.
2. Framework of the Human Factors Education Program for Drivers

It is important to consider an appropriate means of education. Educational effects will be limited if there is only a one-way lecture session by instructors. Studies suggest that active learning—any instructional method that engages students in the learning process—brings more positive student attitudes and better information retention, especially when problem-solving tasks are included. In this sense, Crew Resource Management (CRM) training in aviation is a pioneering human factors training based on active learning, which incorporates problem-solving tasks in simulation. Simulation allows students to face safety-critical situations and visualize the impact of unsafe behaviors with no real harm, and it provides a good opportunity for students to learn from their own failures. Experiences in simulation may differ from those in the real world; however, a study on driving behaviors shows that skills acquired in a driving simulator were retained and reflected in actual driving. Therefore, this education program has incorporated simulator training as a core element in its framework consisting of three steps: (1) learning from experiences with the process by which SPADs occur in a driving simulator, (2) understanding error mechanisms and coping strategies with an educational comic book, and (3) thinking of error-prevention on one's own through discussion with instructors and other drivers. The details of each step are described in the following sections.

Step 1. Learning from experiences with the process by which SPADs occur in a driving simulator

First, drivers go through a SPAD-inducing scenario in simulation and realize how they are vulnerable to error-inducing situations. The aim of this is to motivate them to learn human factors issues and error-prevention skills addressed in the subsequent steps. The SPAD scenario is designed to induce misperception of a home signal and wrong assumptions on ATS-P braking. Before describing this scenario, it would be best to explain an issue with the interface of the ATS-P system, identified as an underlying factor of some recent SPAD incidents.

ATS-P is widely used at JR East and has a function similar to ETCS level 1 with trackside signals, which sets a braking curve to stop a train automatically and prevent SPADs from happening even when a driver ignores or misperceives a stop signal. In this case, emergency braking is applied at all departure signals while maximum normal braking is applied at some home signals. On the other hand, ATS-P sometimes stops a train by applying the same maximum normal braking even after the signal aspect has switched to “proceed” or “caution” from “stop” because the braking curve is updated only after the train has passed the next beacon. Train drivers are allowed to reset the braking by themselves if maximum normal braking is applied while a reset of emergency braking requires authorization from dispatchers. Before resetting maximum normal braking, drivers are supposed to reconfirm the signal and other relevant indicators to make sure they can move forward. However, they could misperceive a home signal, e.g. they actually saw a neighboring signal, resulting in them resetting maximum normal braking by judging it was applied due to a lingering braking curve, and passing the signal at danger.

To create a similar situation, multiple home signals have been set side-by-side in a training route in a driving simulator (Fig.1). Home signals usually stand at the left side of the track, but those for the simulation are built on the right side because they are located at the end of a left curve where right-side construction is reasonable for better visibility to drivers passing through the curve. This situation entices drivers to see the neighboring signal. Furthermore, movement of another train is added in order to induce an assumption that the signal on their route will switch to “proceed” or “caution” as soon as the other train leaves the platform where they are supposed to arrive. An example of the scenario development when a driver failed to notice her/his own misperception and committed a SPAD is as follows.
1. A driver receives a call from a dispatcher saying, “Your train will be stopped at the next stations’ home signal due to a delay of another train dealing with a sick passenger at your platform.”
2. The driver stops before the home signal and waits for the other train to depart from the platform. (The driver can see the movement of the other train from her/his position.)
3. The other train leaves the platform. (At this point, the driver is likely to expect that her/his route will be cleared as soon as possible.)
4. A home signal for a neighboring track switches to “caution”.
5. The driver misperceives the signal and moves forward.
6. ATS-P activates maximum normal braking and stops the train.
7. The driver assumes, incorrectly, that the braking is due to a lingering braking curve and resets the braking.
8. The driver restarts the train at lower speed so that it won’t be stopped again by a lingering braking curve.
9. The driver passes the home signal at danger.
10. Another train running on the neighboring track appears from behind and the driver hits the emergency brake to avoid collision.

After the simulator driving, a quick debriefing is carried out between a driver and her/his instructor. For drivers who misperceived the signal and experienced the process by which SPADs occur in the simulator, instructors ask the reason they misperceived the signal and reset ATS-P braking and give instructions on correct handling in case of ATS-P braking.

Instructors point out error-prevention skills to drivers who did not misperceive the signal, e.g., cautious checking and calm handling in the error-prone situation, and encourage them to acquire more such NTS. Then, instructors ask the drivers to run the train under the condition that they somehow misperceived the signal and think how they would have reacted upon ATS-P braking if they were completely convinced by the wrong signal. This procedure allows them to go through process by which SPADs occur as well, and it lets them learn that erroneous handling of ATS-P is likely to occur due to wrong assumptions when they strongly believe that they are seeing the right signal. In that way, they realize that SPADs can happen to anyone under certain conditions.
Step 2. Understanding error mechanisms and coping strategies with an educational comic book
After experiencing the process by which SPADs occur in simulation, drivers learn why they made/would have made such errors and how they can avoid them. This step is designed to introduce fundamental human factors behind errors related to SPADs and coping strategies. To facilitate their understanding and willingness to learn, human factors education material has been developed in a style of a comic book with the following contents (Fig. 2).

