Optimizing Rail Signaler Disruption Management in the German Railway System

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Abstract:

Signalers have the task of controlling train traffic, setting points and signals and monitoring the functioning of the interlocking. In case of a disruption, the signaler first has to gain a sufficient understanding of the situation and then deal with the disruption to ensure the safety of the railway system as well as a minimal amount of delays. Thus, actions that have to be completed during a disruption are often time sensitive. In addition to handling the disruption, the signaler has to maintain control of the rest of their area of responsibility. Together, this can result in a highly demanding work situation during disruptions. As follows, the goal of the present study was to identify ways in which disruption management can be made less demanding. Furthermore, ways in which the signaler can gain an understanding of the disruption faster were to be identified. As a first step, the process of disruption management was analyzed in depth in cooperation with students of the University of applied sciences in Erfurt. Six typical disruptions were chosen for the analysis. The disruptions were chosen either due to their resulting safety risk, the resulting workload for the signaler or the frequency with which they occur. Data for the analysis was collected three ways: The current rule book used in Germany was analyzed as well as documents used in the training of signalers. In addition, focus groups with signalers were conducted. The analysis resulted in process diagrams that show all tasks a signaler has to complete during a disruption. In a second step, difficulties during disruption management were identified based on the process diagrams. Results identified the high amount of communication needed during the handling of a disruption as one of the main difficulties leading to a high workload. In addition, the process of giving train drivers written orders requires a lot of work and communication. With regard to the signaler having to understand the situation during a disruption quickly and easily, main problems were identified with the design of alarms leading to difficulties with identifying disruptions. In a last step, several countermeasures to minimize difficulties during disruption management were proposed, building on a new and usable interface for electronic interlockings. The countermeasures aim to optimize the process of identifying and managing disruptions, with the overall goal to increase usability and make disruption management easier and more efficient.

Introduction

Railway services are characterized by collaborative work between the infrastructure management and the railway undertaking. If a disruption occurs, it has to be resolved together. Delays due to disruptions pose difficulties for both branches of railway services, as delays result in high costs and unhappy passengers. As such, a quick and efficient disruption management is necessary to keep the resulting delays to a minimum. In the presented study, the current disruption management was analyzed to identify ways in which it could be improved. The focus was on the role of the infrastructure management in managing disruptions. The goal was to analyze the viewpoint of the signaler especially, as they are often the first employee involved during disruption management as alarms are displayed on the interface of the electronic interlocking or a train driver reaches out to the signaler via train radio. Currently, the infrastructure management in Germany is organized by personnel in seven transregional control centers accompanied by a multitude of local regional interlockings. Dispatchers located in the control centers are responsible for the strategic planning of the railway operations across regions. The resulting plans are then carried out by the signaler in the regional interlocking. The signaler is responsible for authorizing the movements of trains by setting points and signals [1]. Thus, the signaler is of central importance to the safety of railway operations.

Different types and generations of interlockings are currently in use in the German railway system, ranging from older mechanical interlockings to the most modern electronic interlockings. It can be expected that in the future, all older interlockings will be replaced by electronic interlockings. Thus, in the current study, only disruption management in the

work environment of signalers in electronic interlockings was analyzed. In electronic interlockings, the signaler observes train traffic using an interface presented on up to ten monitors. The current operating situation as well as current disruptions and the timetable are displayed on these monitors. The signaler uses mouse clicks or keyboard inputs to control train traffic and set signals and points. In addition, several electronic interlockings are equipped with automatic train control (ATC). ATC operates signals and points automatically according to the timetable, while the signaler supervises the correct functioning of the system. During normal operations, this leads to a reduction in active tasks the signaler has to fulfil. In case of a disruption, however, the signaler faces a sudden period of high demand. As the signaler is often the first person to be aware of a disruption, it is of utmost importance that they perceive and understand it quickly and correctly. Then, the signaler has to execute the necessary operating actions correctly and efficiently. The goal of the signaler during disruption management is mainly to ensure the safety of railway operations. In addition, they have to try to minimize delays, keep up functioning operations in their entire area of responsibility and remedy the disruption. Thus, during disruptions, the signaler faces a sudden increase in tasks, many of which are highly important for safety. In previous studies analyzing disruption management from the viewpoint of signalers, the increase in active tasks and communication resulted in an increase in perceived mental workload during disruptions compared to normal operations [2]. In a case study conducted in England, Switzerland and Austria [3], signalers reported that disruptions are high-stress, critical situations with a high workload, which lead to a neglect of less critical tasks (task shedding). Signalers criticized that during these high-stress situations, automation does not support them adequately, while during normal operations the implemented automation would not be necessary. In addition, shortcomings in the interface and alarm design were noted.
In light of the previous findings in other countries regarding flawed alarm design and disruption management leading to a high workload and task shedding, the process of disruption management from the viewpoint of the signaler in Germany should be analyzed in detail. Signalers have to be able to detect disruptions quickly and even during disruptions, signalers have to be able to control the unaffected train traffic without shedding tasks due to overload. As follows, in a first step the workflow of the current management of disruptions in Germany was analyzed from the viewpoint of signalers. As a second step, difficulties during disruption management were identified, also taking into account the design of certain alarms and the interface design overall. In a third step, measures to improve disruption management and make it less demanding were identified. Furthermore, ways in which alarm design and interface design could be improved were developed. Several countermeasures were proposed, based on a new and usable interface for electronic interlockings.

Methods

Disruptions included in the analysis

Six disruptions were chosen to be included in the analysis either due to their resulting safety risk, the resulting workload for the signaler or the frequency with which they occur: Malfunction of a remotely supervised level crossing, malfunction of a level crossing secured by a signal, a points failure due to a train passing the point before it reaching the necessary final position, a point not reaching the desired final position, malfunction of the clear track signaling system and line closures.

Step 1: Analysis of workflow during the management of disruptions

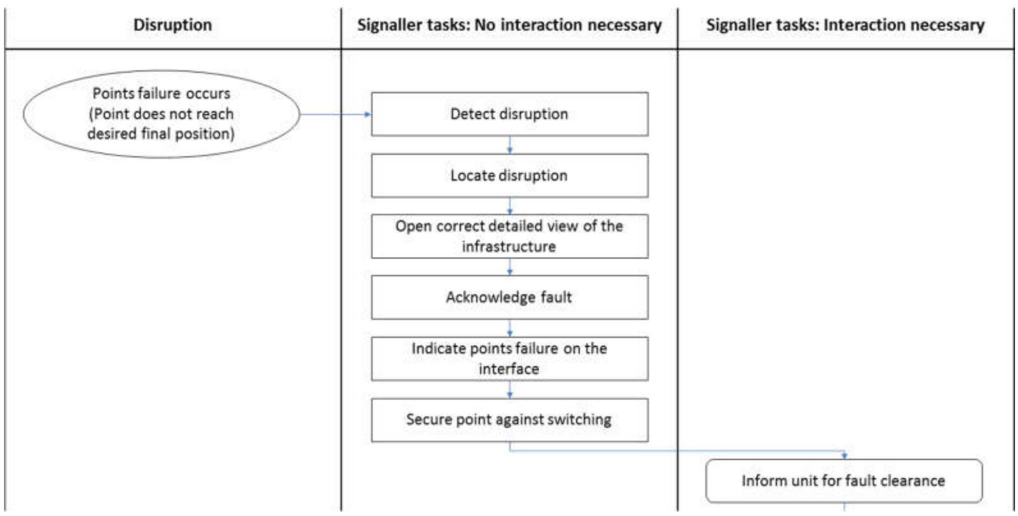

Figure 1: Part of the process diagram for a points failure

The process of disruption management was analyzed in depth in cooperation with students of the University of applied sciences in Erfurt. Data was collected from three sources and later combined. First, the current rule book used by signalers in Germany as well as training documents were used to gain an understanding of the processes a signaler is involved in during the management of disruptions. Second, several focus groups with four licensed signalers of the Deutsche Bahn were conducted, during which the signalers were asked to describe the process of disruption management. Third, disruption alarms, the user interface and the necessary actions to be taken by a signaler during a disruption were demonstrated and observed in a simulated environment of the electronic interlocking. The simulated interlocking is regularly used to teach students of the University of applied sciences in Erfurt the functioning of an electronic interlocking. After completing data collection, the data was combined and visualized in several process diagrams similar to the method applied by [4]. One process diagram was developed for each of the analyzed disruptions. All actions a signaler had to take to manage a disruption were included in the process diagram and separated by degree of interaction necessary. Thus, actions a signaler can complete without interacting with colleagues were depicted in one column and all necessary interactions in a second column. An example for a process diagram is shown in Figure 1.

Step 2: Identification of difficulties during disruption management

A workshop was conducted with ten railway engineering students. Four of the students had previously completed training as a signaler and were licensed to work at Deutsche Bahn. Based on the analysis of the process of disruption management, several difficulties during disruption management were identified.

Step 3: Development of countermeasures

In the same workshop as in step 2, countermeasures for the identified difficulties were developed using the method of Design Thinking. After the workshop, the proposed measures were developed further and adapted to be implemented in a new and usable interface for electronic interlockings.

