

Resilient performance in maintenance operations: managing unexpected failures

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Abstract

Unexpected failures of physical assets are often stated as the primary operational risk to asset-intensive organizations. Managing these failures is of critical importance to maintenance operations. This study demonstrates the operationalization and application of organizational resilience in a railway pit stop system, in order to identify changes for improvement in managing unexpected failures, using the soft systems methodology. A new ability (ability to inform) has been identified from the field as an important driver for resilient performance. Further research is needed to defend this position.

Keywords: Organizational resilience, unexpected failures, maintenance operations

Introduction

Unexpected failures of physical assets are often stated by asset-intensive industries as the primary operational risk to business (LaRiviere et al., 2016). Managing these failures is of critical importance to maintenance operations. In 2015, in response to long lead times for repairing unexpected failures of rolling stock, the Netherlands Railways (NS) introduced a pit stop system to their maintenance depots. The pit stop system is based on the principles of lean thinking (Hines et al., 2004) and resulted in a significant reduction of lead times of repairing unexpected failures. Nevertheless, due to the introduction of new series of rolling stock, the NS expects a major increase in the number of unexpected failures in upcoming years that may threaten their mission to offer reliable passenger railway services.

The main question to be answered in this study is how the current organization of the pit stop system can be improved to manage the expected increase in the number of unexpected failures. The pit stop system can be characterized as a social-technical system. Socio-technical systems describe systems that involve complex interactions between humans (mechanics), machines (rolling stock) and the environmental aspects of the work system (Trist, 1981).

In the next section, we describe our research strategy which also determines the structure of this paper. We start in the real world of events by a thorough understanding of the current pit stop system. Based on this understanding and the root definitions of the system, we construct a conceptual model and compare it to the real world of the pit stop. Based on this comparison we are able to identify and discuss ideas for change and find accommodations that enable

improvements to the current pit stop system. The conclusion section summarizes our conclusions and indicates the significance of the work and our contribution to existing literature.

Methodology

To address the complexity of the socio-technical pit stop system and the necessity to gain a thorough understanding for improvement actions, we selected the Soft Systems Methodology (SSM) (Checkland, 1981) using a single embedded case study (Yin, 2003). SSM is an established systems-based approach represented by four iterative stages (Checkland, 2000):

1. Finding about the problem. This is a continuous process and results in a “rich picture”, that provides a holistic view of the problem situation.
2. Formulating relevant conceptual models. This stage of SSM is about conceptualizing purposeful activities, which are considered relevant to the problem situation and, when compared with reality, can lead to the selection of meaningful improvement interventions.
3. Comparing models with reality and proposing for change. The conceptual models developed in the previous stage, serve as a means to a debate regarding the changes that would improve or resolve the problem situation.
4. Taking action in the real-world situation to bring about improvement. This stage of SSM refers to the implementation of the proposed changes.

As a systems-based methodology for tackling real-world problems, SSM enables the researcher and the participants to understand different perspectives of the situation. The problem is addressed through learning rather than through replacement of the current situation with an improved ideal. We collected our results by conducting open and semi-structured interviews with management and operations, inspection of documentation and observations in the maintenance depots.

Results and discussion

Although the results and discussion section is structured chronologically, the inquiry process was not so straightforward and forced us to jump back and forth between the stages of SSM. The next four sections describe the results of the four stages of SSM.

1. Finding out about the problem situation

In this section, we describe the current situation of the pit stop system. To encourage a holistic view of the situation (Checkland, 2000), we constructed a rich picture of the pit stop (refer to figure 1) based on open interviews and observations of the pit stop system in the maintenance depots. Figure 1 highlights the key features of the pit stop system and shows the complexity involved due to many stakeholders and sub-systems. The next paragraphs provide a high-level description of the pit stop system supporting figure 1.

