Beyond procedures: Team reflection in a rail control centre to enhance resilience

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Abstract

Resilience engineering concepts can complement proceduralization of complex sociotechnical systems (STS). Proceduralization aims at defining precise and quantified system objectives, and at defining a process that describes and prescribes how to achieve those objectives. Although proceduralization has been successfully implemented to capture knowledge and experience, it is limited when the unexpected and unforeseen occurs. Resilience engineering focuses on this drawback and seeks for concepts to enable adaptive responses in these situations. We propose a team reflection process to enhance resilience of a rail STS, complementing its proceduralization. In the present study, we describe how rail signallers used team reflection, supported by a tool that allowed in-depth post-shift inspection of train movements. A near accident, occurring during a one-week observation, is described and used for two purposes. First, it was used as an example to explain the usage of the support tool. Second, it was used as a reference case of topics playing a role in evolving accidents. The analysis showed that the topic categories discussed during the team reflections were similar to the incident categories. This means that relevant topics are available, when things go right, to learn from and anticipate on. In addition, we showed that rail signallers, over the course of the observations, increasingly analysed and reasoned about their work. This enriched knowledge beyond procedures, enhancing the ability to cope with the unexpected and unforeseen.

Key-words

Team reflection, proceduralization, resilience engineering, naturalistic observation, rail control centre, sociotechnical system, rail signaller

1. Introduction

The approach of resilience engineering (RE) seems contrary to the proceduralization approach enabling sociotechnical systems (STSs) to cope with variability of external events. Resilience engineering deals with the ability of STSs to manage their spare capacity to cope with the unexpected and unforeseen (Leveson et al., 2006; Madni and Jackson, 2009). Margins are needed to manage the adaptation to these situations (Branlat and Woods, 2010; Cook and Rasmussen, 2005) when procedures do not exist for the unforeseen or are inapplicable during the unexpected. The emphasis in these situations is on the management of available abilities, for which RE seeks methods and tooling with relevant data to manage. On the other hand, the proceduralization approach focuses on procedures capturing knowledge on “how to do”, job rules, ingenuity and know-how (Fucks and Dien, 2013, p. 27). Rules and procedures are key features for a modern organisation to function (Bourrier and Bieder, 2013) and can lead to confidence in task performance, but also allow a retreat from initiative and responsibility (Fowler, 2013; Schulman, 2013). Proceduralization aims at defining precise and quantified system objectives, and at defining a process that describes and prescribes how to achieve those objectives (Bieder and Bourrier, 2013). This contrast can also be seen as the search for balance between stability and flexibility in operations (Grote, 2014). The procedures have a stable character while the resilience approach has a more flexible one.

Combining both resilience and proceduralization may be beneficial despite seemingly divergent starting points: the rigidity of procedures capturing past experience may be joined with the flexibility to manage available nontangible capacities. Procedures embody the knowledge base of an organization with respect to the operation of its technical system but rigidify behaviour and may result in mindless routine (Langer, 1989; Schulman, 2013; Taylor, 1911). Resilience promotes mindfulness but is as yet less tangible due to the complexity it is dealing with (Madni and Jackson, 2009; Woods et al., 2007). We propose to combine these approaches for a team in a rail control centre.

Rail signallers continuously fit unplanned train movements in the real-time flow of trains. They are responsible for their own part of the system, a particular geographical area in which they monitor the traffic situation or cope with a disturbed situation (Farrington-Darby et al., 2006; Heath and Luff, 2000; Steenhuisen, 2012). Within their decision space, they are expected to work according to prescribed procedures. When they have a break or finish their work, they transfer the status to the next signaller. Procedures with their deviations and other irregularities, at the moment of transfer, are communicated as facts and are seldom discussed. This type of information during their shift is only discussed when things go wrong and need justification and explanation. The results of these discussions, in some occasions, are fed back into procedure updates. The tools rail signallers work with support real-time operations, but offer few opportunities to look back to the past and discuss details. The log information is only available to analysts in the back-office, who analyse requested situations. Neither the tooling nor the regular process provide opportunities to the rail signaller to step out of the procedure space to learn to cope with its limitations. Their professionalism is mainly focused on following procedures. During training and inquiries, they can use their professionalism and think beyond procedures. This happens occasionally and even then the organizational directive to follow procedures remains. It would be desirable to be able to regularly distance oneself from procedural thinking (Norros et al., 2014), to see the continuous minor deviations of procedures, to be critical and open minded, and to share knowledge beyond procedures, which may be used when the unforeseen and unexpected occurs. We propose that before going home the whole signaller team will reflect (Reymen, 2003; Schippers et al., 2014, 2007; West, 2000; Wiedow and Konradt, 2010) on their shift with help of weak resilience signals (Siegel and Schraagen, 2014a). Team reflection includes behaviours such as questioning, analysis, making use of knowledge explicitly, reviewing past events with self-awareness, and coming to terms over time with a new awareness (West, 2000). Team reflection, in a loop with planning and action, is used in a broader reflexive process (West, 2000) where team members collectively reflect upon the team's objectives, strategies, and processes. This concept aims to improve the effectiveness of the team itself and stimulates organizational innovation in the context of the team's work. We extend this well-established reflection process in two directions. The first one is the scope of reflection and the second one is the subject to reflect on. The scope of reflection has so far mainly been limited to the reflecting team itself. We expand this to the whole STS, where the team is part of. Rail signallers operate at the sharp end of the system and are aware of the operating system beyond their scope of control (Flin et al., 2008). For example, they are aware of missing personnel on the trains, which, although not their responsibility, may cause a delay they do have to deal with. Second, the subject to reflect on are weak resilience signals (WRSs) (Siegel and Schraagen, 2014a), which contrasts to previously studied strong and explicit objects of reflection such as plans and performance failures (Schippers et al., 2014; Wilson and Norris, 2005). The knowledge made explicit through the reflection process may also relate to objectives, strategies, and processes but is not limited to these elements it and should go beyond them (Siegel and Schraagen, n.d.). This resilience related knowledge, beyond the knowledge embedded in procedures, will enrich professionalism as well as knowledge for learning, acting and anticipation purposes. These abilities are three of the four resilience building blocks (Hollnagel, 2009), learn, act, anticipate and monitor, and as such are expected to enhance resilience.

A WRS is a resilience related signal which needs further investigation, as opposed to a strong signal which demands immediate action. We have developed a model measuring weak resilience signals of a rail STS (Siegel and Schraagen, 2014a). The WRSs are derived from movements of the operating system towards its boundaries. We adjusted the boundary categories initially proposed by Rasmussen (1997) for a rail system: performance, workload and safety. Each category was modelled to enable quantification and identification of relative movements – changes in value during the working shift compared to a previous period like a week, month or year. These changes can visualize unnoticed drifts, which may contribute to a failure (Dekker, 2011). These relative movements do not need absolute values of the boundaries, which exists in theory but are not known in the real world. The workload measurement model was split into two. The first component was an objective model measuring data from the operational system and was based upon the cognitive task load model (Neerincx, 2003). The second workload component was a subjective unidimensional model (IWS - integrated workload scale; Pickup, Wilson, Norris, Mitchell, & Morrisroe, 2005) measured through a real-time App for each rail signaller. The workload models were tested during an observational study with off-line data. A discrepancy between both models stimulated additional inquiry by rail signallers in that study, which revealed an underlying operational obstacle concerning shunting (Siegel and Schraagen, 2014a). The performance measurement model, related to train punctuality, was tested through a second observational study with off-line data. An identified movement towards the performance boundary triggered further investigation and revealed an operational obstacle, which in that study concerned the communication between the police and rail signaller during a hooligan case (De Regt et al., 2016). The performance model has subsequently been extended to measure the punctuality of a controlled *area* and translated into a real-time application, which was used by rail signallers to reflect at the end of each shift during a third observational study (Siegel and Schraagen, n.d.). We showed how reflection made resilience related knowledge explicit and how the reflection progressed throughout the observation week.

The aim of this paper is to investigate the influence of team reflection, at the end of each shift, on relative system movements with respect to *all* three boundaries. We are interested in capturing team knowledge used during the shift that goes beyond procedures. In addition, we are interested in comparing team reflection on three boundaries, one boundary and without any tooling. Our research question is how team reflection complements procedures and how that possibly influences resilience of the STS. How does the reflection progress in time? Do the three boundaries make a difference in the type of topics discussed? In order to answer this research question, we conducted a fourth observational study at a rail control post with a real-time prototype presenting system movements towards the three boundaries with analysis functions to support the reflection. As it happened, at the start of the observation a near-accident occurred, which we analysed for types of topics discussed as they naturally occurred and used this as a reference to the reflection processes occurring later on that week. We analysed whether there is a relationship between the reflection and the near-accident to answer the first question above. In the next section (2) we describe the methods used, which include the design and requirements of the reflection tool, and the observational setup and analysis. In section 3, we present the results including the reporting and analysis of the near-accident case. In the last section (4) we discuss the results to address our research questions and their theoretical implications.

2. Methods

2.1. Requirements and design of the reflection tool (Resiliencer)

Team reflection needs a tool to support the process of identifying weak resilience signals (WRS; Siegel & Schraagen, 2014) and making resilience related knowledge explicit (Siegel and Schraagen, 2015). The team needs this tool because without it, we hypothesize there would be insufficient and also invalid information to draw upon while reflecting (this hypothesis will be empirically tested by comparing a reflection process without a tool to a reflection process with a tool). For designing such a tool we propose the following method in accordance with ecological interface design (EID) principles, as it was defined as an interface to expose “the constraints of the work environment in a way that is perceptually available to the people who use it” (Burns & Hajdukiewicz, 2004; p. 1). The EID approach is based upon the work domain analysis (Naikar, 2013; Vicente, 1999) using the abstraction hierarchy (AH; Leveson, 2016; Rasmussen, 1985) as a model to understand the work domain constraints. The AH has a similar theoretical background as the WRS, dealing with constraints through system boundaries. The AH uses five levels connecting the overall functional purpose to the physical object of the system. Each level contains a set of what-objects, which have a why-what-how relationship (Lintern, 2009) with objects in the level above and below. The objects in the level above explain why it is needed and the objects below explain how this is done. Figure 1 shows the AH of the reflection tool using the CWA application V1.0.2.1 of BAE systems (Jenkins et al., 2007). The functional purpose is to enable team reflection on Operating State (OS) relative movements to make resilience related knowledge explicit. The relative OS movements are changes of boundary field values in the work shift of the team with reference to those values in a reference period, like the previous week, month, or year. The functional purpose is achieved by presenting relative changes on the three boundaries – performance, workload and safety. Each of the boundaries needs a purpose related function to express its value. From this point, downwards in the AH, the details are more and more depending on the specific nature of the system. Below, we will work out in detail the design for our case – a rail system for reflection of rail signallers. Generically, these functions represent the relative movement of the overall rail system towards the three boundaries. However, this overview screen provides information on a system level, which is not sufficient enough to reflect on. Specific details are needed for the team members to recognize and identify with. The operators are not educated analysts and need a simple search mechanism to relate the system level information to object level details (Siegel and Schraagen, 2014b). The design of the tool needs to provide a simple search mechanism to link changes of each boundary domain to specific details. In the description below we explain, in our case, how this is done.

To make the AH specific for a rail system, we mention in the top row that the functional purpose is aimed at rail signallers, being part of a *rail* system. The values and priority measures are generic, since they refer to the system boundaries. We have edited the performance boundary description to emphasize that we focus only on punctuality, as an performance indicator. The punctuality is defined as the cumulative delay of delayed trains within a control area (Siegel and Schraagen, n.d.). The workload value is split into an objective measure from the operational systems and a subjective workload. The objective measure uses information available in the system: planning mutations, monitoring driven by the number of trains, command lines entered, and number and duration of phone calls (Van Broekhoven et al., 2016). The subjective measure is collected via a rating scale application requesting a 1-9 rating every five minutes (Siegel and Schraagen, 2014c). The safety value is a derivative of possible SPADs (signals passed at danger), which are mandatory reportable events and are used as a safety performance measure (Nikandros and Tombs, 2007). The number of SPADs that occurred in the Netherlands in 2014 was 112 (Dutch Ministry of Infrastructure and Environment, 2015). This is on average 10 times a year for each of the 12 posts or less than once a month. This number of occurrences is not enough to reflect on each shift. Instead of the SPADs, we have therefore taken the number of red signal approaches as safety indicator. The more red signal approaches, the higher the risk of a SPAD (Siegel and Schraagen, 2014d). The other purpose related function next to the movements towards the boundary is the search function for reasoning and discussion, which allows the team to search for relevant technical data. All of the purpose related functions use object related processes, which are related to rail physical objects, like a train, signal and plan (see lowest level in figure 1).

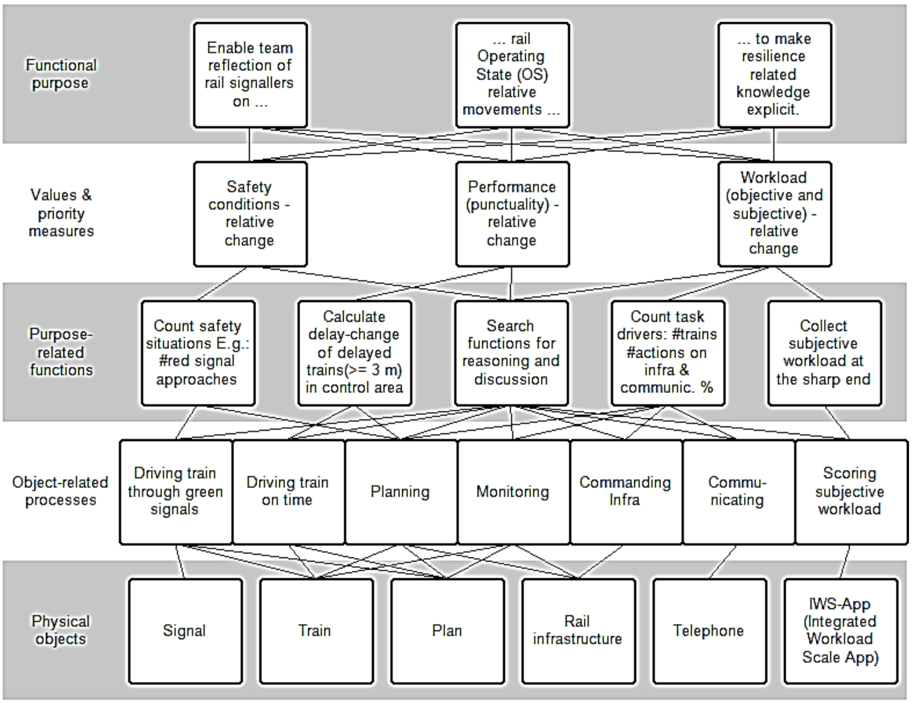

Figure 1 Abstraction hierarchy of the reflection tool (Resiliencer)

This description, through the AH analysis with high-level requirements, has been transformed into a real-time application, we named the Resiliencer, with a main screen, visualising the relative operational state vis-à-vis its system boundaries (see figure 2). The green triangle represents the results of the reference period with values in the green circles. The values in the black circles represent the actual shift and have three position possibilities with respect to the reference – towards the boundary, from the boundary and similar distance to the boundary. The combination of all boundaries enables the understanding of their interrelationships and trade-offs (Cooke et al., 2001; Qureshi, 2008; Tamvakis and Xenidis, 2013). For reaching the specific details from system level values, we designed for each boundary a three-click search (see an example with explanation in the results section Figure 7). The performance boundary analysis links the punctuality change of the controlled area to the contribution of a specific train, searched through train series and time. The workload boundary analysis finds the relation between a subjective/objective workload change and a specific workstation in time through workload stretches (Siegel and Schraagen, 2014a) occurring during a shift. The safety boundary analysis locates the relation of a relative safety change and the hourly occurrences of red-signal approaches, or safety messages, in the area of a specific workstation. The specific details should stimulate discussions, to make related knowledge explicit (Siegel and Schraagen, 2015) beyond the procedures followed or adjusted – one of the goals to be observed during the study.

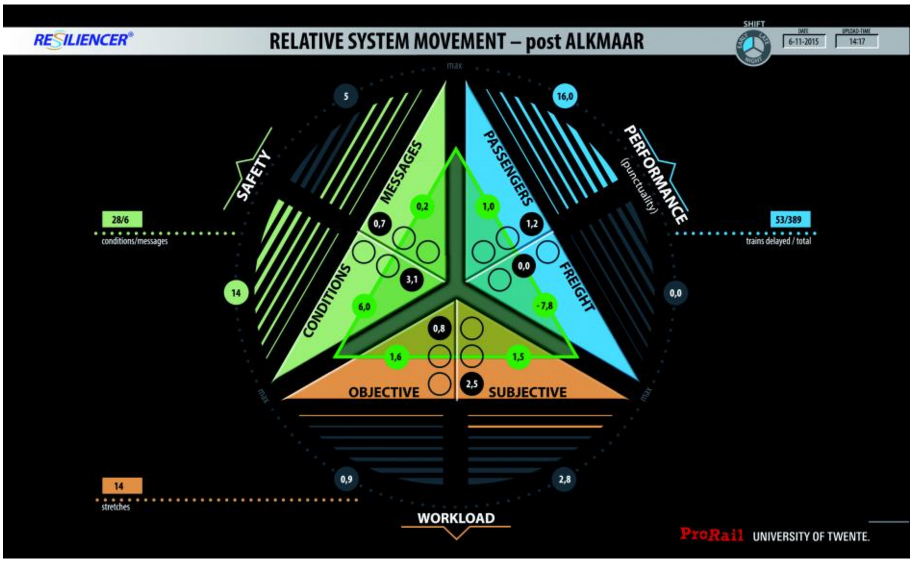

Figure 2: The Resiliencer prototype used in the current study (translated from Dutch)

2.2. Observational study design

The naturalistic observational study took place in the Dutch rail control centre Alkmaar, which is responsible for all train movements to the North and West of Amsterdam. The area contains approximately fifty rail stations and controls about thousand train routes a day. The 24/7 control centre contains workstations for different roles (see figure 3): 1) four rail signallers (RS), 2) regional dispatcher (RD), 3) bridge operator, 4) three public transport announcers, 5) calamity support, and 6) team leader (TL). On the wall near the team leader was a large presentation screen, which was used to display the Resiliencer. In front of the screen was the reflection area, where all RSs and TL gathered. The 24 hours a day are divided into three shifts – the early shift (6:30 AM – 2:30PM), the late shift (2:30 PM – 10:30 PM) and the night shift. In this study, we focussed on the rail signallers only. However, the team leader led the reflection and others in the control room were mentioned in the discussions (section 3.1) and the safety case described (section 3.2). During the observation period the late shift arrived at 2 PM, making it possible for the early shift to reflect with the team leader from 2:00 to 2:30 PM. The late shift reflection took place at about 9:30 PM, during which the backup rail signaller and the regional dispatcher were monitoring the four workstations. The observation took place in a single week from Monday 6:30 AM until Friday 2:30 PM, as well as the Thursday before. This Thursday was used as a baseline measurement when reflection was carried out without the Resiliencer. During the observation week, the Resiliencer was used as the central reflection tool. The team reflection sessions were recorded and transcribed for analysis, while during the shift the rail signallers were observed and interviewed on their findings.

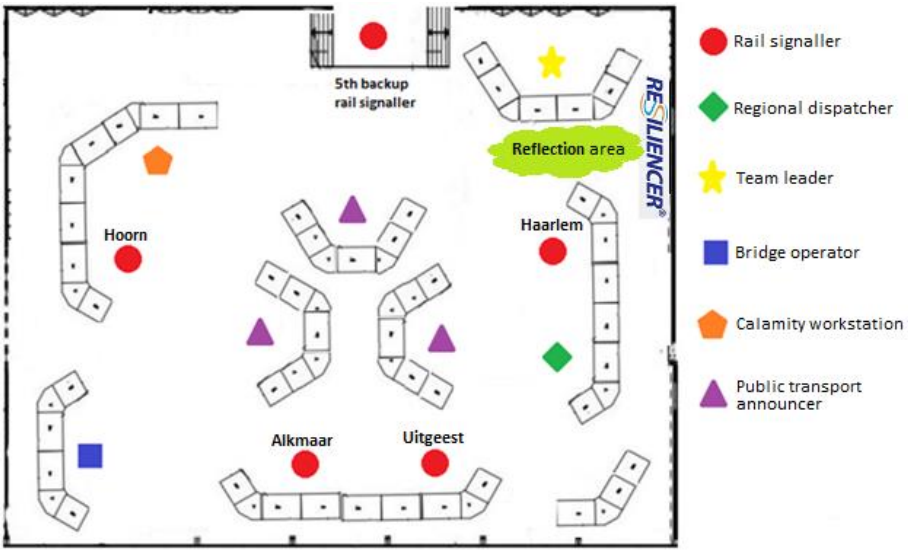

Figure 3 Rail control centre layout with reflection area and Resiliencer on the wall

3. Results

3.1. Team-reflection observation

3.1.1. Daily observations

In the following text we number in brackets in-depth discussion topics, which we summarize and analyse in the next section (3.1.2 Week observation overview).

The first team reflection observation took place on Thursday at the late shift *before* the observation week with the Resiliencer. The team reflection was done without any support and was driven only by the memory of the participants for what had occurred during their shift. During the whole discussion, no specific train number was mentioned. When the RS discussed an event, he only mentioned the train series, and while the other participant knew immediately its trajectory, he did not remember the exact train number. The whole discussion was only about logistics and of a generic nature. For example, a train from the 3300 series coming from Hoorn, a city north of Amsterdam, had been cancelled because of cumulative delays. The discussion topic moved to the role of the regional dispatcher (RD) (1), who was absent at the control centre and whose role was taken over by the RD positioned in Amsterdam. The majority thought that a RD can communicate electronically from another physical location and function well, as was the case in their shift. This topic was about a procedure change. Another topic discussed was the decision of a Dutch railway company (the NS), that decided to add stops to intercities (2) since they had problems with their stop-trains. Their decision influenced freight trains, owned and managed by other rail companies, whose delays grew due to the intercities stopping in front of them on small stations, so the freight trains could not pass. This topic was about the reasoning behind the procedure. The last topic discussed was the inconsistency of the NS with cancellation procedure of trains (3), which happened at that day with the 3400 series. Workload and safety matters were not mentioned at all during the discussion. This strengthens one of the Resiliencer goals: to display information on workload and safety as well, stimulating attention, discussion and interrelationship of system boundaries.

The first reflection with the Resiliencer (see figure 4) took place on Monday afternoon of the early shift. Similar to the late shift, there was scepticism about the value of reflection for the rail signallers. Some of them laughed saying “we have entered a lot of ones” (referring to the subjective workload scoring scale of 1 to 9), which indeed was the case. On the first day, 80% of the IWS scores were one, while the rest of the week on average 59% IWS scores were one with a standard deviation of 8%. One of the TC’s wondered “Do we gain anything personal from this process?”. A large percentage of the time was spent explaining the functionality of the Resiliencer. The serious case of a near accident, described in section 3.2, was barely discussed. The high workload stretch associated with the near accident was identified, but the RS in question was sent home and nobody else knew the details. A few specific trains (1514, 14525, 3328, etc.) were mentioned but only one of the RS’s explained what happened to trains without response and discussion with the other team members. No in-depth discussion took place, which seems a start-up phenomenon of introducing the new process.

Figure 4: Rail signallers and their team leader reflect on their shift with help of the Resiliencer

The Tuesday late shift was the next recorded observation, since there had been a technical problem with the voice recording during the early shift. The reflection topics shifted from train logistics to workload and annoying personnel. Many trains seemed to have problems with the lead guard (LG) starting from Den Helder, which is the start station in the north. The LG's are sometime missing or too late on the trains (4). This is context information influencing procedures. The team started focusing on pattern repetitions of train numbers with similar delay occurrences in the previous period. They understood that the 5400 series was mainly delayed due to delays of the 2100 series in the rush hour – a planning issue to be solved. They identified eight workload stretches and discussed each of them: "I had to do three things at the same time", "I could not get in contact with the node coordinator", etc. There was a long discussion on an instruction-form filled out incorrectly by the NS. They identified an unknowledgeable NS-worker and discussed how they should deal with that. At the end of the discussion they analysed the correlation between safety data and the workload stretches, finding the information to be consistent.

On Wednesday, the teams started to grasp the concepts of the reflections by analysing the reasoning behind their workload stretches. They recalled a case with someone who walked along the rail tracks who happened to be a refugee (5). It seemed that the train driver had taken the person into his cabin until the next station, which is not according to the procedures. A train driver should not take any person into his cabin. A discussion developed on refugees in the Netherlands, which is beyond the procedure concerning a rail-walker but may reveal relevant knowledge to understand the behaviour of the rail walker and the train driver in this context. The 3008 train had a delay caused by a defect train compartment, and they analysed the consequences on the 800 train series. They also identified the delay of train 5156, which was discussed on Thursday as well. This is a good example of returning topics, where the team may identify patterns, which are normally not seen. The next topic were the differences between train drivers, some of whom drive faster to diminish the delay while others drive normally enlarging the delay (6). The difference between rail signallers was discussed as well (7). The workload was analysed and they identified six workload stretches, where one workstation had no stretch at all. All stretches were treated and discussed systematically.