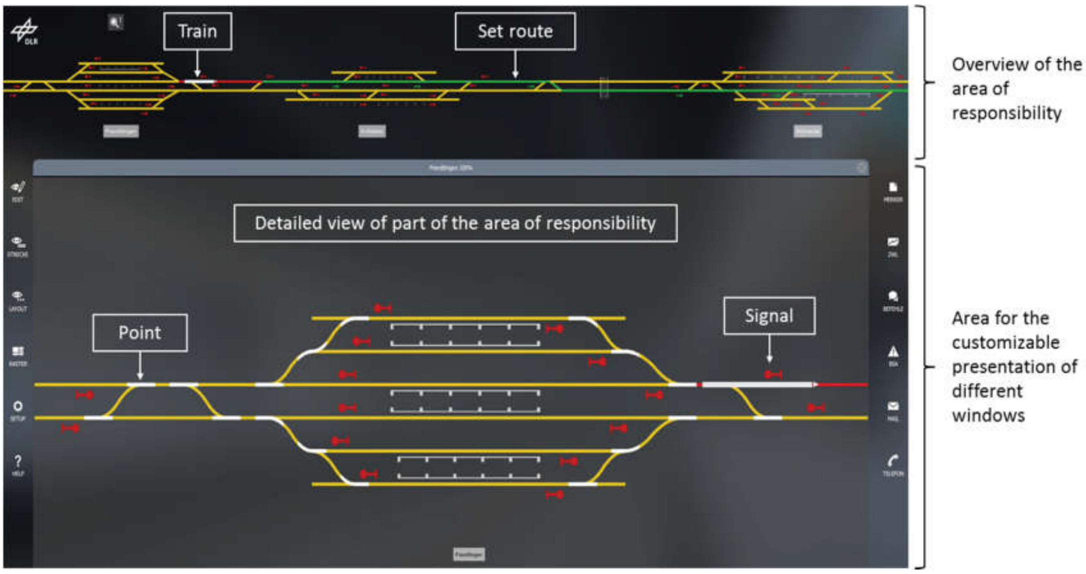

Figure 2: Example of one configuration of the interface of the FaBKon

FaBKon – a new and usable interface for electronic interlockings

In order to analyze the developed measures for an improved disruption management, DLR developed "FaBKon", a prototyping tool for human factors research on future workplace configurations for the rail traffic controller [5]. In the default setting, FaBKon displays a modern version of the human machine interface on a single touchscreen (see Figure 2). The interface elements are customizable and extendible and allow for the implementation and testing of new control and display designs that serve advanced disruption management. Thus, FaBKon can be used to test hypotheses about the effect of innovative elements based on objective criteria like controllers' visual focus of attention, response selection and performance. In addition, FaBKon offers a tangible basis for a design feedback of subject matter experts concerning their needs and preferences.

Results

Step 1: Workflow during the management of disruptions

The results presented in the following section are based on the process diagrams that were developed in step 1 of the current study. The ideal process of disruption management is described in short overviews for each of the analyzed disruptions.

Malfunction of a remotely supervised level crossing

The status of a remotely supervised level crossing is constantly transmitted to the interlocking. However, the level crossing is not secured by a signal; thus, the train driver is not informed about the current status of the level crossing during approach. In case of a disruption, the signaler receives an alarm. They then order an emergency stop for all trains approaching the level crossing. Using written orders, the train driver is informed that the level crossing is to be secured on sight and then crossed at a low speed. After stopping train drivers approaching the level crossing and issuing written orders, the signaler has to document information received from the train driver as well as document the communication with the train driver itself. In addition, the level crossing malfunction is indicated on the interface using a specific marking function. Further, the disruption has to be documented and several third parties have to be informed about the disruption, e.g. the dispatcher, other signalers and the unit responsible for fault clearance.

Malfunction of a level crossing secured by a signal

A level crossing secured by a signal becomes active as soon as a train route is set across the level crossing. The signal securing the level crossing is then only turned green if the active protection of the level crossing is confirmed and safe passage can be ensured. Thus, in case of a disruption, emergency stops do not have to be ordered by the signaler as the train will stop in front of the securing signal. The signaler can then order trains to cross the disrupted level crossing driving on sight using written orders or substitute signals. The process of documentation and fault clearance is similar to a disruption of a remotely supervised level crossing.

Points failure due to a train passing the point before it reaching the necessary final position

In case of a train passing a point before it has reached its final position, first an emergency stop has to be ordered for the train. Second, the point has to be secured against switching. Then the points failure is indicated on the interface using a specific marking function. Before clearing the point by ordering the train to drive on slowly, the signaler has to obtain authorization according to the type of point. After clearing the point, the train driver confirms the complete clearing of the point. The signaler documents every step of the process as necessary. As a final step, a maintenance worker checks if the point is damaged. If so, the point remains restricted until repairs are completed. Otherwise, the point returns to normal operations.

Point not reaching the desired final position

If a point does not reach the desired final position when setting a train route, the signaler first has to secure the point against switching. In addition, the points failure is indicated on the interface using a specific marking function and the unit responsible for fault clearance is informed. Trains affected by the disrupted point have to be rerouted if possible. Otherwise they have to wait for fault clearance. In case a point necessary for flank protection is affected by a disruption, the flank protection can be shifted to another point or signal and the train is permitted to drive on using either written orders or substitute signals.

Malfunction of the clear track signaling system

The clear track signaling system can be disrupted in different ways. Here, one possible malfunction is explained as an example. If a train enters a certain track section, the track section changes its color from yellow to red on the interface of the signaler. After the train has passed the track section, the track color on the display turns back to the initial yellow. If the clear track signaling system malfunctions, the track section on the interface remains red even though the train has already cleared the track section. In that case, the signaler first has to inform the dispatcher and the unit for fault clearance. Afterwards, it has to be determined if the relevant track section is really clear. This can be carried out by an employee checking the track section visually. If that is not possible, the next approaching train is ordered to approach the track section slowly driving on sight and thus confirming the track clearance. If the track is clear and the track clearance is depicted correctly, the disruption is treated as resolved. Otherwise, train integrity has to be confirmed and the process begins again.

