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HOW TO DO IT WITH STICKY NOTES: A METHOD FOR EXPLORING EXPERT KNOWLEDGE TO PREPARE GUIDELINES FOR PRACTICE IN RAILWAY VEHICLE MAINTENANCE

Summary. The process of describing human activities in procedures has been used since the beginning of the 20th century. However, it is increasingly evident that procedures understood as sets of orders and prohibitions can be counter-productive because they do not allow the proper use of employees' knowledge and experience. Therefore, it is postulated that guidelines for practice should be co-developed by employees from the 'sharp end' of the organization, but there are no simple methods that can achieve this aim. In the present work, we propose a procedure based on sticky notes, inspired by how information technology teams function. We present a description of the original sticky notes method (SNM) and demonstrate its application in the railway sector. As a result of the workshops conducted with the participation of experts, we gained knowledge about practices that were not included in the documentation, but that could significantly improve the process under research. The primary purpose of the SNM is to ensure the involvement of employees in the process of creating guidelines for practice. This method is particularly useful for describing linear processes in which activities can be arranged chronologically.

1. INTRODUCTION

Railway undertakings belong to organizations whose activities are characterized by significant risk and the existence of many socio-technical dependencies. Such organizations have been particularly important areas of safety engineering research for many years. One of the first approaches proposed to describe their functioning was Perrow's theory of normal accidents from the 1980s, which assumes that in such organizations, accidents cannot be avoided [1]. However, this approach is questioned by researchers developing two contemporary theories in the field of safety engineering: High Reliability Organizations and Resilience Engineering [2, 3].

The theory of High Reliability Organizations was developed in the United States as a result of research involving the observation of organizations such as air carriers, flight control services, and nuclear power plants [4]. A group of researchers sought to answer the question as to why accidents occur far less frequently in some industries than in others. As a result of these inquiries, the definition of the so-called 'collective mindfulness' was formulated [5], which characterizes some organizations.

The manifestation of activities in line with the collective mindfulness is to encourage employees to report as many events as possible, including the so-called incidents that have not resulted in losses/damage. The reported events are then to be investigated in order to establish and neutralize their

causes. The proposed action is justified by the 'safety pyramid' theory, based on the study of Heinrich [6], according to which the reduction in the number of incidents should result in a reduction in the number of accidents correlated with it [7]. The above assumption was criticized by Resilience Engineering approach [8]. It is based on the concept of 'Safety-II', according to which both successes and failures result from the continuous variability of systems and their adaptation to environmental conditions. Therefore, Resilience Engineering postulates to focus the study on successes with the aim of strengthening their causes [9–11]. An important element of Safety-II is the clear distinction between work-as-done and work-as-imagined [12], and thus the identification of the discrepancy between what employees actually do and the intended way of performing tasks, defined in the respective procedures.

There is abundant literature on safety management procedures, as they play a key role in shaping the safety levels of various types of human activities [13]. Two distinct periods of intense introduction of new procedures can be identified in history [14]. The first of these happened at the beginning of the 20th century with the emergence of Taylor's concepts of scientific management and belt-system production. The procedures were then employed as a method of standardizing how people ('work forces') function, and were used alongside other ideas from those times, such as additions to salaries dependent on order in their place of residence, prohibition, or the sterilization of people considered less intelligent [15].

The number of procedures remained at an almost constant level for many years, varying depending on the industry, ranging from relatively strong regulations enforced in air transport, to the near absence of formal procedures in medicine [16]. The main regulator of all types of activities was the state, which itself was often the recipient of regulations; for instance, until the 1980s, the railway sectors in Western Europe were practically not separated from state structures [17].

A significant change occurred in the 1980s and the 1990s, when a series of great disasters (including Chernobyl, Piper Alpha, and the Three Mile Island) revealed the obsolescence of state regulations, as the supervised systems became increasingly complex and coupled. Gradually, changes pertaining to de-centralization were introduced, and individual companies were allocated responsibility for their safety levels [18]. They were obliged to implement safety management systems, the functioning of which was (and remains) audited by supervisory authorities. The concept of the safety management system is widespread now. The industries where it is an obligation to have such a system range from maritime to food production and in the European Union, they also include Entities in Charge of (railway vehicle) Maintenance [19].