On Thursday, the early team identified topics they analysed in depth and enjoyed their understanding. The late team started experimenting with the reflection sequence. The early team had a case with a troublesome traveller (8) in train 3047 arriving at the small station of Castricum, with no possibilities for other trains passing by. The train caused an extra delay for train 3441 that had to wait before the station until the police arrived. The team analysed the difficulty of forecasting the expected delay and the new role of the back-office to be the contact entity with the police. Before, they had the contact themselves and could better estimate the delay. In the new situation they communicate only with the train driver, who in some cases is not on the train or inaccessible. This influences their replanning task. They concluded that train 3047 should have continued until the next station, Uitgeest, where there are more shunting and switch possibilities. This topic clarified reasoning behind events and needed further discussion with the NS. Another topic analysed was "the rush hours with thousands of passengers and missing rolling stock" (9) and different ways to deal with that. During the discussion on workload they explained to each other how they rated the subjective workload. One RS said “via IWS we tell our story even if we do not feel extra work stress”. “We use the low rating until IWS=5 for small events to tell the story”. The early team finished their discussion on red planning lines (10) and their use for controlling the system. A red plan-line cannot be executed by the automated system for various reasons and needs manual handling of the RS. The late team experimented with the discussion sequence starting from the safety boundary to the performance boundary, through the workload boundary, which was the opposite direction until then. This approach was the own initiative of the team leader, which showed trust in the process. They identified many red planning lines (10) around the rail station Hoorn, revealing delays of trains coming from Amsterdam crossing each other at Hoorn. In addition, they identified a delayed train, the 5156, which one of the RSs discussed the day before - “we discussed that one yesterday and now it is part of the reference period”. The repetitiveness was an issue to be reported to the planning department. From this point on they put more emphasis in their analysis on the delayed trains appearing in the previous period. At the end they discussed the large number of stretches (11), 15, mainly caused by the many delays that day. During one stretch the RS was 9 minutes on the telephone, a parameter they were not aware of.

The early shift on Friday was the last reflection. The team seemed to enjoy the analysis and the word “interesting” was mentioned eight times. The special procedure of “high green” (12) was discussed. Through manual settings of the RS they were able to set a rail path with only green signals without yellow ones, even when entering a station. In a normal situation the exit signal of a station is red causing the previous signal to be yellow, forcing the train driver to reduce its speed on entrance. By setting the exit signal to green together with the previous signal, the train driver brakes at a later moment and leaves the station earlier. This way rail signallers can reduce the delay. Some of the RS’s use this tactic, while others do not. The pros and cons of this tactic were discussed, which could become a formal procedure. One RS expressed how he was rating his subjective workload; “IWS=1 – I have nothing to do, 2 – I have one thing to do, 3 – I do a few things parallel, 4 – it is getting complex, … 7 – an alarm is additionally coming in”. They also discussed three tactics (13) to deal with delays. One RS was updating his delay continuously in the plan. The second RS judged each train individually within its context whether the plan should be updated. The third RS left the plan as much as possible untouched. The pros and cons of these strategies were discussed, enriching the formal procedures. The team wrapped up the reflection week expressing their understanding of the contribution and belief in the concept, emphasizing the need for organisational change to feed the results back into the organisation - “yes, it is very useful, but only if something is done with the things we say”. In addition, they suggested to incorporate other parties in the reflection process like the passenger, freight and maintenance companies.

3.1.2. **Week observation overview**

From the daily description in section 3.1.1, we discerned progress throughout the week. The first day started with scepticism about the value of team reflection. The second day the topic of discussion expanded from train logistics, which was their main concern, to topics related to workload. The third day, RSs started to understand the new concepts. The fourth day, they started to analyse the topics in more depth. The last day, RSs were really searching for topics they framed as “interesting.”

To quantify their growing trust in and ease of use with the support system, we counted their subjective load stretches with IWSs smaller or equal than 4. We assume that RSs rated IWS =<4 when something happened they wanted to explain, while stretches with IWS>=5 were used when a serious external event occurred. This was also expressed by one of the RSs on Thursday. When RSs rate more stretches with IWS=<4, they are more involved, as this indicates a more urgent internal need to explain, rather than an externally imposed need caused by external events. We saw that during the week the number of small stretches increased (see Figure 5). This finding supports our observation of a growing involvement during the week.

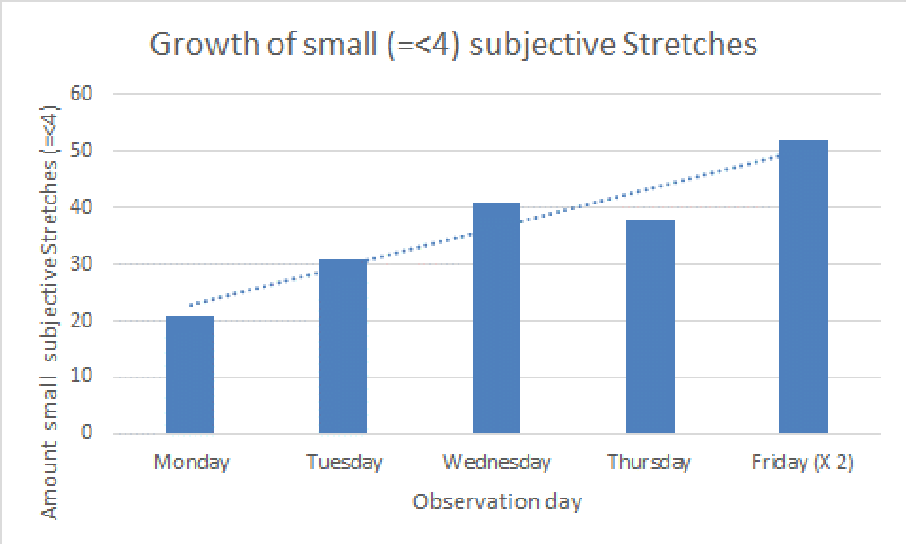

Figure 5 Growth of small (=<4) subjective stretches throughout the observation week

We summarized the description in section 3.1.1 into a list of topics, which were discussed in depth, throughout the week. In Table 1, we added a column of topic categories, to enable comparison with the topics contributed to the near accident described in the following section (3.2). Most topics are related to procedures and add knowledge beyond them in three ways. First, the knowledge leads to procedure update and improvement. Second, the topic discussion enriches details of the procedure description, which is always limited (Fucks and Dien, 2013). Third, the topic reveals knowledge about the real complex world, contrasting the world assumed when constructing the procedure.