As soon as a failure has been detected in railway operations, which prevents safe and reliable operations, the train driver informs the rolling stock control center. They determine the severity of the problem for routing the train to the right location for further analysis and repair (service depots or maintenance depots). Based on this classification the national railway control center determines the best routing available based on the railway schedule.

The pit stop coordinator is physically located in the maintenance depots at the dedicated pit stop track and is responsible for coordinating all the activities for repairing rolling stock with unexpected failures. A pit stop team consists of four people, including the pit stop coordinator. This guarantees the availability of resources to repair the train as fast as possible. The pit stop coordinator collects information (for example failure data and a date of arrival at the pit stop track) from the rolling stock control center or the information system and publishes this

information on the pit stop board. The pit stop board consists of three sections, showing unexpected failures in railway operations, the current status of rolling stock in the pit stop track and an overview of repaired rolling stock (recidivism monitoring for two weeks). The pit stop coordinator starts planning tasks and schedules resources based on the information available. Examples of these tasks are involving maintenance engineering or suppliers for additional expertise in the diagnosis or ensuring the availability of spare parts in close cooperation with supply chain operations.

When rolling stock arrives at the pit stop track, the pit stop coordinator will start a clock. The clock counts down from 24 hours to zero, indicating the time passed for repairing rolling stock. The clock is shown visually and helps to create awareness of the current situation at the pit stop track. The pit stop team starts with diagnosing and analysing the failures. Based on this analysis a plan is made for repairing the failures, taking into account the available resources and capacity. A final test will be performed before rolling stock will be declared ready for railway operations. The current pit stop system defines three key performance indicators: safety of maintenance operations, quality of repairs and the reliability of delivering rolling stock back to railway operations according to plan.

