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Seeing the woods for the trees: the problem of information inefficiency and information overload on operator performance

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Abstract

One of the recurring questions in designing dynamic control environments is whether providing more information leads to better operational decisions. The idea of having every piece of information is increasingly tempting (and in safety critical domains often mandatory) but has become a potential obstacle for designers and operators. The present research study examined this challenge of appropriate information design and usability within a railway control setting. A laboratory study was conducted to investigate the presentation of different levels of information (taken from data processing framework, Dadashi et al. in Ergonomics 57(3):387–402, 2014) and the association with, and potential prediction of, the performance of a human operator when completing a cognitively demanding problem-solving scenario within railways. Results indicated that presenting users only with information corresponding to their cognitive task, and in the absence of other, non task-relevant information, improves the performance of their problem-solving/alarm handling. Knowing the key features of interest to various agents (machine or human) and using the data processing framework to guide the optimal level of information required by each of these agents could potentially lead to safer and more usable designs.

Keywords Human computer interaction · Decision support system · Usability engineering

1 Introduction

One of the recurring questions in designing dynamic control environments (from a simple mobile app to an advanced control setting) is whether providing more information leads to better operational decisions. The idea of having every piece of information available and potentially increasing the ability for operators to build up their 'situation awareness' (Endsley 1995) is so tempting (and in safety critical domains often mandatory) (N290.6-16 (2016) Requirements for monitoring and display of nuclear power plant safety functions in the event of an accident) that it has become a real obstacle for designers and further will become a challenge for operators. This "getting lost in the trees and not seeing the woods" can potentially leads to fatal errors [e.g. Three Mile Island nuclear accident (Venda and Venda 1995)]; or at best it will cause operational inefficiencies (e.g. McLennan et al. 2006; Wu et al. 2016). The problem is to convince designers and

system owners that there is no need to present every piece of information to the users and to provide clear tools and methods to enable the designers to select appropriate information to be presented. To achieve this, we propose a framework to guide the order and amount of information presentation.

One such setting where real-time situation awareness is maintained and informed by complex information displays is alarm handling in railway control rooms. With the introduction of centralised and integrated control systems, different members of staff with different roles are responsible for broader and more complex problem-solving situations [i.e. multi-agent control shared between signalling, disruption management and track-worker protection functions (Golightly et al. 2013)]. The challenges facing these operators are twofold: not only they are presented with huge amounts of information related to each function they perform; they also have to collaborate with other cognitive entities to complete each case of problem-solving. While these cognitive entities are primarily human, automation is increasingly playing a role in the management of traffic on the railways (Naghiyev et al. 2016) and in maintenance monitoring (Dadashi et al. 2014). While automation can in theory ease the workload of the operator, there is often a

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need for the operator to perceive and interpret information regarding the actions of the automation (Balfe et al. 2012).

This paper aims to understand the effectiveness of a data presentation framework [i.e. D2I (Dadashi et al. 2014)] and to explore its impact on guiding operators and decision makers with relevant and sufficient information. Although the case study adopted in this paper is within a railway setting, the alarm-handling scenario has parallels with remote condition monitoring, asset management and intelligent infrastructure in other sectors. The move towards centralised and connected platforms (e.g. Internet of Things, Smart Cities, etc.) calls for a more in-depth and guided approach for data presentation, and the case reviewed and validated in the present study has the potential to provide such platform.

2 Background

Alarms range from simple prompts for an operator to carry out further actions, through to semantically rich messages carrying verbal, textual or pictorial information about the source or cause of the abnormality. Successful implementation of alarm management systems, however, is not straightforward. Poor alarm handling has been a contributory factor in a number of safety–critical incidents such as the Three Mile Island incident in 1979 (Campbell 1988) and the Texaco refinery explosion in 1994 (Wilkinson and Lucas 2001; Timms 2009). In transportation, aircraft hazard reports confirm that alarm problems contributed to about 50% of all of the incidents recorded between the years of 1984–1994 (Gilson et al. 2001). Other examples include the Ladbroke Grove train accident (Cullen 2001) (though see Stanton and Baber 2008), for a different perspective) and the Channel Tunnel Fire (Kirkland 2002).

Major problems associated with alarm systems include alarm flooding, poor system state indication, poor priority management, nuisance and false alarms (Wilkinson and Lucas 2001; Gilson et al. 2001; Seagull and Sanderson 2001). Research on alarm design suggests many instances where alarms are irrelevant or present unnecessary duplication of information (Omodei et al. 2005). Alarm problems are mainly rooted in some form of information complexity and poor information design. Cummings and Mitchell (2006) listed the sources of complexity as:

- Volume of information,
- Ambiguous sources of information, and
- Unclear relationship between different information sources.