Line closure

A line closure can be either planned or unplanned. A planned line closure (e.g. due to maintenance work) is not considered a disruption, thus here, the focus is on unplanned line closures (e.g. caused by a tree on the line). In case of an obstacle on the line, the signaler must be informed by the train driver. The signaler first has to identify the location of the disruption and then assess if there are additional trains approaching the location. If so, the signaler subsequently has to order an emergency stop for these trains. Next, the necessary documentation has to be completed and the line closure is indicated on the interface using a specific marking function. The unit for fault clearance and the dispatcher are informed and if a train had to stop in front of the obstacle, authorization for moving the train back in the opposite direction has to be obtained. During the clearance of the obstacle, the signaler has to reroute all trains that were supposed to access the closed line.

Step 2: Identification of difficulties during disruption management

Based on the process diagrams developed in step 1, difficulties with disruption management processes were identified as a second step during a workshop with signalers and railway engineering students. In the following, the main findings are summarized.

Overview of difficulties regarding disruption management procedures

In case of a disruption, signalers have to communicate with many actors. Communication usually takes place using telephone, train radio or GSM-R. Signalers have to inform several third parties about the disruption; in addition, they have to discuss the course of action for the affected trains with the dispatcher or controller. During the time spent communicating, fulfilling other time-sensitive complex tasks can be difficult. The need for communication increases even more if a disruption requires the signaler to direct train drivers using written orders. To issue a written order, the signaler fills out the order in paper form. The order is then read to the train driver via train radio. The train driver takes down the order in their order form and reads it back to the signaler, who then confirms the order. This process is very time-consuming and requires the signaler to communicate with each train driver affected by the disruption. Especially during level crossing disruptions accompanied by lengthy repair processes lasting several weeks, the amount of time a signaler has to spend giving written orders is tremendous, leaving little time to attend to other tasks. In addition, as the order is dictated using train radio, the process is dependent on signaler and train driver understanding each other correctly.

During a disruption, signalers may need to refer to the rule book or local guidelines, especially if the type of disruption is seldom. These documents are available in paper form in binders containing a multitude of pages. In addition to the high workload already imposed by the disruption, the signalers has to first locate the correct binder and then search for the correct entry manually. This process can be time-consuming as well and keep the signaler from attending to the disruption quickly. To summarize, difficulties in the management procedures were identified as a high need for communication claiming signalers' time and attention, heightened by the communication necessary to give written orders. In addition, the rule books and local guidelines are only available in paper form.

Overview of difficulties in the design of interface and alarms

In case a disruption is detected by the technical systems of the interlocking, the signaler receives an auditory alarm issued by the interlocking system. In addition, the disruption is displayed visually in the common alarm indicator using general error identifiers, e.g. "BÜ" for a disruption of a level crossing. However, the exact geographic location of the disruption is not shown. When noticing the alarm, the signaler has to find the area on their interface depicting the disrupted element. As the alarm is not shown closely to the disrupted element in a salient manner, the process of locating the disruption can take up valuable seconds. This can be dangerous especially in the case of disruptions of remotely supervised level crossings, where fast action might be required of the signaler to order an emergency stop. However, in the depiction of the infrastructure on the interface, the disruption of a level crossing is only shown using a small, hard to detect red S underneath the depiction of the level crossing.

After receiving an alarm regarding a disruption and identifying the location, the signaler has to acknowledge the disruption with a specific operating command. After acknowledging the disruption, the auditory alarm stops. The button to execute the operating command for the acknowledgement of the disruption, however, is not located closely to the disrupted element or infrastructure, but in some spatial distance in the bottom area of the interface. Thus, the signaler can acknowledge the disruption without first locating it on the interface. This might lead to the auditory alarm being switched off without finding the location of the disruption on the interface first.

Finally, difficulties were identified with regard to locating line closures. On the interface, closed lines are depicted as double lines instead of a single yellow line, with a small red X in the middle. This depiction of line closures lacks clarity and salience, making them difficult to spot. To summarize, difficulties regarding the design of the interface and alarms were identified mainly with locating disruptions and line closures quickly, as well as the danger of acknowledging alarms without having located the disruption on the interface.

Step 3: Proposed measures to improve disruption management

Building on the need for safe and fast disruption management and taking into account the issues described in the previous sections, measures to systematically improve disruption management are proposed in the following section. In the current paper, the adaptation of the measures for implementation in the FaBKon is reported. However, in addition the measures were adapted to be implemented in the user interface of the electronic interlocking currently in use in Germany.

Improvement of the design of interface and alarms

Several issues were identified regarding the design of alarms and the interface. A first measure proposes more ***salient visual alarms at the location of the disrupted element in the interface.*** If for example a points failure occurs, the alarm for this disruption would be shown closely to the disrupted element instead of in the common alarm indicator, as alarms are most effective when presented in close proximity to the depicted hazard [6]. A salient alarm can be achieved by choosing a color with a high contrast to the surroundings and introducing blinking [6]. As such, the visual alarm was designed as a blinking circle surrounding the disrupted element (see left in Figure 3). The color of the circle was chosen as fuchsia, as this color is visible very well against a black background. In addition, it is not yet used for anything else in the interface of the rail traffic controller. Red might be the traditional choice for an alarm, but the color is already chosen for other content and therefore not suitable. After the signaler acknowledges the alarm, the circle stops blinking and switches to a grey color (see right in Figure 3), as several continuously blinking circles in case of several disruptions might lead to information overload. The auditory alarm issued by the interlocking system in case of a disruption will stay in place in addition to the improved visual alarm, as alarms utilizing several channels of perception improve noticeability in times of high workload [7].