Table 1 Discussion topics during reflection (numbered according to appearance sequence marked in the text of section 3.1.1) with related underlying procedure.

No	Discussion topic during reflection	Topic category	Related procedure
1	Role of RD with cancelling trains	Work overview	Cancel train
2	Adding extra stops for intercities	Procedures	Order acceptance
3	Inconsistent train cancelling	Procedures	Cancel train
4	Absence of train staff	Staff functioning	Update plan, Recall train path
5	Rail-walker	Procedures	Lower speed, Inform police
6	Dependency on rail driver to decrease delay	Staff functioning	Delay handling
7	Culture differences between posts	Work conditions	-
8	Troublesome traveller	External conditions	Call police, Update plan
9	Rush hour with missing rolling stock	Infrastructure	-
10	Reasoning about red plan-lines	Planning	Manual commands
11	Explaining workload	Work conditions	-
12	The "high green" procedure	Alternatives	Manual commands
13	Tactics coping with delays	Alternatives	Update plan

3.2. Near-accident case: Two nose-to-nose stopped trains

In the case description we entered numbers in brackets near the main contributions of the accident evolvement, which we summarize and analyse in the end of section 3.2.3.

3.2.1. **Background**

During the day shifts of post Alkmaar four workstation are ordinarily manned: 1) Haarlem; 2) Uitgeest; 3) Alkmaar and 4) Hoorn. During the night shift workstation Uitgeest is unmanned and divided up across the other workstations. The area of station Zaandam is moved from workstation Uitgeest to Hoorn and projected on a separate screen (1) (see Figure 6). Between rail-station Zaandam and the next rail-station Zaandam-Kogerveld is Zaanbridge BR4151 crossing the Zaan river. Signal 194 is positioned before the Zaanbridge and the previous signal on the track, located at the exit of station Zaandam, is number 278. The bridge operator can open the bridge twice an hour: 1) between 10 to 20 minutes over the hour and 2) between 40 to 50 minutes over the hour. Train 1514 is daily planned to leave Zaandam at 6:42 AM and arrive at Zaandam-Kogerveld at 6:47 AM being in conflict with a potential opening of the bridge (2) when a boat is requesting to pass. This conflict in the plan has been discussed among all related parties and accepted. A boat passing through between 6:40 AM and 6:50 AM will cause train 1514 to wait before red signal 194 and to be delayed for several minutes. This situation does occur occasionally.

3.2.2. **Sequence of events**

Rail signaller X (RS_X) worked in the evening before the accident in the late shift (3). Normally RSs do not work in the early shift the following day, but in this case RS_X finished the late shift at 7PM instead of 11PM having more time to rest before getting up early next morning. The responsible team leader believed that the gap between 7PM and 6AM was sufficient to start the next day in the early shift. At 5 AM one of the rail signallers called in sick (4) and the team leader on duty decided to continue with the night shift formation into the morning shift (5) until a replacement had arrived. RS_X, a new employee working for half a year independently on workstation Hoorn but never in the night formation during the day shift (6), arrived at 6 AM working at the extended workstation Hoorn including rail-station Zaandam. This morning showed dense fog (visibility less than 100 m) (7) and train 1514 was driven by a train driver in training (8). The Zaanbridge was open causing signal 278, at the exit of rail-station Zaandam, to be yellow, indicating signal 194 to be red and demanding velocity reduction. Unfortunately, the red lamp of signal 194 was faulty and did not show (9). The rail-driver in training, detected the defect signal too late for braking on time, and stopped the train after the ”red” unlit signal – a SPAD (signal passed at danger).

The alarm went off at the control centre, where RS_X contacted the train driver of train 1514 and started the prescribed procedure. A facet of the procedure is to take the tracks, PP and PC, on the bridge out of order and to take measures instructing trains approaching the bridge to turn. Train driver 3325, being at track PB, called RS_X to turn in Zaandam-Kogerveld according to the measure. RS_X discussed two options to turn (10) (see Figure 6). Option 1 was to enter the station on track PC, which is the normal platform to continue towards Zaandam. Option 2 was to enter the station on track PP, which is the platform used to drive in the other direction, making clear to the passengers that the train is turning. RS_X decided for option 2 for passenger clarity and gave train 3325 permission to approach track PP. At the end of the procedure with train driver 1514, he asked for permission from RS_X to progress to rail-station

Zaandam-Kogerveld on track PP, which had been taken out of order. The request was granted with the instruction to drive slowly. Train 1514 approached the station carefully and spotted train 3325, through the fog. He stopped the train, avoiding a collision and standing nose-to-nose.