However, as Power [20] noted, 'auditing is not a collection of technical tasks but also an idea which promises a certain style of control and organizational transparency'. The necessity of ensuring the possibility of auditing the activity led to the emergence of a second wave of procedures, focusing on the regulation of all activities affecting safety levels. The relatively fast change, which was imposed externally, rendered several companies incapable of adapting to the new ways of functioning, and compliance with new regulations was facilitated with the participation of external consulting companies. The introduction of safety management systems, which in many places were more generic than industry- or company-specific, led to situations in which employees were no longer in charge of their own safety, as they were not able to use their practical experience in the new framework of safety management [21, 22]. This is noted by Dekker and Nyce [23], who proposed conducting research on the interactions between power and safety-related activities or models. Similar work in the railways had commenced previously; an example is the analysis of 'transitive' and 'intransitive' powers of different types of railway rules and procedures [14].

The introduction of procedures leads to several phenomena, sometimes called 'compliance culture', such as refusals to perform work if it contains activities not defined in the procedure [24], or compulsive seeking of responsible entities, such as in the case of minor train delays [25]. Assigning responsibility for breaking procedures is also characterized by many post-accident investigations, which makes it impossible to eliminate the original causes of accidents [26]. In extreme situations, strict compliance with procedures can prove fatal; the Piper Alpha oil rig explosion is a pertinent example [15, 27]. However, it is difficult to imagine a modern world without procedures, although maintaining them often requires significant investment of time and resources [28] owing to the phenomenon of 'safety clutter' appearing over time [29].

An interesting proposition to mitigate some of the negative effects of compliance culture is to change the vocabulary, i.e., replacing 'procedures' with 'guidelines for practice' [30]. Thus, procedures would not form the basis of controlling the way employees work but, most importantly, would help in the implementation of repetitive activities. Documents of this type can be categorized as Model 2 procedures based on the classification proposed by Dekker [31] and developed by Hale and Borys [32]. In their companion paper [27], the authors provide a literature review on how to develop appropriate procedures of this type, concluding that user participation in the formulation of procedures is vital to success.

However, the body of knowledge on safety science contains little information on tools that are not intended for academic study, but can be used by business entities in their day-to-day operations to conduct workshops to develop procedures or guidelines for practice based on exploration of the knowledge of experts. Therefore, the aim of this paper is to describe a new methodology for the formulation of such safety guidelines and present a trial execution of this methodology in real circumstances. In Section 2, we present details of the methodology and general information on the topic of guidance: a maintenance task performed on passenger trainsets. Section 3 presents the results of the workshop organized with railway employees working at different organizational levels. Section 4 presents a discussion of the results obtained.

2. MATERIALS AND METHODS

2.1. Sticky Notes Method for gathering knowledge from experts based on the concept of user stories

The method we propose for gathering knowledge from experts is based on the concept of 'user stories', which are used in agile software development (among other areas). User stories in information technology (IT) teams are tools to ensure that customers and programmers have the same understanding of software requirements [33]. The user story itself is usually a sentence or short description, written on a sticky note, in accordance with the scheme, 'As a <role>, I want <goal>, [so that <benefit>]', the last section in square brackets being optional. An important factor that determines the results of working with user stories is the way they are arranged, and the process of arrangement is called mapping [34]. In the method proposed, we combine the advantages of mapping user stories with the principles of systematic brainstorming discussion, with questions derived from Hazard and Operability Studies [35]. The details of our sticky notes method (SNM) are presented in the following subsections.

2.1.1. Selection of workshop participants

To ensure completeness of the results obtained, it is necessary that workshop participants include people who are responsible in various ways for the processes described. Therefore, this should include both people who physically work at the 'sharp end' of the organization in addition to their superiors, who are responsible for planning, organizing, and supervising the implementation of the process. The participation of both groups of employees in the workshop provides access to a wider context and strengthens the sense of shared responsibility for the guidelines of the practice being developed.

Our experience shows that no more than five people should participate in the workshop, because it is difficult to maintain the focus of a larger group when discussing the merits of the case. In a situation where the process is more complicated and the presence of a larger number of experts is necessary, the spherical aquarium method can be applied, as described in the literature [34]. In this method, the room in which the workshop is conducted is divided into two parts. The inner part, i.e., the 'aquarium', comprises a board, the workshop leader, and participants who can actively engage in discussions. Other participants in the outer part can only observe the course of the discussions. Only a limited number of participants (three to five) can be present in the aquarium; if a participant from the outer part wishes to join the discussion, one from the inner part must exit.

2.1.2. Preparation and mapping of activity descriptions

Each participant receives a stack of post-it notes. On these notes, the participants describe the activities necessary to implement the process under consideration, using the format, '<Who> does <what> [in order to <reason>]', the last part being optional. It is important that only one entry be made for each activity. In a situation in which several people of the same competence are required to perform the same activities, this information should be written directly on the notes when determining competence, using the symbol 'x' and the number of people involved in the activity. The level of detail required for the activity descriptions or scope of analysis should not be specified; participants should write whatever they deem important on the cards.

The person conducting the workshop collects all the notes and, together with the participants, places them on the board. The notes are placed in rows, listing the activities carried out by successive actors (for instance, mechanic, electrician, or master); additionally, ambient conditions are treated as an actor. It is important to leave room between rows for the results of the subsequent challenging of the map. The activities of each actor are placed chronologically from left to right. Activities that are in some way related to each other, such as activities performed together or in a specific sequence, or activities that are mutually exclusive, should be identified with a pen/marker directly on the board.

Repetitive or more general descriptions of activities should not be removed, but should be stuck one above the other. This helps avoid conveying the impression that one participant is 'better' than another based on a greater number of cards being retained on the board. During mapping, new cards can also be added to describe activities that were not realized at the initial stage.

2.1.3. Challenging the developed map

The map being developed is the basis for the preparation of guidelines for practice; hence, it is important that it reflects the actual process together with its variability as faithfully as possible. In our experience, however, experts often have a tendency not to notice possible problems unless they have experienced them themselves in the past. To supplement the map with this type of information, we suggest using the HAZOP keywords for each of the map elements to stimulate discussion.

The set of basic keywords of HAZOP is included in the relevant standard [35] and in publications using this method. Questions using keywords are formulated based on the principles of HAZOP for each activity identified. In these situations, when a given question leads to a meaningful answer, this answer, along with a method for reducing the identified variability, is recorded on a note, which is then placed under the note describing the action under consideration.

The final step of the proposed method allows for the results obtained to be checked, and informs us about the process based on the created map. During the reading of the complete history, particular attention should be paid to the ways of connection (such as specific order) between the activities. All the participants of the workshop should agree that when the history is read, it correctly describes the analyzed process.

2.2. Power Pack assembly in a diesel multiple unit

The power pack is a motor-hydraulic power unit that includes the following components in one support frame: the diesel engine, an exhaust gas cleaning system, gears, an electricity generator, a compressed air generator, and a cooling system (see Fig. 1). The main section of the power pack is usually mounted under the vehicle at the level of the bogie, to which it is connected via a shaft to transfer torque to the wheels of the vehicle. The elements of the cooling system, such as coolers, are placed on the roof of the vehicle.

In the following section of this paper, we consider the process of assembling the power pack in a rail vehicle intended for regional traffic. Power from the power pack unit is transferred by means of a drive shaft to an intermediate axial gearbox mounted on the first wheel set of the drive bogie. From the intermediate axial gearbox, power is transmitted by means of a shaft next to the final axle gearbox mounted on the second wheel set of the drive bogie. The power pack unit is fitted with a compression–

ignition diesel engine with a turbo charger, and has a nominal power of 500 kW. The vibrating components of the power pack are flexibly attached to the support frame, which in turn is flexibly attached to the vehicle structure. The total weight of the power pack unit (when not filled) is approximately 5000 kg.
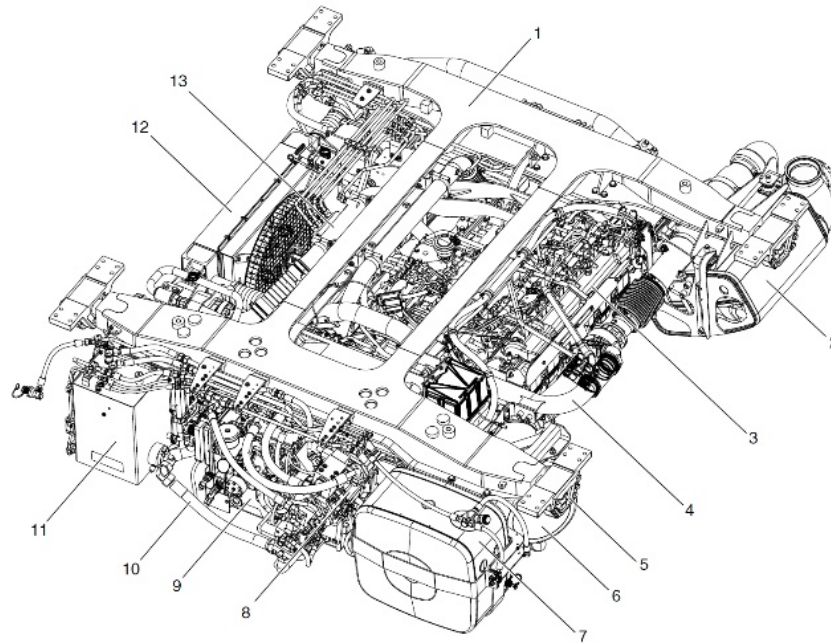

Fig. 1. Typical power pack assembly: 1 – framework, 2 – silencer, 3 – diesel engine, 4 – charge air ducts, 5 – bearing, 6 – air filter, 7 – Selective Catalytic Reduction tank, 8 – hydrostatic pump, 9 – turbo gear unit, 10 – hydrostatic oil lines, 11 – hydrostatic oil tank, 12 – cooling system, and 13 – coolant lines

Before assembling a new power pack, the bogies must be removed, the vehicle raised, and the previous power pack disassembled. The actual assembly of a new (or renovated) power pack begins with its final assembly on the frame outside the vehicle. Next, the power pack should be placed on the transport device, which allows it to be moved to the fixing points under the vehicle. The vehicle is then lowered on lifting mechanisms, until the mounting points are correctly aligned and mechanically connected. After the power pack is connected to the vehicle structure, the transport device must be removed. Finally, all electrical and mechanical connections must be made to the rest of the vehicle.

3. RESULTS

The proposed method of gathering knowledge from experts was used in a workshop organized in January 2019 in the technical maintenance facilities of a regional railway undertaking in Poland. It was carried out in a training room equipped with a horizontally mounted table on which one could write with markers. There were five participants: two representatives of the university and three representatives of the railway undertaking. The latter comprised of the following:
-   two people aged 30-45 years, with about 8 years of experience in the process of power pack assembly and working in positions related to the maintenance of rail vehicles for about ten years.
-   the Technical Department Manager, responsible for the correct performance of maintenance activities on vehicles, who had contributed to the development of the SNM.

The employees of the railway undertaking were chosen for the workshop due to their working experience with the studied process. They participated in the meeting voluntarily, during their work hours, without extra pay. The duration of the workshop was not limited in advance. Owing to the

nature of the analyzed process, which practically does not require the active participation of the Technical Department Manager, only line employees were asked to register the activities. At the beginning of the workshop, they were informed that the activity was not aimed at evaluating their competence and they would not be punished in case of non-compliance with the applicable procedures. We believe that this assurance was sufficient to ensure the accuracy of the information provided by workshop participants because the problem of inadequacy of procedures to the actual course of work is a subject of open discussions between the employees and the management in this organization.

The participants had no problem understanding the task, although (as expected) they were doubtful about the level of decomposition of the activities. In the first stage, each participant was able to list and describe about 15 activities. First, the notes were stuck onto the board in chronological order and classified by position: mechanics and electricians. In a few situations, only during the process of sticking the notes did it become evident that certain activities had not been identified in the first stage. This concerned, among others, the connection of batteries necessary to perform power pack connection tests using dedicated software. During the discussions, the necessity of using additional tools not provided for in the existing procedure was also identified, such as a hand pump for venting the fuel system.

During the discussion on activities and their interrelations, information was obtained on the existence of a technique that allows, or even facilitates, the installation of the power pack in a manner that is inconsistent with the provisions of the respective procedure. According to the procedure, all electrical and mechanical connections to the rest of the vehicle are to be performed only after the power pack is mounted under the rest of the vehicle. In fact, some activities, such as pre-connecting the generator plug or positioning the motor cables in relation to the cooling system, are carried out before the vehicle is lowered. This is because there is much easier access to these elements before the power pack is mounted under the vehicle.

Although the shortcut described is a significant facilitation in the assembly of the power pack, and practically does not generate additional hazards, the experts participating in the workshop were not inclined to discuss this topic at first. Information about the use of the shortcut was gleaned accidentally in the course of discussions on the sequence of activities; when the workshop leaders drew attention to this, the experts began to withdraw, asserting that the issue was not worthy of mention. Only an unambiguous assurance that this information is very useful and valuable encouraged further discussion on the subject.

The map of the notes obtained from the workshop was redrawn in a graphic program and translated into English, which is presented in Fig. 2.

4. DISCUSSION

Increasingly, safety science often proposes that employees at the 'sharp end' of the organization be granted some freedom in making decisions, suggesting that this should increase the overall safety levels of socio-technical systems [36]. On the other hand, a certain degree of unification among the ways in which employees work in typical situations is beneficial because it reduces the number of misunderstandings and increases trust between co-workers [25]. We believe that the right relationship between obligatory and supportive rules can only be determined in consultation with the people performing the given activities. Hence, in our paper, we have presented a tool used to gain mutual understanding in IT projects, and adapted it to task analysis in railway vehicle maintenance. It is based on experts' intuition, which is one of the common approaches used in risk management [37].

The basic task analysis method, used in ergonomics since the middle of the twentieth century [38, 39], is the hierarchical task analysis (HTA). In this method, the way of executing a given process is presented by dividing it according to the objectives pursued in individual stages. This method has been used in many different domains, including rail transport, in which it has been employed to describe the process of a train being driven by two drivers [40]. The features of HTA include [38] the following:

– the possibility of using HTA results as inputs to other methods, such as event analysis of systemic teamwork [41], and
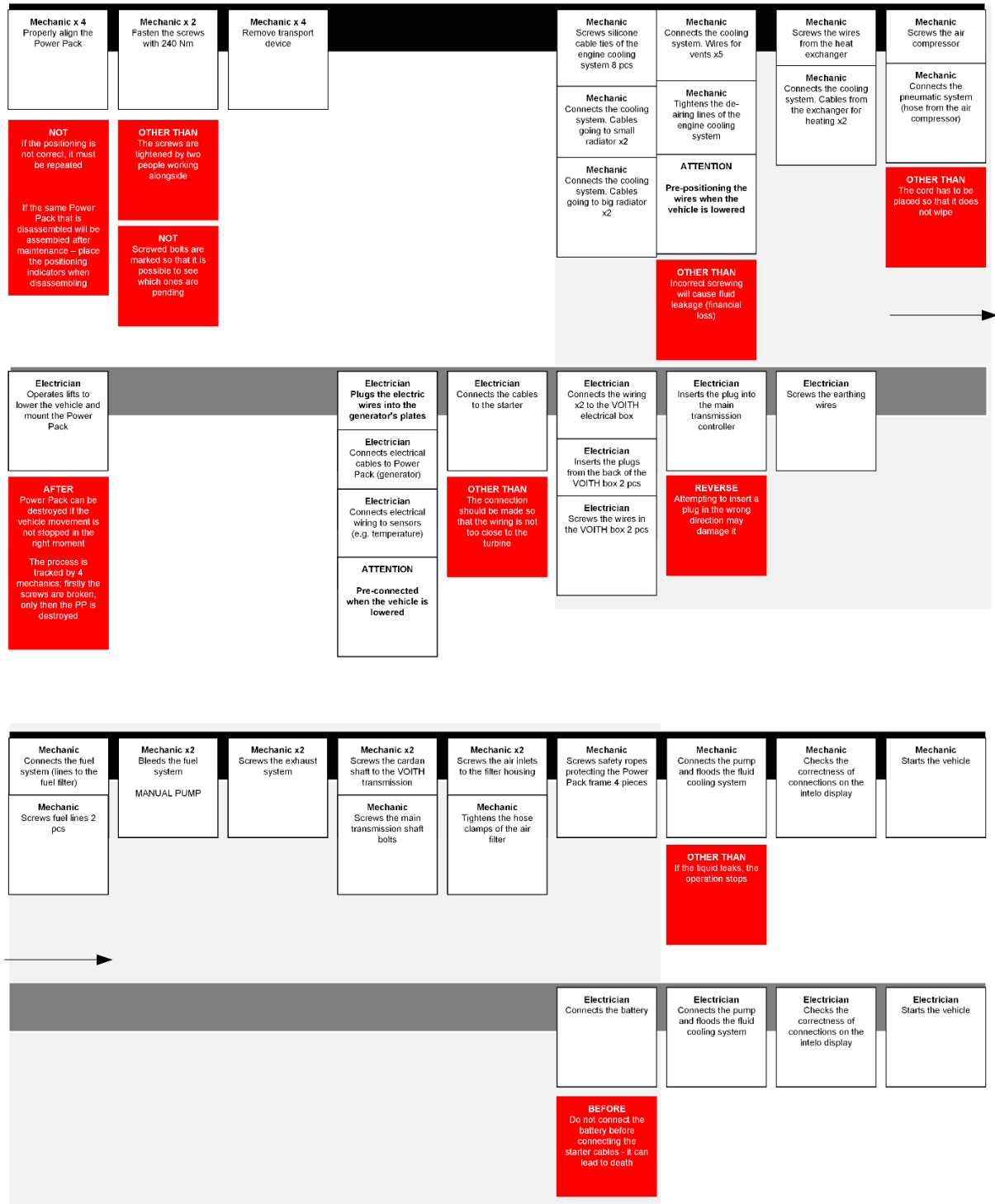– enabling analysts to understand the process surveyed more fully.

Fig. 2. Record of activities necessary to assemble the Power Pack, presented with the help of a map of notes made during the workshop. Actions on gray backgrounds can be performed in any order

Therefore, it can be concluded that HTA has a slightly different field of application than our proposed SNM. Although both methods can be described as being a means to an end, rather than being end goals themselves [38], the 'end' in HTA is more scientific and theoretical, whereas our method is intended for improving cooperation. Replacing typically scientific activities (such as observation or asking questions) with collaborative tasks (such as creating a map of notes) makes participants feel less like objects in an experiment and more like experts sharing their knowledge.

The two methods differ in terms of the time necessary to obtain information. It is generally agreed that it may take several months to master the HTA method. Moreover, the application itself is time-consuming, because it normally includes on-site observations. This would be difficult to organize in the railway maintenance context; the example process of power pack installation described in this paper is performed on one trainset every 300 000 km; hence, considering a fleet of several vehicles, it may take weeks (or even months) before such a process can be undertaken. In addition, the execution of a single process takes approximately 40 working hours (10 h × up to 4 workers), which would also make it necessary to engage more than one researcher in the observation phase. These issues may not be an obstacle in the case of scientific research but definitely hinder adoption of any method by the industry [42].

The experience gained from the conducted workshop indicated that discussions with experts are more effective when the leaders have knowledge about the process. This is especially useful in the final stage of the application of SNM, when questions are asked to challenge the existing map. Our experience reveals that experts often filter responses and do not comment on situations that they perceive as impossible. The task of the workshop leader is to intervene in situations where this opinion of 'impossibility' stems not from the laws of physics, but only from the fact that 'this has never happened'.

Knowledge of the process studied also enables the detection of inaccuracies in the statements of experts. However, the research simply cannot yield credible results if the experts deliberately falsify the information they provide. The temptation to conceal certain shortcuts is greater when the difference between the work-as-imagined and work-as-done is higher. The probability of this type of behavior depends on several factors:

Degree of proceduralism: The more the process is regulated, the greater the number of shortcuts that will ensue because of employees flouting procedures, although they may not want to admit to it.

Management approaches to procedure compliance: As reported by Kanse et al. [43], the pervasive positive role played by procedure management strategies involving the provision of learning opportunities can strongly influence adherence to maintenance procedures.

Both the degree of proceduralization and the management's approach to controlling compliance with procedures depend on implementation of safety management systems that are mandatory for entities operating in most transport sectors (rail, air, and maritime). Unfortunately, the actual way of implementing safety management systems often contributes to marginalization of people who possess practical safety-related knowledge [22]. A way to overcome this problem is the proposed solutions facilitating the exploration and exchange of expert knowledge [44].