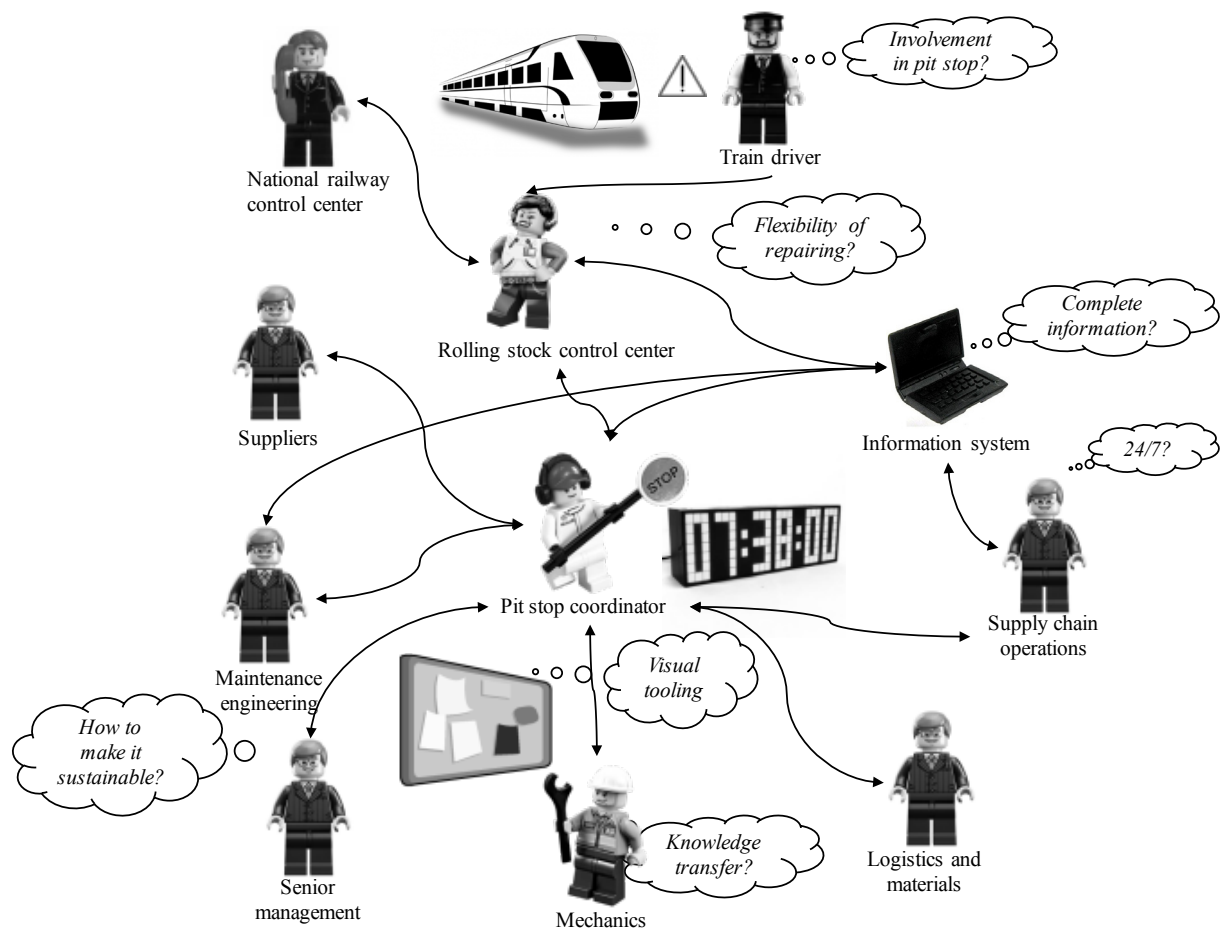


Figure 1 - Key features of the pit stop system

2. Formulating relevant conceptual models

The conceptual models are accounts of concepts of pure purposeful activity, which can be used to stimulate questions about the real situation and the desirable changes to it (Checkland, 2000). The rigor of the SSM depends on this stage. The modelling process is not an idea generation process but a logical process of excluding all factors not logically flowing from the root definition of the system. Before we present our model, our first step is to examine current literature on managing unexpected failures.

Literature for relevant conceptual models

Organizations exist in an increasingly tightly coupled and complex environments where the unexpected is omnipresent (Weick and Sutcliffe, 2011). We identified two schools of thought from safety management whose adoption yield further insights in managing unexpected events: High Reliability Organizations (HRO) (Roberts, 1990, Weick and Sutcliffe, 2015) and Resilience Engineering (RE) (Hollnagel et al., 2007, Woods, 2015).

The HRO paradigm was developed by a group of researchers at the University of Berkeley to capture observed commonalities of high-risk operations among aircraft carriers, air traffic control and nuclear power plants. They examined the characteristics of these organisations and the practices and processes that they adopt, enabling them to both achieve and maintain their excellent safety performance record. Effective HROs tend to develop both anticipation and resilience to achieve reliable performance (Schulman, 2004). Anticipation refers to the prediction and prevention of potential dangers before damage is done, whereas resilience refers to the capacity to cope with unanticipated dangers after they have become manifest and learning to bounce back. Unlike effective HROs, traditional non-HRO organizations tend to lean heavily toward one or the other of the two. They typically lean towards anticipation of expected surprises, risk aversion, and planned defenses against foreseeable risks (Weick et al. 2008). HROs are not immune to adverse events, but they have learned the knack of converting these occasional setbacks into enhanced resilience of the system (Reason, 2000). The HRO theory has a strong focus on the social and organisational underpinnings of system safety (Weick et al., 2008), but pays little or no attention to the technical and engineering aspects (Saleh et al., 2010). This observation directed us the school of RE.

RE has been applied in several high-risk systems, including the aviation, petrochemical, and nuclear industries. A system cannot be resilient, but can have a potential for resilient performance. Resilient performance has been defined here as: “A system that sustains required operations under both expected and unexpected conditions by adjusting its functioning prior to, during, or following events (changes, disturbances, and opportunities)” (Hollnagel, 2011). RE emphasizes function over structure and ability over capacity. In order to be resilient, an organization must be able to do certain things, which can be expressed by four basic abilities. The ability to respond, the ability to monitor, the ability to anticipate and the ability to learn (Hollnagel, 2011). The four abilities need to be addressed by any organization to some extent in order to be resilient. For a fire brigade, for instance, it is more important to be able to respond to the actual than to consider the potential (ability to anticipate).

By using a pragmatic approach to both schools of thought (Haavik et al., 2016), integrating the organizational and engineering perspectives on managing unexpected events, we were able to construct a purposeful activity model based on the HRO and RE paradigms. Before we introduce this model, we will first highlight the relevance of resilient performance to the context of railway maintenance operations.

Relevance to maintenance operations

HROs can be important to other non-HRO organizations because they are harbingers of adaptive organizational forms for an increasingly complex environment (Weick et al., 2008). They may be considered as a good practice in achieving reliable performance. Nevertheless, attempts to apply these ideas outside the ultra-safe sectors, such as the nuclear industry, within which they developed, have so far been limited. This study will contribute to that gap by operationalizing and assessing the concepts of RE and HRO in a railway maintenance context.

Railway maintenance operations faces an increasing complex environment due to the introduction of new rolling stock (with new complex technologies) and a higher density of trains services in an already tightly coupled railway infrastructure. This resembles the characteristics of high-risk organizations in ultra-safe sectors, who manage tightly coupled and interactively complex systems. Coupling refers to the degree of interdependence among a system's components and interactive complexity refers to the extent to which the interactions among the system's components are unpredictable (Perrow, 1984).

Conceptual model

Based on our inquiries with the different stakeholders in the first stage and our literature review on unexpected events, we defined the following root definition which guided our efforts in building a relevant conceptual model for the pit stop system. A root definition ensures that there is clarity of thought about the purposeful activities to be modelled (Checkland, 2000) and expresses the core purpose of the activity system as a transformation process:

The pit stop system is able to respond effectively to unexpected failures of rolling stock by adjusting its functioning to succeed under varying conditions to ensure and maintain reliable performance of railway operations

Because our focus in this study is on the organizational level, we selected the four abilities of resilience (Hollnagel, 2011) and the five processes of a mindful infrastructure for high reliability (Weick et al., 2008) to be translated in our conceptual model as purposeful activities. We recognize the overlapping concepts of HRO and RE (Le Coze, 2016), but chose to adopt both perspectives (organizational and engineering) to promote diversity in our approach in addressing the challenges of the pit stop system. As a result, the conceptual model (refer to figure 2) consists of nine purposeful activities in the domains of anticipation and resilience. Anticipation has been earlier defined as prediction and prevention of potential dangers before damage is done, whereas resilience refers to the capacity to cope with unanticipated dangers after they have become manifest and learning to bounce back. We did not include linkages and dependencies between the activities because we did not intend to prescribe a certain balance or proportion among the activities (Hollnagel, 2011) when comparing our conceptual model with reality.

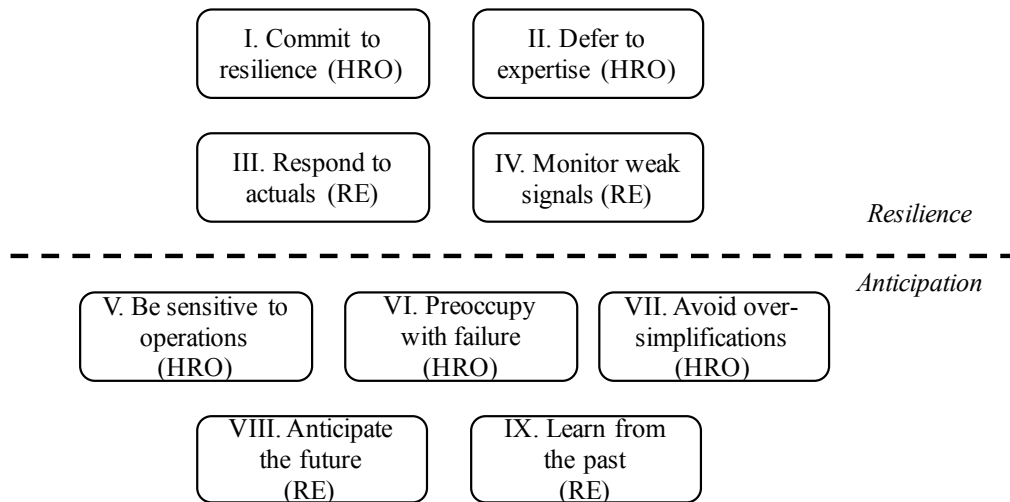


Figure 2 - Conceptual model for resilient performance adopted from ((Weick et al., 2008) and (Hollnagel, 2011))

3. Comparing models with reality and proposing for change

By using our conceptual model for resilient performance in semi-structured interviews, we identified claims, concerns and issues from the key stakeholders (Guba and Lincoln, 1989). A claim is a positive statement about the pit stop system, a concern is a negative statement about the pit stop system and an issue is a reasonable question about the pit stop system. We mapped the quotations to our conceptual model to identify relevant changes to improve the resilient performance of the pit stop system. For each activity in figure 2, we will highlight the main claims or concerns based on our inquiry with key stakeholders.

Resilience domain

- I. Commit to resilience is defined as developing capabilities to cope with, contain, and bounce back from mishaps that have already occurred, before they worsen and cause more serious harm (Sutcliffe, 2011). The use of mobile teams for repairing unexpected failures (if possible) contributes to the resilience of the pit stop system and prevent unnecessary track movements of rolling stock.
- II. Defer to expertise refers to the migration of decision-making to the person or people with the most expertise with the problem at hand, regardless of authority or rank during high-tempo times (Sutcliffe, 2011). A claim that was made is the standard employment of an external company, specialized in air conditioning, during summer time. A perceived concern was raised that decision-making is still largely based on authority and rank.
- III. Respond to actuals is defined as knowing what to do, or being able to respond to regular and irregular changes, disturbances and opportunities by activating prepared actions or by adjusting current mode of functioning (Hollnagel, 2011). Perceived claims were the successful application of a “rapid response table” to solve any issues raised in the pit stop system and a dedicated pit stop track and pit stop team 24 hours per day. A concern was raised on the critical dependence on only a few key players in repairing specific failures (single point of knowledge).
- IV. Monitor weak signals is defined as knowing what to look for, or being able to monitor that which is or could seriously affect the system’s performance in the near term – positively or negatively (Hollnagel, 2011). The pit stop system includes a countdown clock, which contributes to the awareness of mechanics, management and staff on what is happening on the pit stop. The pit stop clocks are also displayed at the central

head office. A concern was raised to include more sensors and indicators on trains to be able to detect unexpected failures.

Anticipation domain

- V. Be sensitive to operations is defined as an ongoing interaction and information sharing about current human and organizational factors to create an integrated big picture of ongoing situations so that small adjustments can be made to prevent errors from accumulating (Sutcliffe, 2011). The use of the recidivism section on the pit stop board forces the pit stop team to monitor repaired rolling stock for 14 days and contributes to a better understanding of ongoing situations.
- VI. Preoccupy with failure is defined as operating with a chronic wariness of the possibility of unexpected events that may jeopardize safety (and reliability) by engaging in proactive and pre-emptive analysis and discussion, and after action reviews (Sutcliffe, 2011). The pit stop coordinator pro-actively monitors the information system to identify rolling stock in operations with unexpected failures to be repaired. A concern is the current reservation of people to report near-failures. For example, train drivers, who manage to prevent successfully unexpected failures, do not report these near-failures.
- VII. Avoid over-simplifications is defined as deliberately questioning assumptions and received wisdom to create a more complete and nuanced picture of current situations (Sutcliffe, 2011). The use of a large physical pit stop board with the diagnosis, analysis, testing and reparation stages, encourages mechanics to question their assumptions on failures and functions as a strong enabler in the discussion between mechanics on the root cause of failures.
- VIII. Anticipate the future is defined as knowing what to expect or being able to anticipate developments further into the future, such as potential disruptions, novel demands or constraints, new opportunities, or changing operating conditions (Hollnagel, 2011). One of the perceived concerns is the lack of forecasting of unexpected failures based on seasonal influences and the condition of rolling stock. Another perceived concern was raised on flexibility. The current pit stop systems in the maintenance depots are aimed to repair a limited number of different rolling stock. To become more resilient, the pit stop system needs to become more flexible in repairing different series of rolling stock.
- IX. Learn from the past is defined as knowing what has happened, or being able to learn from experience, in particular to learn the right lessons from the right experience (Hollnagel, 2011). A claim was made that by building dossiers of rolling stock with pictures and stories, new mechanics without experience are able to learn from past experiences of other mechanics. One of the perceived concerns is the (lack of) involvement of the train drivers in the pit stop. Unexpected failures are also caused by operating errors, but a structural feedback loop seems to be missing.
- X. Based on our comparison, we also identified an important attribute from practice that is perceived to be critical in achieving resilient performance, but was not included in our conceptual model. For now, we term this the “ability to inform”, defined as developing capabilities to mobilize explicit and tacit knowledge and expertise of the members in the pit stop system for accurate decision-making. It resembles the characteristics of the concept of the knowing organization (Choo, 1996) and can be considered as a strong driver of both domains of anticipation and resilience in our conceptual model. Concerns raised related to this activity are the transfer of information between mechanics in different working shifts, analysing information on unexpected failures for better (central) forecasting, ensuring a single source of truth

and knowledge sharing between the mobile maintenance teams and the pit stop teams at the maintenance depots.

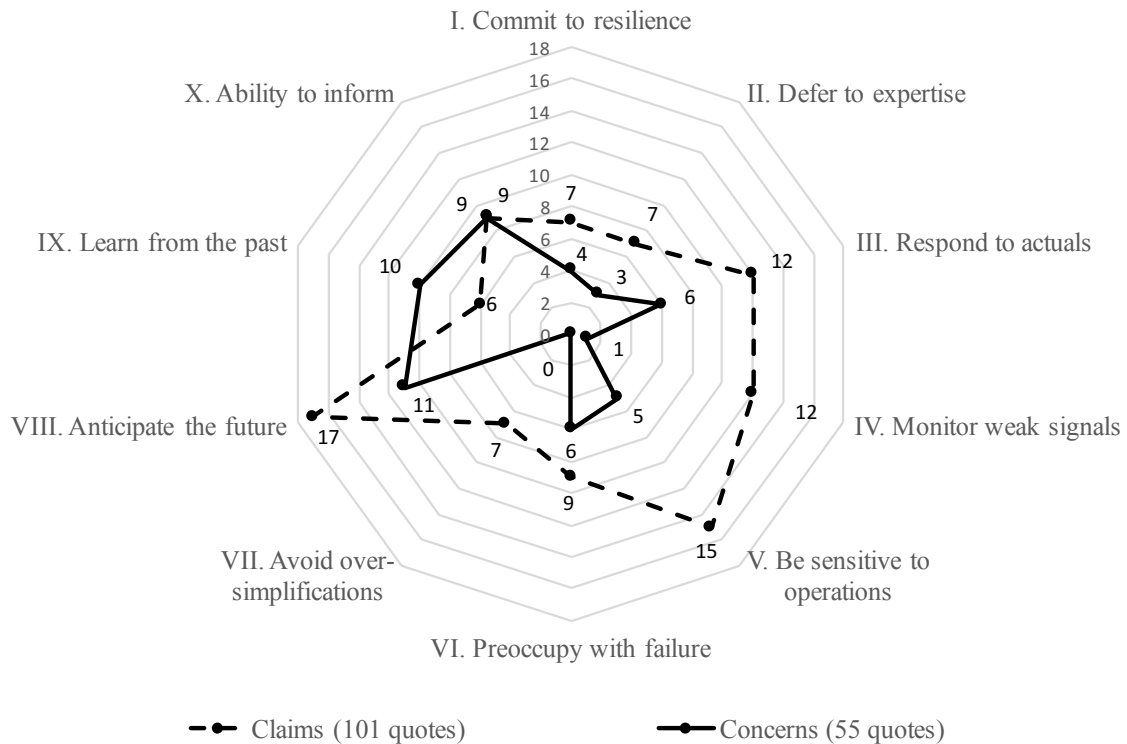


Figure 3 - Claims and concerns for resilient performance

While we observed many positive quotations (101 quotes) of resilient performance (refer to the dotted line in figure 3), our main focus in this study is on the concerns (refer to the straight line in figure 3). Analysis showed that almost 70% of all concerns of the stakeholders are in the anticipation domain of our conceptual model and 55% of all concerns relate to the activities of “anticipating the future”, “learning from the past” and “ability to inform”. Based on our analysis, we agreed on the following changes to respond effectively to the expected increase in the number of unexpected failures:

- Increase the involvement of train drivers and train guards in managing unexpected failures by starting to provide feedback on resolving unexpected failures, showing a strong need for near-failure reporting and rich descriptions of near-failures and failures in the pit stop system (learn from the past and preoccupy with failure).
- The current pit stops at the maintenance depots are limited in repairs of different series of rolling stock. To increase resilient performance, the pit stop system needs to become more flexible in repairing different series of rolling stock by increasing the mobility of resources and further standardization of equipment at each maintenance depot (anticipate the future).
- To improve forecasting of unexpected failures, further application of seasonal forecasting and condition-based maintenance is required. Condition-based maintenance recommends maintenance decisions based on the information collected through condition monitoring. This will increase the capability of (real-time) monitoring weak signals for unexpected failures in railway operations (anticipate the future).

- Introduce a dedicated shared knowledge infrastructure with all stakeholders to increase the mobilization of tacit and explicit knowledge of unexpected failures in the entire pit stop system. The owner of this infrastructure will be the pit stop coordinator (ability to inform).

An important issue raised by several stakeholders was the question of how to ensure a sustainable performance of the pit stop system. The suggested improvements in the anticipation domain, focused on pro-active adjustments of the pit stop system, provide a good starting point in addressing this issue.

4. Taking action in the real-world situation to bring about improvement

Due to the strategic nature of our improvements, covered in multiple projects and programs, we were unable to include the implementation results in the short-term period of this research. We expect to include our findings in a follow-up study.

Conclusions

The main question to be answered in this study was how the current organization of the pit stop system can be improved to respond to an increase of unexpected failures. Our study demonstrated that by building a rich picture of the pit stop system, developing a relevant conceptual model of resilient performance and comparing it to the current pit stop system, we were able to discover organizational changes for improvement to address the challenge of a major increase in the number of unexpected failures. We showed that both concepts of HRO and RE can be operationalized and applied to the context of railway maintenance operations.

Based on our comparison, we identified an important ability from practice, perceived to be critical in achieving resilient performance, that was not included in our initial conceptual model. For now, we term this the “ability to inform”, defined as developing capabilities to mobilize explicit and tacit knowledge and expertise of the members in the pit stop system for decision-making.

The transformation process towards resilient performance in the pit stop system is an ongoing process and the implementations of the improvements will be monitored closely for further reporting.

Implications and limitations

This study contributes in closing the gap between theory and practice in an empirical case study by operationalizing and applying the concept of resilient performance in the field of maintenance operations. Based on our comparison of our conceptual model with reality, we identified a new ability from practice, the “ability to inform”, that may be considered as a strong driver in managing unexpected failures. As the results of this research are specific to this case study, further research is required to defend this position.

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