A significant effort has been devoted to exploring alarm design problems. Topics covered include alarm-handling response times (Stanton and Baber 2006), direction of attention (Gilson et al. 2001; Woods 1995), modelling the operators' diagnostic procedures (Stanton and Baber 2008; Woods 1995), information load (Woods et al. 2002) and assessing how informative and meaningful alarms are (Seagull and Sanderson 2001).

Alarm management is one critical part of ensuring rail infrastructure is operational and running as intended. Alarms can cover issues with the infrastructure (e.g. signal failure, track failure, power failure), issues with underpinning control systems, security and fire alarms as well as weather-related alarms (e.g. wind alarms, ice alarms). Weather-related alarms are important, as they have direct impact on the performance of the train while on the move. Failing to address the alarm in a timely manner can put the train in an unsafe position (i.e. train speed limits need to be adjusted in order to ensure train stability during wind gusts).

Based on Stanton and Baber (2006), alarm handling consists of four key activities: notification, acceptance, diagnosis and clearance. Applied to the railway infrastructure context, railway track workers, train drivers and, increasingly, remote sensing of trackside assets and environment are responsible for identifying faults and informing control room operators ("notification"). Control room operators then assess the authenticity of the fault ("acceptance") and conduct the early stages of diagnosis ("diagnosis") in order to assist the operational railway ("clearance"). This information would then be presented to the strategic analyst, who would recommend long-term solutions for the fault and ideally to prevent them in the future ("clearance").

This is particularly relevant to the future design of centralised and integrated 'intelligent infrastructure'-type systems. In such systems, an increasing burden of the capture and processing of alarm-related data is taken on by automation. As the processing of asset-related data moves from data through to intelligence and decision-making on the part of technology (ISO13374), the operator at some point needs to interpret lower level automated analysis to understand the reasons for diagnosis and potential maintenance action required. Therefore, there can be something of a paradox whereby the automation is conducting some or all of the stages of alarm handling on behalf of the operator, but then it needs to generate information about that alarm handling for the operator to verify or to understand in order to inform maintenance action. The kind of information required will also vary by role—for example whether the user is charged with reacting to real-time infrastructure failures, or has more of a long-term strategic planning and renewals role. The question is that while designing the intelligent infrastructure user interface, what should be presented to each of these roles to ensure that they are presented with sufficient information to fulfil their role and yet are not overloaded with too much. D2I led to categorisation of relevant information to three levels. These levels corresponded to the four stages of

alarm handling listed above and are assessed in the present study.

Figure 1 shows the Data to Intelligence (D2I) data-processing framework and the hypothetical levels of information for alarm handling. The framework has three rows; each row corresponds to different cognitive activities that are required during problem-solving (alarm handling in this case). The assumption explored in the present paper is that by presenting the relevant level of information (as recommended by D2I), the performance of operators while conducting that cognitive task (e.g. alarm handling) will improve. For this paper, the particular focus is on reactive, real-time operational response to critical weather-related alarms.

There are parallels between the process of alarm handling described in Dadashi et al. (2016) and a traditional information processing approach that underpins models such as the four-stage model of automation (Parasuraman et al. 2000). In particular, notification supports information acquisition, diagnosis supports decision selection, and clearance is a form of action implementation that has been selected, and automation or technological support for alarm handling can be described within the Parasuraman et al. (2000) framework. Recent work (Patterson 2017) has put forward the view that different stages of information processing are underpinned by different cognitive systems—specifically that information acquisition and information analysis, the first two stages of the Parasuraman et al. (2000) model are underpinned by skill, pattern-matching, and largely heuristic processes. The later stages of decision selection and action implementation are more effortful than rule and

knowledge-based cognitive processes. Because they are underpinned by different mechanisms, these latter stages are more prone to different types of bias and error.

In order to verify the relationship between information type and alarm handling, a low-fidelity simulation-based experiment was conducted. The hypotheses explored here is that there is a relationship between the stages of problem-solving and its corresponding level of information as suggested in the D2I framework. As described above, each level on the D2I corresponds and supports a particular aspect of decision-making and alarm handling. Level 1 of D2I: Data and Information supports alarm notification and acceptance, level 2 of D2I: Knowledge supports alarm clearance and level 3: Intelligence supports proactive maintenance (i.e. predict and prevent). Therefore, it is reasonable to assume that when operators are presented with the relevant and sufficient information (i.e. optimal information design), their performance when conducting each of these activities will be improved (i.e. enhanced usability). This performance can be quantified as both speed of response and accuracy, though there may also be a subjective sense of ease or confidence in being able to accurately handle the alarm.

3 Study approach

Episodes of weather-related alarms were simulated for the purpose of this study. Decision ladders (Rasmussen and Goodstein 1985) and in-depth exploratory (field studies, semi-structure Critical Decision Method-inspired interview
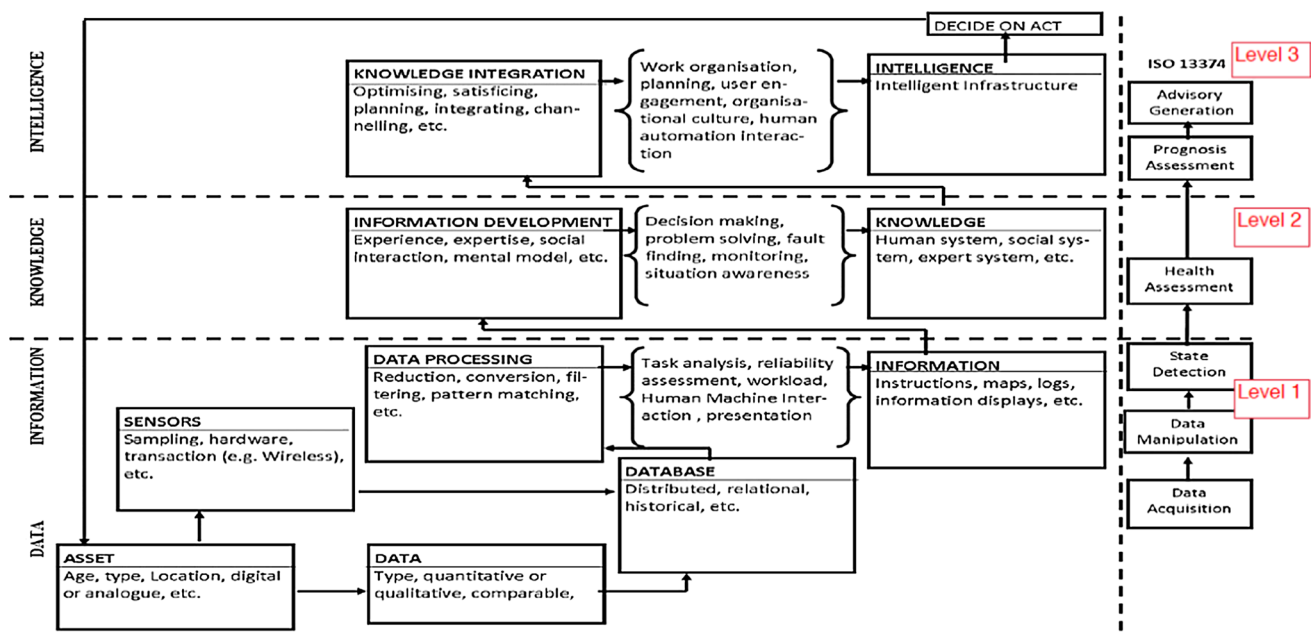

Fig. 1 Hypothetical optimal level of information for alarm clearance (Dadashi et al. 2014)

studies and observations) developed within an earlier study (Dadashi et al. 2010) led to an understanding of the activities associated with this particular type of alarm and informed the selection of tasks and scenarios. Exploring the information that was utilised during alarm handling and corresponding them to different aspects of the decision ladders led to understanding operators' information requirements. This provided detailed understanding of the range of remote condition monitoring equipment available to railway operators and their societal challenges and potential opportunities. This informed the details associated with the experimental scenarios as well as the selection of the secondary task that was conducted as part of the experiment.

3.1 Experimental tasks

Two experimental tasks were selected for this study: 1—alarm acceptance and 2—alarm clearance. They were selected because they incorporated the other two activities that have been identified, i.e. noticing the alarm and diagnosing the alarm. One cannot accept an alarm without noticing it; similarly, it is not possible to clear an alarm without diagnosing it. Also, both of these activities, i.e. accepting and clearing the alarm require the operator to interact with the experimental prototype and will provide a measure of performance. It should be noted that these tasks are simplified forms of the activities observed in real wind alarm handling episodes.

The task stages were as follows:

Task 1 accepting wind alarms: When an alarm is generated, operators have to check to see whether it is authentic or not (i.e. true failure or false alarm). This is referred to as alarm acceptance. When there is a wind alarm, an audible siren will be generated to inform the operator of the alarm. Participants had to check the wind gust shown on the alarm's main window and compare it against the threshold table provided to them. If the wind gust speed presented on the main window was higher than the threshold, then the alarm was true and participants had to accept it. In order to accept an alarm, participants were instructed to press '1' on the keyboard and, to cancel the alarm, they had to press '2'.

Task 2 clearing wind alarms: The second task was to correct the fault by imposing a speed restriction on the train in the alarmed location. The recommended speed restriction varied depending on the type of trains; therefore, the participants had to identify the type of train and impose the specific speed restriction accordingly. Moreover, if participants were presented with information about ice alarms, they were advised to consider this in their clearance task. If there were also problems with ice in the alarmed location, a new set of speed restrictions had to be recommended. Note that attending to ice alarm infor-

mation was optional for participants. This was due to the fact that ice alarm information provided additional context that was not immediately necessary for either alarm notification or alarm clearance. By providing participants flexibility to choose, it was possible to explore whether participants opt in for additional pieces of information during alarm handling.

3.2 Levels of information

Three levels of information as recommended in the data processing framework (Dadashi et al. 2014) (Fig. 1) were examined in this experiment (Table 1). The first level of information includes rule-based collection of data and storing the measured data in a distributed database. In this scenario, level one information refers to basic information that is required to handle the alarm (e.g. data regarding location of the alarm and basic conditions). Level two information refers to information that is processed and can provide additional insights to the problem-solving

Table 1 Levels of information

Level	Task	Information
One	Alarm acceptance	Location of the alarm
		Wind gust speed
		Threshold tables
One	Alarm clearance	Location of the alarm
		Wind gust speed
		Type of train
		Speed restriction guidelines
Two	Alarm acceptance	Location of the alarm
		Wind gust speed
		Threshold tables
		Wind alarms in other locations
		Ice alarm information
Two	Alarm clearance	Location of the alarm
		Wind gust speed
		Type of train
		Speed restriction guidelines
		Ice alarm information
Three	Alarm acceptance	Wind gust speed
		Threshold tables
		Wind alarms in other locations
		Ice alarm information
		Wind gust speed in the neighbouring weather station
Three	Alarm clearance	Location of the alarm
		Wind gust speed
		Type of train
		Speed restriction guidelines
		Ice alarm information

scenario (e.g. wind alarms in other locations), and finally, the third level of information provides knowledge towards making more optimised decisions and to be able to conduct proactive problem-solving (e.g. predict when an alarm will occur). In this scenario, the third level of information refers to the wind speed in the neighbouring location, and the operator can utilise this knowledge to predict whether there is an upcoming wind alarm in that location or not.

3.3 Experimental hypothesis

Experimental hypothesis: There is an effect (primary and secondary task performance) of the information provided (level 1–3) on the performance of alarm-handling tasks (alarm clearance and alarm acceptance). The independent variables explored are the alarm handling tasks (clearance or acceptance) and also the level of information provided (level 1–3). The dependent variables are the primary or secondary task performances that are measured under each of the experimental conditions. These include completion time, errors in primary tasks and errors in secondary tasks.

The alarm acceptance completion time is expected to increase from level 1 to level 3. The first level of information provides the participants with only a basic understanding of the problem by giving tables of train speeds and train types. The second level of information provides the wind alarm status in the neighbouring weather stations to provide the participants with an overview of the domain and the third level of information provides information regarding future potential wind alarms.

The increase in the completion time can simply relate to the increase in the amount of information presented to the participants. Moreover, information at levels 2 and 3 is not necessarily useful for the alarm acceptance task. Although the second level of information can provide participants with an overview (e.g. status of wind alarm in the neighbouring weather stations) of their choice ('accept' or 'cancel'), it is not a necessary piece of information.

Similarly, errors are also expected to increase from level 1 to level 2, but will decrease when participants are presented with the third level of information. The errors in the second level will increase possibly because operators become confused and their tasks do not really need an overview to aid their understanding. However, giving information to participants about future alarms means that, when those alarms occur, they are expecting them and therefore their errors may decrease.

4 Method

Thirty-one students (14 males and 17 females, with a mean age of 22 years) from the University of Nottingham participated in this study. None of the participants had any prior experience of alarm handling systems but were given related training and were assessed prior to the experiment. The study received approval from the University of Nottingham Faculty of Engineering Research Ethics Committee.

Participants were briefed and asked to review the information sheet before agreeing to take part in the study. In all of the experimental trials participants had to perform task 1 (alarm acceptance) prior to task 2 (alarm clearance) and they received training for each of the tasks. Participants were guided through a 7–10-min training session for task 1 and then performed a practice run with the experimental prototype. Next they were asked to attend to 24 cases of alarm episodes. After the completion of task 1, they were briefed and trained on task 2 for another 7–10 min. They then practised with the experimental prototype, after which they were asked to attend to 16 cases of alarms.

There was a 30-s interval between each of the alarm cases and participants were asked to monitor and find 'point machine' faults on the fault log and complete the fault log recording form (paper based). This was their secondary task and was used to infer the participants' spare mental capacity during the alarm handling (Sharples and Megaw 2015).

Finally, participants were asked to comment on the alarm episodes and to describe their reasons for the decisions made. Their comments about the experimental prototype and the tasks were recorded using an audio recorder.

Three groups of participants (group A, group B and group C) were instructed to conduct both alarm acceptance and alarm clearance tasks. A between subject study was designed: each group of participants was presented with only one of the levels of information. Both tasks were examined and participants' response times, and the number of errors they made while conducting the tasks was recorded.

A 15" Sony VAIO™ laptop was used for displaying the screenshots of the wind alarm prototype (Fig. 2). The experimental prototype is developed by E-prime 2.0 ™. E-prime 2.0 ™ is a software that is able to design an experimental study using drag and drop interfaces and simple scripting for the run of the experiment. Therefore, it is possible to define the sequence of activity live logging of participants' responses and their completion times.

A 15" Dell™ laptop was used to display the maintenance control fault log to participants when they were not handling alarms. A fault log recording form was completed by participants while monitoring the log. Finally, an Olympus™ audio recorder was used to record participants' comments after the completion of the experiment.

**Fig. 2** Example of a simulated wind alarm window
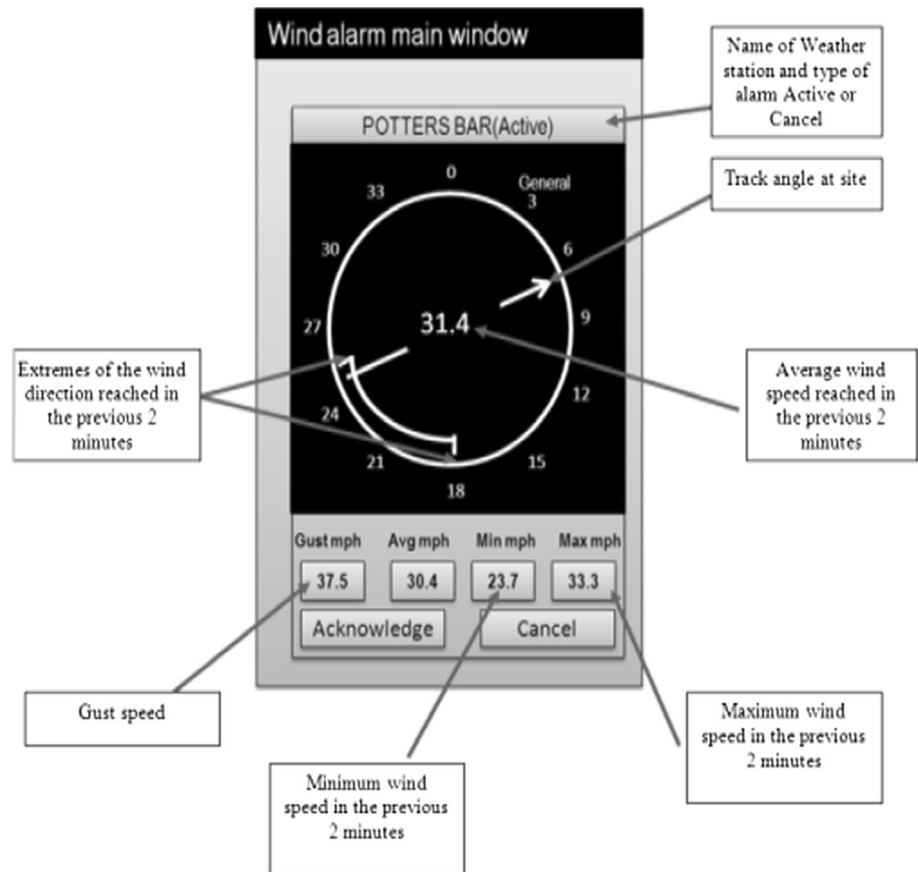
5 Results

Participants' completion times and errors during the trials were recorded using E-prime 2.0™. A 2X3 between subject ANOVA test was conducted. The results have been analysed statistically using SPSS™ 18.0. Participants comments were reviewed and the main themes mentioned by participants were explored.

5.1 Completion time

For both alarm acceptance and clearance, a linear increase in response time was visible from level 1 to 3. Means of the response time associated with alarm acceptance and alarm clearance tasks while presented with three levels of information are shown in Fig. 3 below. Despite the existence of this trend, for alarm acceptance, this increase was not statistically significant; $F (2, 28) = 2.94, p > 0.05$.

Multiple comparisons between different levels of information show significant difference between completion times of alarm acceptance when presented with level 1 information, compared with alarm clearance when presented with level 3 information ($p < 0.05$).

When participants were clearing the alarm the response time was significantly different depending on the level of

|	Alarm acceptance	Alarm clearance
■ Level 1	4076.29	3654.85
■ level 1	5881.39	10001.32
■ level 3	8365.44	15948.68
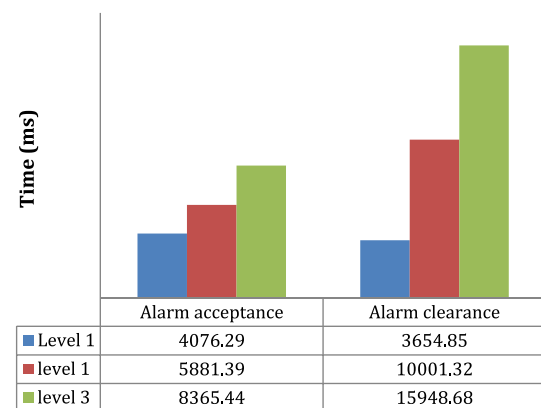
Fig. 3 Mean of completion time for two tasks at three different levels (milliseconds). Level 1: Basic understanding of the problem that is absolutely necessary to solve the problem. Level 2: Information that assists participants to explain the issue in addition to the minimum information required. Level 3: Information that enables participants to predict the future status of the system in addition to the minimum information required

information: $F (2, 28) = 11.73, p < 0.001$. It was the highest when participants were presented with level 3 information and lowest when they were presented with level 1
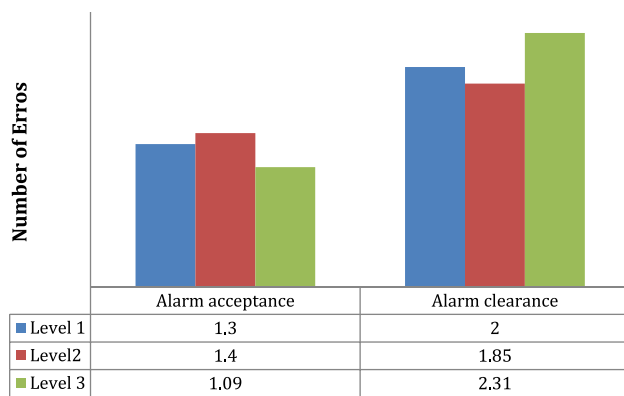
Fig. 4 Errors made while alarm acceptance and alarm analysis in three conditions
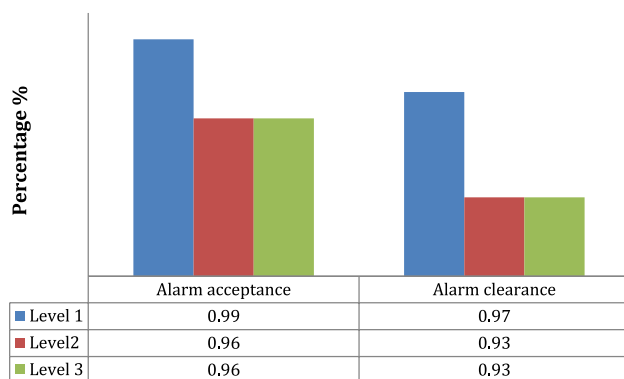
Fig. 5 Percentage of faults logged correctly while conducting tasks 1 and 2 in three conditions

information. Multiple comparison shows significant difference between all levels ($p < 0.001$).

5.2 Errors—primary task

The mean of the number of errors while performing both tasks and when participants were presented with the three levels of information is shown in Fig. 4. Even though the third level generates the fewest errors while accepting alarms (task 1), this was not statistically significant; $F(2, 28) = 0.73$, $p > 0.05$. Multiple comparisons of various levels also do not show any significant difference among various levels.

When participants were clearing alarms (task 2), depending on the level of information available to them, their errors were significantly different: $F(2, 28) = 5.871$, $p < 0.05$. Multiple comparisons between different levels of information show significant difference between levels 1 and 2 ($p < 0.05$) and levels 2 and 3 ($p < 0.01$) (Fig. 5).

5.3 Errors—secondary task

Secondary task performance refers to the percentage of faults logged correctly. There was no significant difference between secondary task performance in both alarm acceptance and alarm clearance tasks when presented with various levels of information.

When participants were presented with the first level of information, they found alarm clearance easier than alarm acceptance. One participant mentioned that *task 2 (alarm clearance) was easier because I only had to look at one thing*. In other words, the perceived difficulty was associated with the amount of information available, which explains the higher response time for alarm acceptance tasks in comparison with alarm clearance. Out of the 10 participants presented with the first level of information, only one participant said that alarm acceptance was easier than alarm clearance and the reason mentioned was*: the location of information was more organised on the screen than in task 2*. It must be noted that task 2 (i.e. alarm clearance) had the potential to explore additional information since participants could access various pieces of information about the location of the alarm as well as neighbouring weather conditions.

When presented with the second level of information, participants had the option of reviewing location information and using this data for decision-making, if they wanted to. Although this was an optional piece of information, all 10 participants in this condition considered it. One of the participants mentioned*: well there is an option there and you just want to use it*. Unlike the first group (level 1 information), 7 of the 10 participants in the second group found alarm clearance more difficult. This was due to the increase in the amount of information that they felt obliged to review and analyse. This difficulty is reflected in the quantitative data as well: errors and response times are higher for the alarm clearance task than for the alarm acceptance task. The three participants who found task 2 easier under the second condition (i.e. second level of information) have different reasons. One participant said that the second task was easier because they were familiar with the system after performing alarm acceptance. Another participant made a mistake when accepting alarms due to distractions caused by monitoring the fault log and therefore found the task more difficult.

All 11 participants performing the tasks under the third condition attended to location information for the alarm clearance tasks but mostly ignored it when accepting alarms. One of the participants said that, during alarm acceptance, *I got quite stressed and I could not attend to any additional information regarding the location, I just wanted to deal with the absolute minimum*. However, five participants used the information regarding the gust speed in the neighbouring location as a clue to predict future alarms. This explains the reason for the lower number of errors when performing

the alarm acceptance in the third condition (level 3) in comparison with the other two groups. Other participants chose not to refer to the wind speed in the neighbouring stations as they wanted to handle alarms as quickly as possible and therefore did not want to attend to information believed to be beneficial in the future. One of the participants mentioned that: *I was not sure when these alarms would happen, so I thought by the time they are generated I might have forgotten them already*.

In the third group, only one participant used the route information to predict future alarms when clearing alarms; the rest chose not to use that information. One participant mentioned that, "I felt it was too much", another said that *because there were too many pieces of information I knew I would not remember that route anyway, so it was better to deal with them when they were generated.*

In the third group, 7 out of 11 participants found the alarm acceptance task easier than the alarm clearance task. One participant thought that alarm acceptance was more difficult because, in alarm clearance, the user felt more engaged and felt that they had control over the situation. The participant said: *Task 1 (alarm acceptance) is too boring for the operator and should be done by a machine, not a human.* A number of participants reported confusion when they had to deal with various pieces of information when clearing alarms and admitted that they might have made some mistakes.

6 Discussion

The study presented in this paper attempts to merge two challenging aspects of design that are relevancy and sufficiency of information. The D2I framework has parallels with theoretical foundations that were explored in Vicente and Rasmussen (1992). Skill, Rule Knowledge (SRK) taxonomy offers three distinct levels of information processing and offers different information presentation formats supporting each of these levels (S/R/K). D2I framework does not offer a way of categorising user behaviour, it aims to explore the overall system. This holistic understanding can further be decomposed into systems of systems and further explained with Ecological Interface Design (EDI) framework or SRK taxonomy.

The results have partially confirmed the hypotheses of the study. The results for alarm clearance, incorporating the later stages of alarm processing (Stanton and Baber 2006; Dadashi et al. 2016), broadly follow the hypotheses. More information leads to slower response time, and more errors when presented with Level 3 information (predictive information). This pattern is not, however, replicated for alarm acceptance. There are no significant differences in either response time, or for error rate, as a result of presenting different levels of information.

In terms of alarm handling models such as Stanton and Baber (2006), these results suggest that the impact of additional information is more profound at the later stages of alarm handling than at earlier stages. Again, this has parallels with the theoretical framework that later stages of information processing are more dependent on effortful, conscious problem-solving and decision-making (Patterson 2017), and are more prone to being slowed or misdirected by spurious information, even if that information is potentially predictive in supporting future alarm handling episodes (Level 3; Dadashi et al. 2014). The stages of alarm handling that are more likely to be skilled, perceptual and pattern-matching are less prone to the effects of information overload and spurious information (Patterson 2017).

This study was limited due to the use of trained, novice participants rather than operational experts. It must be noted that the novice participants who conducted the study were trained and evaluated to ensure that they were familiar with the tasks. While the actual standard of performance must be different for operators, the differentiation between the independent variables is anticipated to be consistent, though this requires further validation. In-line with Gray (2002) the experimental setting that was set up for this study was tractable (i.e. easily managed, taught or controlled), corresponded to the tasks explored and were engaging (i.e. participants were not bored and thus provided continuous feedback). The simulated environment was not identical to an industry system, but provided a comparative level of authenticity, based on familiarisation visits, while supporting the control the level of task complexity. As it is noted in Balfe et al. (2018), the use of a simulator provided the opportunity to rehearse and replicate the operational activities. These activities may often be too intertwined and hard to observe within the real-life work setting. Nonetheless, future studies should be conducted with more sensitive simulators to facilitate assessing the cognitive processing of railway experts, one example being to develop synthetic environment or microworlds as suggested by Gonzalez et al. (2005) to explore dynamic decision-making. Moreover, assessing the framework within other types of control systems (e.g. manufacturing, energy, process control, etc.) will develop insights on temporal aspects of information presentation. This is particularly the case when one role is responsible for different levels of decision-making. The other limitation of this study which explains the lack of significant difference can be due to the number of participants. Although this number was suggested through a power analysis, the effect size was estimated to be medium.

7 Conclusions

The present study simulated the application of the data processing framework in guiding the design of a cognitive system. This framework can be utilised in similar contexts in order to assist designers and developers with creating more effective end products. When designing large scale complex multi-agent control systems, D2I framework can be used to inform relevant human factors techniques that should be conducted by designers to ensure that appropriate level of understanding of the context is available for an effective design (For more information regarding the application and utilisation of D2I framework please see Dadashi et al. 2014). In particular, the guidance to be taken from this study, subject to further validation, is that additional information will have more impact at the later stages of decision-making and action selection (clearance) of alarms. Earlier stages of identifying alarms will be more robust in the face of additional information, but we should not assume they are completely robust. The wealth of historical evidence into alarm flooding suggests that there will be a point where new alarms are lost in the sheer volume of demands placed on the operator. Accordingly, the trends shown for task 1 (alarm acceptance) for both response rate and error indicate that with a more complex domain or with a higher number of synchronous task, performance on this early stage of alarm handling would also be prone to degradation, but possibly not at the same rate as clearance. These results also suggest that the kind of predictive information that new forms of maintenance and asset monitoring technology will generate (Dadashi et al. 2016) will form an additional load if not carefully managed within user centred design.

These findings from this study highlight the need for robust methods that allow the impact of display content on decisions to be analysed in order to anticipate situations where 'too much' information is presented. Approaches such as Ecological Interface Design (Vicente and Rasmussen 1992; Houghton and Patel 2015), Cognitive Work Analysis (Dadashi et al. 2013) and Cognitive Task Analysis (Morison and Woods 2016) point the way forward. However, it is important to understand that for such a method to be effective, all likely tasks would need to be known. This is to ensure that an appropriate level of contextual understanding is developed and hence relevant level of information processing is supported. It must be noted that an overall understanding of tasks will determine the level of detail that is required for data collection and task analysis. Therefore, it is recommended that alongside such a task-driven approach, participatory methods are used with subject matter experts to understand the unintended consequences that would occur if data are removed from a display. A methodology that simply asks 'what if this piece of information is removed?' has the potential to be very powerful to test the implications of display simplification.

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