The method of knowledge exploration that we propose in this paper represents the so-called proactive approach to safety management, postulated, e.g., in air transport [45]. It is characterized by the prediction of system states that could lead to an accident. This is a significant change in relation to the retrospective approach, based on the analysis of past events. In SNM, the proactive approach is particularly reflected at the stage of challenging of the developed map, when the knowledge exploration is transferred to another cognitive level according to the SRK model [46]. Instead of focusing only on how to implement maintenance procedures (R), during workshops, the experts are motivated to perform abductive reasoning [30], i.e., use their knowledge (K) to anticipate negative scenarios.

The result of using SNM is knowledge about work-as-done, which can be used to identify hazards that actually exist in the analyzed area. We believe that people are more aware of negative domain states if they notice and formulate them themselves. As a result, during the implementation of maintenance processes, they can intuitively use one of the risk treatment tactics, i.e., risk avoidance. Our approach is in line with the postulate of Aven [47], who believes that 'Identification of initiating

events is a critical task of the [risk] analysis' because 'what you have not identified, you cannot deal with'. SNM can also be used in risk communication as its interactive component [48].

At this point, it is worth noting that any tools used in the risk management process in entities responsible for the maintenance of railway vehicles in the European Union must be consistent with the provisions of their safety and/or maintenance management systems. For example, introducing a change to the existing procedures must be subject to an assessment of significance and possible further analysis, in accordance with the provisions of the relevant regulation [49]. An important aspect is also the issue of continuous compliance of the vehicle maintenance process with the requirements of, e.g., technical specifications for interoperability. This may make it impossible to introduce certain types of changes – especially if they concern not only the measures taken but also the results achieved.

The power pack replacement described in the present paper is an example of a process in which a certain set of operations must be carried out, with each activity being executed only once. This is an important assumption that allows sticky notes to be easily mapped and arranged in chronological order. Such processes are typical in the field of rail vehicle maintenance but are also used in the maintenance and operation of other technical systems. In our research, we have encountered them, e.g., in military aviation [50,51].

However, it cannot be unambiguously assumed that all processes have the same character. For instance, the traffic management process described by Siegel and Schraagen [52] is also carried out within the railway system, but this process may not be correctly described using the method proposed by us. Repeatability of activities in the process means that employees are unable to recall most unusual situations from memory without the help of a dedicated tool, such as a computer program.

5. CONCLUSIONS

It can be inferred from the research on safety science that nothing supports the increase in the overall safety levels of socio-technical systems better than the involvement of, and respect for, the knowledge of those closest to the sources of hazard. Therefore, it would be very beneficial to explore their knowledge to achieve an adequate level of safety, such as in the process of carrying out technical maintenance. However, there is little information in the literature on safety about how to accomplish such a task, in particular, which tools to use in the everyday practice of business entities, and how to conduct workshops to develop procedures/guidelines for practice based on the knowledge of experts.

Therefore, we decided that it is necessary to develop a new method (SNM), whose primary goal is to involve employees in the process of creating guidelines for practice. To achieve the goal of the present study, we have demonstrated an application of the method in real circumstances.

Our proposed method of gathering knowledge from experts is based on the concept of user stories, which are used in agile software development techniques (among other applications). We combine the advantages of mapping these stories with the principles of leading systematic discussion based on HAZOP keywords. This makes it possible to replace typically scientific activities, such as observation or asking questions, with the activity of creating a map of notes together with the experts. Participants do not feel like objects in the experiment, but are motivated to share their knowledge. The time needed to obtain information is also reduced.

We demonstrated the application of the SNM in the railway domain for power pack assembly in a diesel multiple unit. From the workshop conducted with the participation of experts, we gained knowledge about practices that were not included in the documentation, but could significantly improve the process under research. Already, we can state that the method works for a typical process in the field of rail vehicle maintenance, in which a certain set of operations should be carried out, with each operation being executed only once. However, the approach is not devoid of certain limitations, for example,
- the application may be difficult if the processes are not strictly sequential,
- experts may not provide answers regarding situations that seem impossible to them, and
- it is difficult to verify input information that is deliberately falsified by experts.

Among other solutions, the appropriate selection of participants can help resolve these problems relatively easily.

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