- Human vulnerability: Situations inducing human errors
- Human factors behind SPAD related errors
- Effective measures to prevent SPAD accidents

In this step, drivers read the material by themselves in a lecture room and get themselves ready for the subsequent discussion with instructors and other drivers (in the third step). For example, special emphasis is placed on the danger of assumptions and on potential measures to recover from wrong assumptions. The material explains the difficulty of getting away from assumptions once they are held and the importance of changing viewpoints at ATS-P braking. For instance, we ask ourselves “Am I seeing the right signal?” and/or contact dispatchers to make sure they are doing the right thing, i.e., we take someone else’s viewpoints.

In addition, drivers learn that there are several opportunities for them to contribute to preventing SPAD accidents. The structure is described in a framework of the Swiss Cheese Model with three phases: preventing errors (phase 1), noticing and recovering from errors (phase 2) and mitigating the impact of errors (phase 3). Preventing errors is the most straightforward measure, but it is not the only way to prevent accidents. Even when a driver makes an error, no harm happens if s/he immediately notices and recovers from it. For instance, even when a driver misperceived a signal, a SPAD will not happen if the driver notices that s/he was looking at a wrong signal by correctly interpreting the meaning of ATS-P braking. Furthermore, even when a SPAD incident has actually occurred, it will not cause any harm if the driver realizes and correctly handles the situation such as immediately hitting the emergency brake and protecting other trains. This lesson widens drivers’ perspectives on SPAD-prevention strategies. In fact, the conventional driver training tends to focus much on preventing errors and is less explicit about the importance of error management.

Step 3. Thinking of error-prevention on one’s own through discussion
In the last step of this education program, instructors facilitate discussion by asking a series of questions such as what kind of actions drivers can take or are taking to prevent misperception of signals, what could be done to get away from wrong assumptions, and why the current rules and procedures such as pointing and calling in signal confirmation are important to comply with. Based on the knowledge and experiences shared with instructors and other drivers, each driver is encouraged to think of their own error-prevention actions and apply them in daily operations. Since instructors play a key role as facilitators during the discussion session, their understanding of human factors is essential. Therefore, we have also developed a guidance book for instructors as well, which includes more detailed descriptions of this education program and various examples of relevant driver errors.
3. Evaluation of Learning Effects of the Education Program

Pilot test
This human factors education program was pilot-tested from March 2015 through September 2015 at a training center. During the period, 170 drivers participated in the program as a part of regular driver training.

Evaluation method
Kirkpatrick's four-step model was referred to in evaluation of this education program. This model suggests that training programs are evaluated based on trainees’ reactions (step 1), learning (step 2), behaviors (step 3) and the results in business (step 4) because a favorable evaluation in one step does not guarantee the other steps' outcomes. Drivers' behavioral changes and the resulting effect in SPAD numbers require long-term evaluation, especially for this kind of education program for rare incidents. Therefore, the first two steps—reactions of drivers to the program and learning of SPAD-prevention strategies—have been evaluated by questionnaire in this research. The questionnaire was administered at the end of the education program and collected anonymously in order to facilitate honest responses.

Reactions of drivers were measured by two items: “Do you think you became motivated to learn human errors after this training?” and “Did you realize the danger of assumptions?” Drivers answered with a four-point Likert scale (1 = agree, 2 = slightly agree, 3 = slightly disagree, 4 = disagree).

As for learning of SPAD-prevention strategies, the questionnaire has two multiple-choice questions asking about a change of recognition before and after this education program: “What cause comes to your mind when ATS-P maximum normal braking was applied?” and “What is your most likely reaction to ATS-P braking application?” For the former item, drivers choose one option out of three: “signal misperception”, “lingering braking curve” and “failure of ATS-P system”. For the latter item, the response options are “to confirm not only the signal aspect but also the location of the signal”, “to confirm the signal aspect only”, and “to reset AST-P braking if maximum normal braking”.

Results
Error rates in the SPAD inducing scenario in simulation
During the pilot test, 45% of drivers misperceived a home signal and 94% of those faced ATS-P maximum normal braking by failing to notice the signal misperception, resulting in 72% of SPAD by resetting the ATS-P braking due to wrong assumptions (n=159). 57% of drivers whose train was stopped by ATS-P braking reported the event to a dispatcher, but 87% of those replied “the signal is indicating caution” with no realization of misperception when asked the aspect of the signal by the dispatcher.

It should be noted that the error rates do not necessarily reflect the reality of daily operations. Drivers know all relevant signals on the route they drive, while they had run the simulation route for the first time. Additionally, dispatchers played by instructors urged drivers to keep driving when they reported “the signal is indicating caution” rather than carefully checking various other aspects before giving permission to reset braking as real dispatchers would normally do.