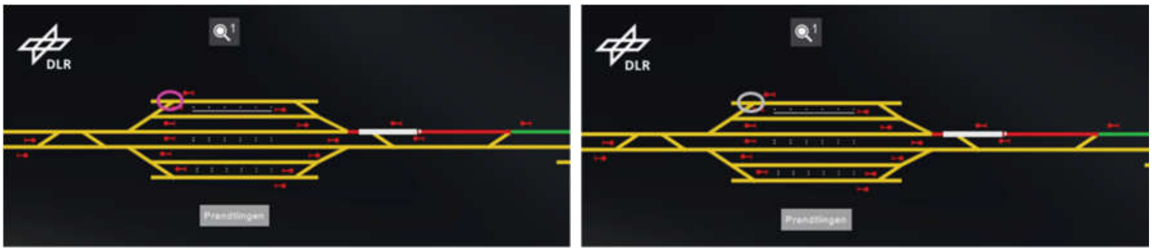

Figure 3: Salient visual alarms at the location of the disrupted element in the interface

The ***acknowledgment of the disruption*** takes place ***directly at the disrupted element.*** This prevents an acknowledgement of the disruption without finding the location of the disruption on the interface. In addition, interaction with an alarm or warning can increase noticeability and recall [6]. The signaler can acknowledge the disruption by clicking on an icon located directly next to the visual alarm (see left in Figure 4). The icon appears and can then be accessed by moving the mouse into the circle. When clicking on the specific icon for acknowledging a disruption, a dialogue window opens, in which the signaler can then confirm his action. After acknowledging the disruption and the circle turning grey the right icon shows a new symbol for deleting the disruption alarm after the fault is cleared (see right in Figure 4).

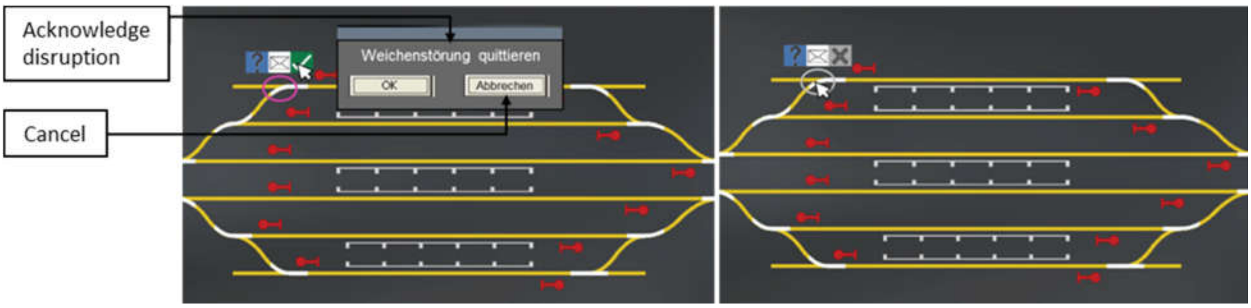

Figure 4: Acknowledgement of the disruption directly at the disrupted element

Similar to the design of visual alarms, the depiction of line closures on the interface was identified as not distinct enough. Thus, a more ***salient depiction of line closures*** was developed (see Figure 5). In the developed depiction, line closures are displayed along the entire track section that is closed by "crossing out" the line using the shape of the letter X. The color was chosen similar to the design of the visual alarm in case of disruptions. This design was chosen to display the unavailability of the track section intuitively.

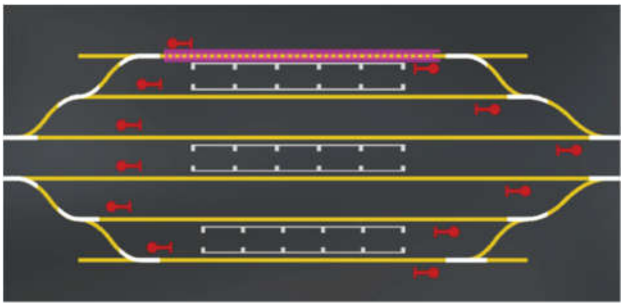

Figure 5: Salient depiction of line closures

As a final measure dealing with the design of the interface an ***overview of delayed trains*** was developed. This can be useful e.g. when regarding the example a disruption of a point for side protection. If such a disruption occurs when the ATC is active, the train will not start moving, as the train route cannot be set by the automation. The signaler does not receive an additional warning and has to identify the disruption if they are not called by the train driver waiting in front of the signal. If all delayed trains are displayed together in an integrated overview, the signaler might notice such stopped trains faster and easier. In addition, when dealing with a disruption, the signaler has to manage the disruption as well as the rest of their area of responsibility. An overview of all delayed trains lets the signaler know which trains they have to deal with in addition to dealing with the disruption and affected trains. As such, task management becomes easier. The overview of delayed trains was designed as an additional display window the signaler can open or close as they need to. The train number of delayed trains as well as the length of the delay are depicted (see Figure 6). Trains are ordered according to dispatch rules, with the most severely delayed trains shown at the top in red. Less severely delayed trains are depicted in yellow.

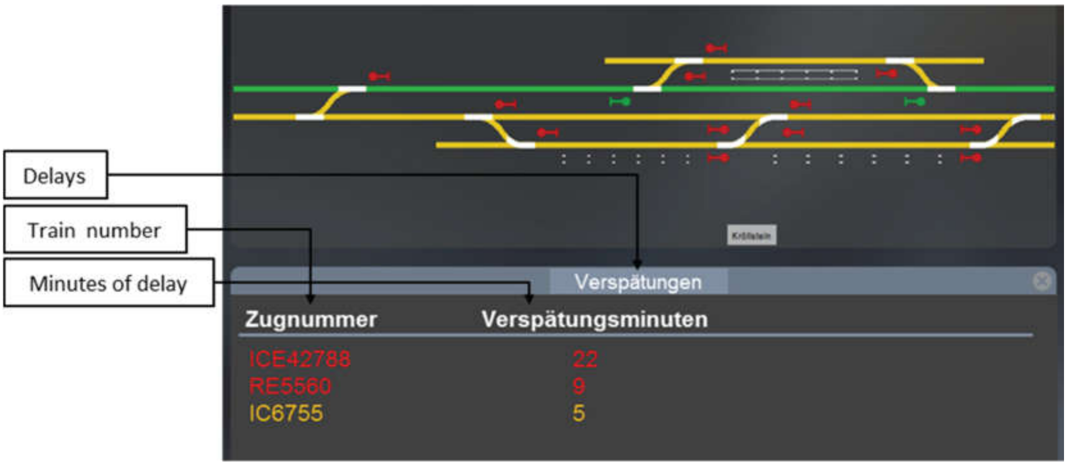

Figure 6: Overview of delayed trains

Digitalization of disruption management procedures

Communicating via GSM-R, train radio and telephone significantly adds to signaler workload during disruptions. On the one hand, the signaler has to inform several third parties about the disruption (e.g. the dispatcher, the unit for fault clearance or the emergency control center). On the other hand, the signaler has to communicate with the train driver to issue written orders. A digitalization of both processes is proposed in the following.
First, the ***digital reporting of a disruption*** to third parties is proposed. In a new display window, the signaler can inform the dispatcher, unit for fault clearance and emergency control center by completing a short digital form (see top right in Figure 7). The signaler can choose who to inform using check boxes. In the bottom half of the display, all reports already sent are listed together with recipient, content of the report and current status (see bottom right in Figure 7). The current status of a report can be sent or read – a report is marked as read if the recipient has opened and

acknowledged that he has read the report in their corresponding interface. The signaler can access the form for reporting a disruption by clicking an icon located directly next to the disrupted element, similarly to the previously described function for acknowledging disruptions (see left in Figure 7).

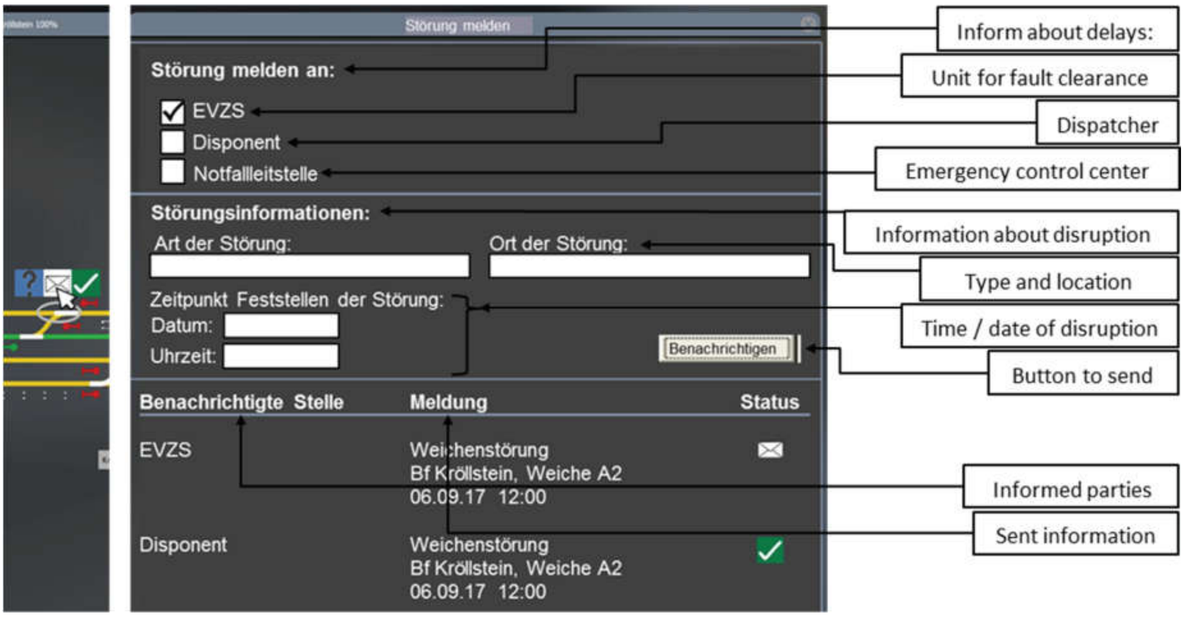

Figure 7: Digital reporting of a disruption

Second, a ***digital issuing of written orders*** is proposed to reduce signaler workload. For this function, a new interface for the train driver as well as a new display window for the signaler have to be designed. In the current paper, the focus is on the new display window for signalers. In the new window, the signaler can fill out the written order digitally (see right in Figure 8). All necessary information still has to be completed by the signaler; however, the train position is supposed to be completed automatically upon entering the train number. The written order is sent with the click on a confirmatory button. If the form is not completed in full, the signaler is informed, missing information is highlighted and the order is not sent (see right in Figure 8). All sent orders are shown in an overview (see left in Figure 8). Information for each order shown in the overview includes type of order issued, the train number of the train receiving the order, the time and date of issue as well as the status. Similarly to the digital reporting of a disruption, an order can either be sent or read. For the order to have the status read, the train driver has to acknowledge the order in their corresponding interface. Challenges for the design of the train driver interface are reviewed in the discussion.

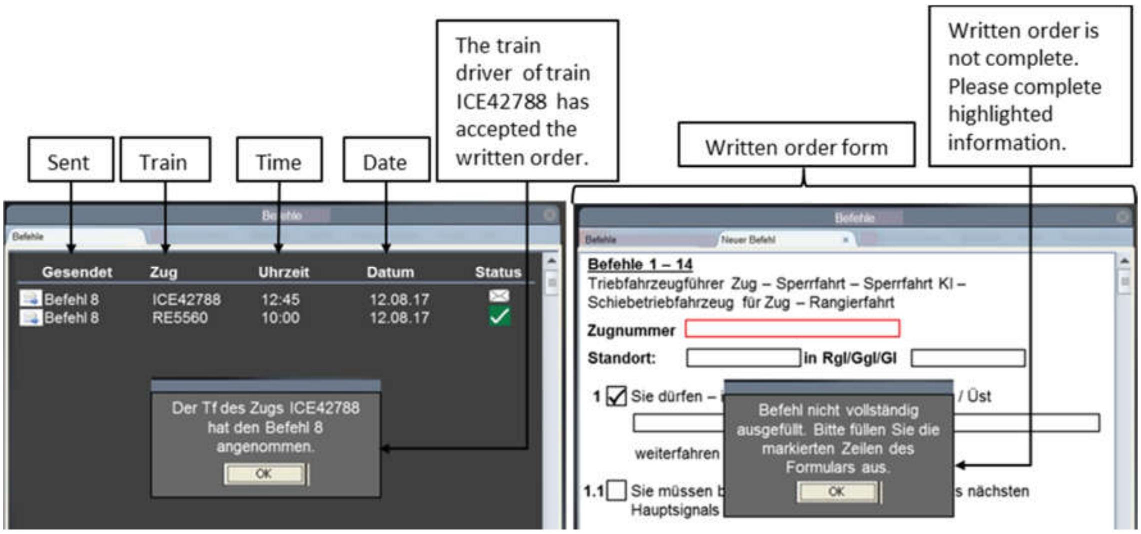

Figure 8: Digital issuing of written orders

As mentioned before, in case of a disruption, the signalers may need to refer to the rule book or local guidelines, especially if the type of disruption is seldom. To improve the current procedure, ***digital access to rule book and local guidelines*** is proposed. By clicking an icon located directly next to the disrupted element, the signaler can access a digital copy of local guidelines and the rule book (see **Figure 9**). In addition, the type of disruption present is displayed. Furthermore, it would be possible to implement guidelines for dealing with certain types of disruptions that could then be accessed using the same interface. This might be helpful for the signaler especially in case of novices or seldom disruptions.

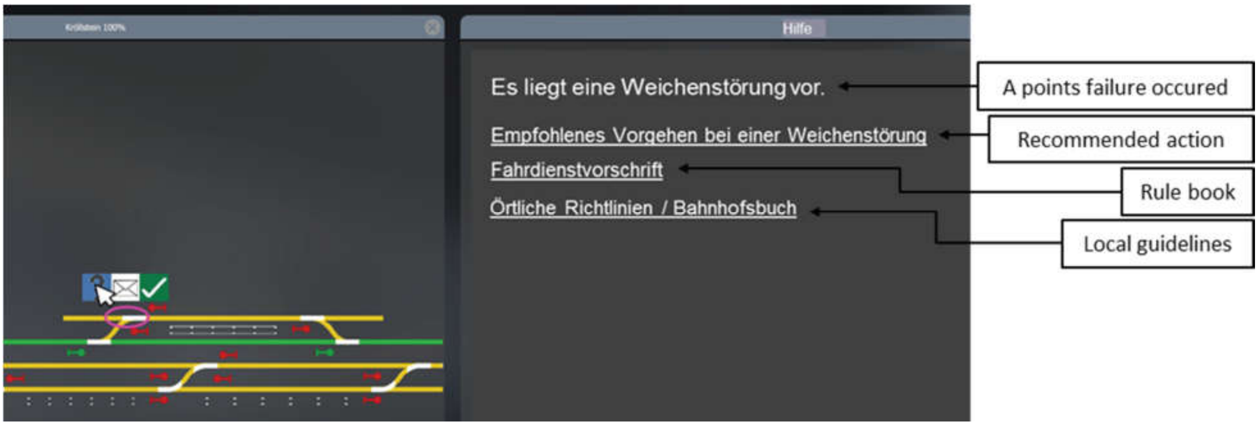

Figure 9: Digital access to rule book and local guidelines

Discussion

Several issues affecting the signaler during disruption management and increasing signaler workload were identified. Similar to previous findings [4], a high need for communication is one of the problems increasing signaler workload significantly during disruption management. Furthermore, shortcomings in the interface and alarm design were identified, similar to those mentioned by signalers in England, Switzerland and Austria [3]. As such, the results of the analysis of disruption management warranted the identification of countermeasures to improve the process of disruption management. Several countermeasures were developed that are adaptable to the FaBKon [5] and also to the interface of the electronic interlocking currently in use in Germany. In a next step, the developed countermeasures will have to be evaluated in user centered studies.

On the one hand, the countermeasures described in the article address the high need for communication claiming signalers' time and attention, increased by the communication necessary to give written orders. Tools for the digital reporting of disruptions and digital issuing of written orders were developed to support the signaler and decrease workload. These tools could decrease the need for lengthy and inefficient phone conversations and thus free valuable time for the signaler to deal with other tasks during disruption management. An additional advantage of the digital issuing of written orders is the possibility of implementing a logic check. Currently, the train driver is the only one checking the information in the written order entered by the signaler for errors. A logic check could verify the information entered by the signaler before passing on the written order to the train driver. This possibility of additional verification might help prevent errors during the completion of written orders.

However, to implement the digital reporting of disruptions and digital issuing of written orders it would be necessary to look at how the corresponding interfaces at e.g. the unit for fault clearance or in the train driver's cab should be designed. Especially with regard to the train driver, several issues have to be kept in mind. First, to avoid information overload in the train cab, it has to be decided whether a new interface is necessary or if the needed function can be included in an existing interface. Second, the functions regarding written orders have to be implemented in such a way that the train driver can fulfill the requirements for written orders in the rule book for train drivers (e.g. keep the digitally issued written order visible in the cab; take it with them when leaving the cab; indicate orders that were fulfilled). One idea for the design of such an interface would be to use a tablet as the basis for the system to ensure mobility. Third, it has to be ensured that the train driver actually read the order and understood it correctly before acknowledging it. In the current process of issuing written orders, this is ensured by the train driver reading the order back to the signaler. In a digital process, the reading back could be replaced as follows: The train driver could be required to type in the information of the issued order, to verify that the order was understood correctly. Only when typing the correct information would the train driver then be permitted to acknowledge and fulfil the written order. In summary, further work for the digital reporting of disruptions and digital issuing of written orders is needed in the design of necessary corresponding interfaces.

In addition to the digitalization of certain communication procedures, digital access to rule books and local guidelines was proposed. In Great Britain, a customizable app for a digital rule book was developed [8], showing positive results in a pilot study during operations (e.g. increased use of the rule book). In the solution proposed in the current study, a digital rendering of the usually printed documents is presented. This allows the use of a search function, supporting the user in quickly accessing needed information and thus reducing search times. However, a more comprehensive redesign of the rule book might be necessary to include functions for customization (e.g. choosing favorites and having shortcuts to access these favorites) to further reduce search times for relevant content.

Finally, several countermeasures were proposed with regard to the design of the interface and alarms. First, a more salient visual alarm for disruptions along with acknowledging the disruption closely to the disrupted element should decrease the time needed to locate disruptions. In addition, by acknowledging the disruption closely to the disrupted element, the signaler has to locate the disruption before acknowledging it. Second, a redesign of the depiction of line closures makes it more salient and easier to identify. Third, a new display window on the interface was developed to show an overview of all delayed train traffic. The goal here was to give the signaler a quick and easy way to gain an understanding of the current status of all trains located in their area of responsibility. This will enable the signaler to plan necessary actions efficiently. For the future, it might be valuable to include further functions in this overview. One option would be to include a digital documentation of the reasons for delays. Currently, the documentation of reasons for delays is completed using a paper document. By including an additional function in the overview of delays, this process might be digitalized and simplified.

In addition to the measures presented in this paper, it might be necessary to further investigate time and stress management strategies applied by signalers (e.g. strategies for task prioritization), as those might either improve or hinder performance in high-pressure situations. It might be valuable to identify effective strategies as well as ineffective ways to deal with stress and time pressure. Building on these results, trainings designed to teach signalers appropriate strategies might be developed. However, these investigations were outside the scope of the current study.

As a next step, all developed measures will be implemented on the interface of the FaBKon [5]. In the following, the measures will be evaluated with regard to usability and the overall effect they have on disruption management. If positive results can be achieved with e.g. regard to signaler situation awareness, workload or speed of disruption management, the question of a technical feasibility of the developed measures has to be investigated. All in all, several countermeasures were proposed, further improving a new and usable interface for electronic interlockings. An implementation and evaluation of the interface and countermeasures will provide valuable insight for the design of future interfaces at the signaler workplace.

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