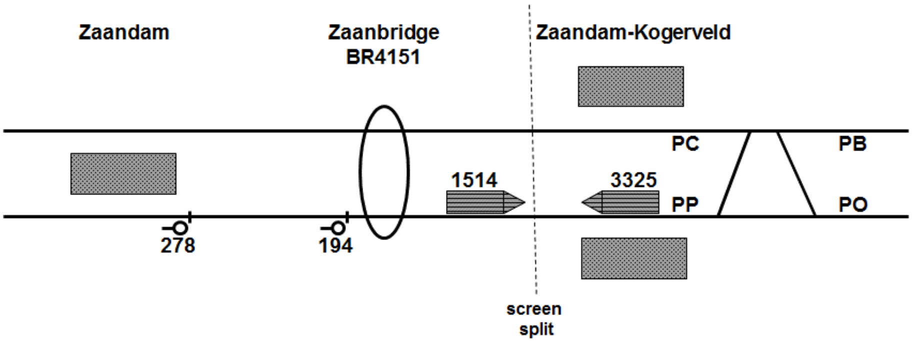

Figure 6 Situation of the nose-to-nose near accident

3.2.3. **Case overview – relevancy for team-reflection**

This near-accident case, occurring during the observation period, is in two ways relevant for team reflection. First, the Resiliencer presented technical information of the incident enabling discussion. Second, the analysis of the incident revealed a list of facts playing a role in the outcome, which could have been different when treated through previous reflections. The Resiliencer supported the reflection in the afternoon of the first day. The workload analysis revealed the incident. The subjective workload (IWS) was the largest at workstation Hoorn. During the shift the average IWS at Hoorn was 3.7, while the average of the whole post was 2.8, as seen in Figure 7 marking 1. This caused the team to push on the "Hoorn" button (marking 2). The workload analysis showed two stretches, where the largest was 4.68 at 6:40 AM (marking 3). When choosing this stretch, the Resiliencer presented its workload over time (the window of marking 4) and detailed alphanumeric information of the stretch (the window of marking 5). The subjective workload (IWS) was initially a 4 for 5 minutes, then a 5 for 20 minutes, followed by a 7 starting at 7:20 AM for almost an hour. At 8:15 the IWS dropped to 4 until 11:30 AM with a jump to 5 at 9:45 for 25 minutes. Alphanumeric data of the stretch showed a duration of 315 minutes, an average subjective workload score of 4.68 an objective workload score of 2.38, list of involved trains from the 1500, 3300, 3400 series, 54 minutes on the phone, and 23 red plan-lines, which were not executed by the automated system. The information was noticed by the team during the reflection but no relevant knowledge was made explicit because RS_X, handling the near-accident had been sent home. The other RSs did not know the details, which were sensitive at the time they discussed this.

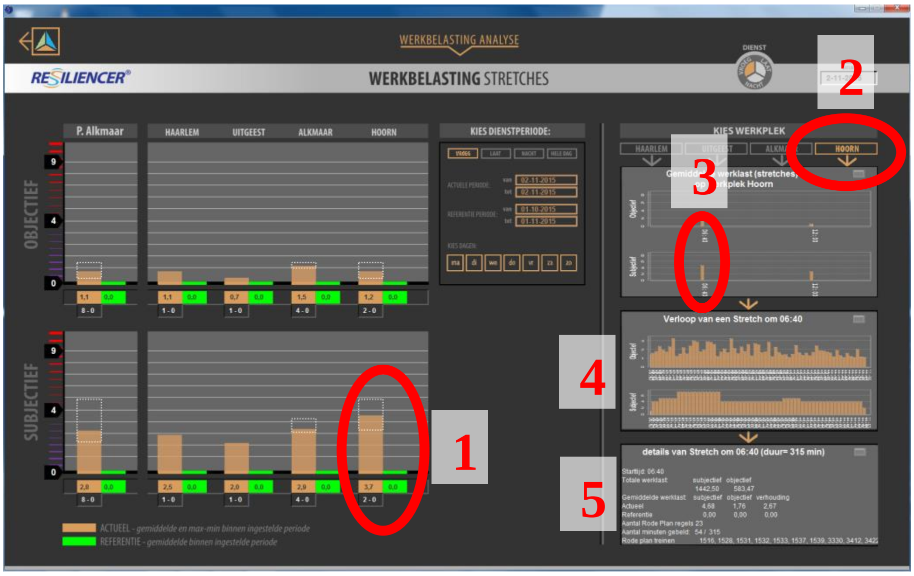

Figure 7 Resiliencer - Workload analysis of the near-accident case. 1 - Subjective workload at workstation Hoorn; 2 - Choosing Hoorn analysis; 3 - Choosing stretch at 6:40 AM; 4 - Objective & subjective workload during the stretch; 5 - Alphanumeric data of the stretch (duration, average workload, involved trains, minutes on phone, etc.)

We analysed the incident described in sections 3.2.1 and 3.2.2 and used as reference an unreleased internal report of ProRail, the company incorporating all rail posts and responsible for the Dutch railway network infrastructure, on the incident. We listed the topics contributing to the incident and added a topic category (see Table 2) to enable comparison with the topics discussed during the reflection (see

Table 1).

Table 2 Topics contributing to the incident (numbered according to appearance sequence marked in the text of sections 3.2.1 and 3.2.2)

No	Topic contributing to the incident	Topic category	Related procedure
1	Information split between 2 screens	Work overview	Night formation
2	Bridge opening in conflict with train route	Planning	Bridge opening
3	Early shift after late shift (until 7PM)	Work conditions	Working hours
4	Call in sick at 5AM	Procedures	Sick reporting
5	Night formation during early shift rush hour	Work overview	Night formation
6	RS without experience in night formation	Work conditions	Authorization
7	Fog with low visibility	External conditions	Extreme weather
8	Train driver trainee drives	Staff functioning	Authorization
9	Broken signal	Infrastructure	Disruption handling
10	Two options turning train	Alternatives	Rerouting

The topic categories listed above are similar to the topic categories during the team reflections (

Table 1) and imply that the discussions of the reflections can influence the interrelated process of incidents. A concrete example, mentioned in a talk the researchers had with an RS and team leader, concerned the schedule conflict of the train-bridge interference. Due to performance pressure planners made a conscious decision that a train may be delayed by a boat, which does not occur daily. RSs on the post warned about the consequences of possible delays, but were overruled. If the conflict would have been resolved in the planning, the bridge would not have been open and the interrelated sequence would not have occurred. Another example, is an action taken *after* the incident, which could have been discussed and activated *before* the incident and influence the outcome. The post decided to have an extra RS on partial duty at home, ready to be called at 5 AM joining the early shift at 6 AM. A sick call in at 5 AM occurred before, but was not discussed in depth. Such a discussion and action could have been triggered through team reflection. Previous research shows that signalling itself is not enough to cause related actions (Vaughan, 2002). The results above indicate growth of relevant knowledge beyond procedures influencing in three ways. First, some knowledge items are related to deficiencies and may lead to anticipation by updating the procedures. An example is the procedure of open bridge planning. Second, some knowledge includes items related to unwritten details enabling to learn and act better. An example is the combination of information on split screens. Third, some knowledge refers to the understanding of the real world, as it unfolds. An example is the rail-walker with another cultural background, behaving different then the Dutch.

4. Discussion

We wanted to know how team reflection, at the end of each shift, enriches the knowledge of procedures followed, and how it influences the resilience of the STS. To answer this question, we conducted a naturalistic observational study. A team of rail signallers reflected on their shift with help of a real-time tool, presenting relative OS movements towards system boundaries and providing analysis functions to relate the OS movement to identifiable details. The team discussed topics similar to topics contributing to a near-accident that occurred during the observation. Most topics were related to underlying procedures and revealed a context which is not described in the procedures and went beyond them. The similarity of these topics support our assumption that relevant topics contributing to accident evolvement are topics occurring daily, when thing seemingly go right, and contain valuable knowledge. This adheres to the notion that only the outcome of a process can distinguish between knowledge and error, given that both stem from the same cognitive sources (Mach, 1905). The team reflection executed is a type of after action review (AAR), which is a de-briefing process for analysing what happened, why it happened, and how it can be done better (Morrison and Meliza, 1999). The AAR is frequently used after a training or exercise to unfold the scenario step by step and discuss the response of each team member. The main novelty of our approach is that we enable this process in actual and continuous operations by providing real-time access to operational data in a dedicated lay-out for this purpose. To design this lay-out, we used ecological interface design principles (Burns and Hajdukiewicz, 2004) such as the abstraction hierarchy (Rasmussen, 1985), which is corresponding to system boundary constraints. Since the method is used during normal daily operations, the emphasis is more on learning from what goes right as opposed to what goes wrong (Hollnagel, 2014, 2011). It goes beyond the usage of team reflection to discuss the mission, strategy and processes at ad hoc moments (West, 2000). It expands the scope of reflection beyond the scope of the team's span of control to the whole rail-STS and influences it as such. The team at the sharp end sees how all parties of the STS are acting, for which they are not responsible, and can give them feedback, anticipate by adapting the written and unwritten procedures, or use the knowledge during future events. For example, RSs can adapt their procedures on the handling of rail-walkers by train drivers, give feedback to the train company or understand and react on a rail driver in a future case. Knowledge, beyond procedures, on the whole STS is an essential component for managing the unforeseen and unexpected (Schraagen, 2015). This implies that the proposed method contributes to resilience enhancement of the STS.

Additional novelties of our research are 1) the simultaneous presentation on three boundaries, 2) the use of weak signals, and 3) the ability to translate, out of big data, abstract system values to identifiable details. Quite often research is focussed on single domains such as performance (Marsden and Bonsall, 2006), workload (Lowe and Pickup, 2008) or safety (Jeffcott et al., 2006). We have shown to rail signallers the dynamic interrelationships among these domains to trigger interrelated discussion. Through comparison with a previous observation study with reflection on only the performance boundary (Siegel and Schraagen, n.d.) and one reflection session without tooling (current study), we could clearly see a difference with the reflection on multiple domains. The reflection without the tool focussed solely on the logistics of train series of main events during the shift. The rail signallers did not remember specific trains nor minor events, which is to be expected when only memory is consulted. They referred to obvious patterns in the previous period, but creeping changes (Dekker, 2011) were not identified. The lack of specific information may have led to a focus on logistics only. As logistics are mainly governed by procedures, current practices may reinforce a procedure-oriented culture. Adding more detailed information on the performance boundary still led to predominantly logistic discussions of specific trains and concentrated discussions on the procedures followed (or deviated from) and the entities communicated with (Siegel and Schraagen, n.d.). When the team was given access to information on safety, performance and workload together, it started searching for interesting phenomena, trying to explain the reasoning behind these phenomena. Personal subjective workload scoring was used as a reminder of details and was explained to the whole team. These differences in discussion topics are in line with the information to which the team of signallers had access to. However, the variety of topics grew, when reflecting on all three boundaries, among which new-fangled relations were established by the team members.

The usage of weak resilience signals (Siegel and Schraagen, 2014d) stimulated discussion and understanding as opposed to strong signals, where action is needed and false alarms undermine the trust in the system (Breznitz, 1984). Weak signals appear earlier than strong signals and allow time to learn, anticipate and prevent escalation (Lekka, 2011). The discussion topics were initiated by OS movements towards the boundaries, together with correlation of these components. For example, a change with respect to the performance boundary was not always correlated with a workload change, or vice-versa, which caused discussion. Within boundaries, variables also did not always correlate, such as with the relation between subjective and objective workload. Any discrepancy related to their understanding of the system, was seen as a weak signal, triggered a discussion and made related knowledge explicit.

The rail operational system produces a very large amount of data on a daily basis, which is not easily accessible. This fact looks like mastering big data (Kezunovic et al., 2013), with the addition that operators at control rooms, as opposed to dedicated analysts, must be able to use and understand the tools and figures. Moreover, it is important that each worker on the floor is able to translate the system level to his own context. In our concept we required such a function, in order for team members to identify with figures on an OS level and reveal related information to their colleagues. During the reflection the RSs were able to refer to technical details and share supporting information. A side effect of this feature was a growing trust in the system (Pfautz et al., 2009), since they could verify the information with their memory.

The scope of this research was the explicit knowledge beyond procedures revealed through team reflection. A next research step can focus on learning and anticipation using this knowledge enhancing the performance by preventing occurrences or avoiding escalation of incidents. That research would first require the necessary organisational adjustments to be implemented to feed the knowledge back into the organisation. A longer period of observation would then be needed to identify links between the knowledge made explicit and fed back and future prevented or deescalated incidents.

The team-reflection with a WRS reflection-tool described in this paper is also applicable to other domains with control rooms. The control operators from the team, reflecting at the end of their shift. System analysis and software development are needed for a dedicated reflection tool. The generic design method using the AH analysis (section 2.1) can be applied. The top two level of the AH will look similar, but the level from the purpose related functions and below are specific – the quantification of relative OS movements towards the boundaries. The quantification of each boundary does not, and cannot, be comprehensive but needs to be sufficient for the operators to trust and identify with. This was also the case in our prototype. Another challenge for the analysts is to find a search mechanism for the operators, to translate values from system level to personally identifiable components. We found a mechanism with three button presses to go from high level to specific. Observations are needed to verify similar results in other domains.

We have chosen for a naturalistic observation to study our theoretically derived proposition. This method allows for a large variety of unknown situations open to discover new concepts, which need in a further stage verification in a more controlled environment (Woods, 2003). This is also the case for our study where components need to be verified in a controlled setting. Especially the creation of a WRS is a challenge since its occurrence is not necessarily related to a future event, thus hard to simulate. However, a much longer observation period may strengthen the patterns, where natural WRSs occur. The adaptation of the methodology is also a good candidate to verify during a longer period. With these caveats and limitations in mind, our tentative conclusion is that team reflection with the right tooling complements the experience and knowledge residing in procedures, enhancing the handling of the unforeseen and unexpected.

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