Reactions of drivers
Reactions of drivers to this education program were largely positive. 98% of drivers, including 60% indicating “agreement” and 38% indicating “slight agreement” (n=170), answered that they became more interested in human errors after this program (Fig.3). In addition, all drivers, including 81% indicating “agreement” and 19% indicating “slight agreement” (n=170), replied that they realized the danger of assumptions (Fig.4).
Learning of SPAD-prevention strategies

Fig. 5 shows the responses to the item (n=162): “What cause comes to mind at ATS-P maximum normal braking?” Before this education program, 81% of drivers responded that they would have suspected the lingering braking first in this situation while only 12% of drivers responded that they would have suspected signal misperception by themselves. However, a significant change was observed in the post-program responses where 83% of drivers responded that they will suspect their own misperception when ATS-P braking is unexpectedly applied ($x^2 (2) = 166.7$, Cramer’s $V = 0.7$, $p < 0.01$).

Fig. 6 shows the responses to the item (n=161): “What is your most likely reaction to ATS-P braking?” It reveals that only 17% of drivers would have confirmed both location and the aspect of the signal, while 42% of drivers would have reset the brake without careful checking in case of maximum normal braking and 40% would only reconfirm the signal aspect before the program. However, the proportion of the proper response significantly increased from 17% to 83% and mistaken or insufficient reactions to this situation lowered from 82% to 22% in the post-program responses ($x^2 (2) = 128.0$, Cramer’s $V = 0.6$, $p < 0.01$).
4. Discussion

A strong impact of wrong assumptions was observed through the pilot test. Even in cases where drivers contacted dispatchers about the unexpected ATS-P braking, 87% of drivers did not notice that they were seeing a wrong signal and reported to the dispatchers that the signal aspect indicates caution. In some cases, drivers even believed that it was the neighboring train that passed the signal at danger and intruded into their path when they noticed an approaching train from behind. This tendency is also shown in the pre-program results of their likely reactions to unexpected ATS-P braking illustrated in Fig. 5 and Fig. 6.

Under this situation, the danger of driving with assumptions and the importance of NTS were well recognized through this program. NTSs seen as being important included careful recognition of a signal’s position in addition to its aspect.

Considering the reported benefits of blended learning", which combines multiple educational approaches such as activity-based learning and classroom lectures, the learning effects could be partly attributable to the framework of this program. That framework consists of various learning modes including experience-based training in simulation, self-paced learning with an educational comic book, and information-sharing with others through discussion.

It is also argued that motivation is a key factor in successful learning and learners become motivated more if the materials are to be relevant to their job or personal interests". Especially when it comes to simulation training, realism is important in order to lead to higher involvement and motivation". From these perspectives, it is implied based on the reactions of drivers shown in Fig. 3 and Fig. 4 that the experiences with the process by which SPADs occur in simulation made them realize the possibility of SPADs for everyone, including themselves, under certain situations. It is also implied that experiences stimulated their motivation to learn human factors and SPAD-prevention strategies.

Although there were groups composed of drivers who misperceived the signal and those who did not experience the process by which SPADs occur in simulation as described in the step one, there could be some difference in degree of learning effects between the two groups. The results of the pilot test suggest that learning effects were achieved in both groups when considering that all drivers realized the danger of assumptions and nearly 80% of them understood the SPAD prevention strategies after this program, although the majority of participants did not misperceive the signal in simulation. Those who did not misperceive the signal were told to keep driving on the assumption that they somehow mistakenly saw the neighboring signal and imagine how they would have reacted upon ATS-P braking under a strong belief that they were seeing the right signal. This approach might successfully let them realistically have the experiences with the process by which SPADs occur in simulation. However, this was not analyzed here because the evaluation questionnaire was submitted anonymously, making it impossible to link the responses to the questionnaire with a record of drivers’ performances in simulation.

Since the effects of learning on behavioral change has not yet been confirmed during the pilot test, further evaluation would be required through, for example, on-board instructions. On the other hand, 22% of drivers who received this education still failed to understand the importance of NTS according to the results of their likely reactions to ATS-P braking application (Fig. 6). While continuous training is required for drivers, it is also important to improve the interface of the ATS-P system and relevant procedures in order to eradicate SPADs as much as possible. Emergency braking at all home signals and separation of reset switches between those for emergency and maximum normal braking have been undergoing so that drivers can easily recognize the difference in the braking due to signal misperception and lingering braking curve. The rule for resetting maximum normal braking was also changed to require drivers to get dispatchers’ permission if maximum normal braking is activated twice at the same place. The implementation of various measures based on human factors approach will diminish the occurrence of SPADs and improve the safety level of JR East in the future.
A human factors education program for train drivers has been developed as a measure to reduce SPAD incidents and accidents. Upon confirmation of the learning effects in the pilot test, such as recognition of a danger of assumptions and understanding of SPAD-prevention strategies, this program has been rolled out companywide and incorporated in regular driver training that all drivers receive once every two years. This program provides a good start for drivers to recognize the importance of human factors issues in safe operations and improve their NTS. To facilitate their learning, effective feedback from instructors and local managers is crucial. Thus, it is important to provide further support for those in charge of drivers’ competence management in order to gain a deeper understanding of human factors.

Reference: