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Assessing the Performance of Human-machine Interaction in eDrilling Operations

Denis Besnard
Mines-ParisTech
denis.besnard@mines-paristech.fr

Summary

It has been clear since the 1980s that the introduction of automated systems for control and supervision tasks has significant drawbacks resulting from human-machine interactions (HMI). However, there have been few attempts to create a method to assess either the existence or the effect of these drawbacks. This chapter describes such a method and documents the various engineering steps. This chapter first surveys the literature on the drawbacks of automation and then describes how these can be converted into a set of HMI assessment criteria. These criteria are then engineered into a prototype method and finally deployed in a case study in an eDrilling scenario. The results show that the prototype method can be used to assess the performance of human-machine interaction in control and supervision tasks.

1 Automation and Complex Systems

The automation of complex systems does not mean that human intervention is no longer needed in control and supervision tasks. In fact the opposite is true; the fact that systems can enter exceptional and unforeseen states makes the role of humans all the more important. Given that the role played by automated systems has become increasingly business-critical it follows that, more than ever before, humans are needed. This is one of the ironies of automation identified by Bainbridge (1987). However, the essential contribution that humans make to the control and supervision of complex and dynamic tasks can be jeopardised by the system itself. This chapter will investigate this paradox.

Control and supervision refers to the mental activity that humans use to manage dynamic processes – from flying an aircraft to controlling production chains. Put simply, it is an activity where environmental cues are used to assess the current state of a given process and decide whether something has to be done or not, and if so when and how, etc. To take the example of piloting an aircraft, pilots have a flight plan that they try to follow. The plan consists of various way points, altitudes and speeds that govern the progress of the aircraft. A simple view is that the role of the pilot is to execute the actions that make the aircraft follow the flight plan and reach its destination. For the most part, these actions now involve keying data into the on-board flight management computer.

The computerisation of the human-machine interaction (HMI) and the high level of automation that came with it were initially thought to guarantee reliability. However, in the mid-late 1980s (when Information Technology was becoming more and more prevalent in the world of process control) some important issues started to surface. Concomitant with the technological shift, new forms of accidents began to appear in which pilots lost control of their aircraft under normal flying conditions. Such events began a reconsideration of the role of automation in control and supervision tasks (Besnard & Baxter 2006). Research was initially pioneered by the safety-critical commercial aviation industry, which was badly affected by such events. Today, HMI automation is a paramount concern in many domains and extends well beyond the field of aviation, for example to the control rooms of oil and gas pipeline systems (Meshkati 2006) or collaborative decision making (Pierce & Salas 2003).

This chapter addresses the issue of HMI automation in the specific context of offshore oil and gas drilling operations and focuses on a tool known as eDrilling. The tool, which is able to simulate drilling operations offers a 3D visualisation, provides control from a remote drilling expert centre and is supported by real-time data. It is used in a case study to develop a prototype HMI assessment method. This method aims to identify factors that might develop into a loss of situation awareness on the part of operators, particularly where there might be insufficient understanding of automated behaviour (Endsley, 1996). The eDrilling tool is safety-critical, extensively computerised and includes complex control interfaces, all of which means that operators using it can expect to face the same challenges that have created mishaps in other industries and makes its assessment interesting. Hollnagel and Woods (1999: 346) express the idea in another way: the purpose of the evaluation is to assess the ‘match between the system’s image and user characteristics on a mental or cognitive level’.

The following section reviews some of the drawbacks of automation. Next, these are converted into a set of interface-centred evaluation criteria for eDrilling. Finally, this material is integrated into a prototype method which aims to assess HMI performance in automated environments such as Integrated Operations (see Chapter 2 for a description of Integrated Operations).

2 Six Drawbacks of Automation

The literature provides several classifications of automation levels, dating back to the seminal study of Sheridan and Verplank (1978). This study influenced later work such as Parasuraman Sheridan and Wickens (2000), which lists ten levels of automation. These ten levels include situations where the operator:

- has full and direct control over the task;
- has full, but indirect control over the task through an automated interface, decides which actions to perform and receives feedback; and
- interacts with the task indirectly through an automated interface, does not always decide which actions to perform and does not always receive feedback.

These various levels of automation are summarised in Figure 1.

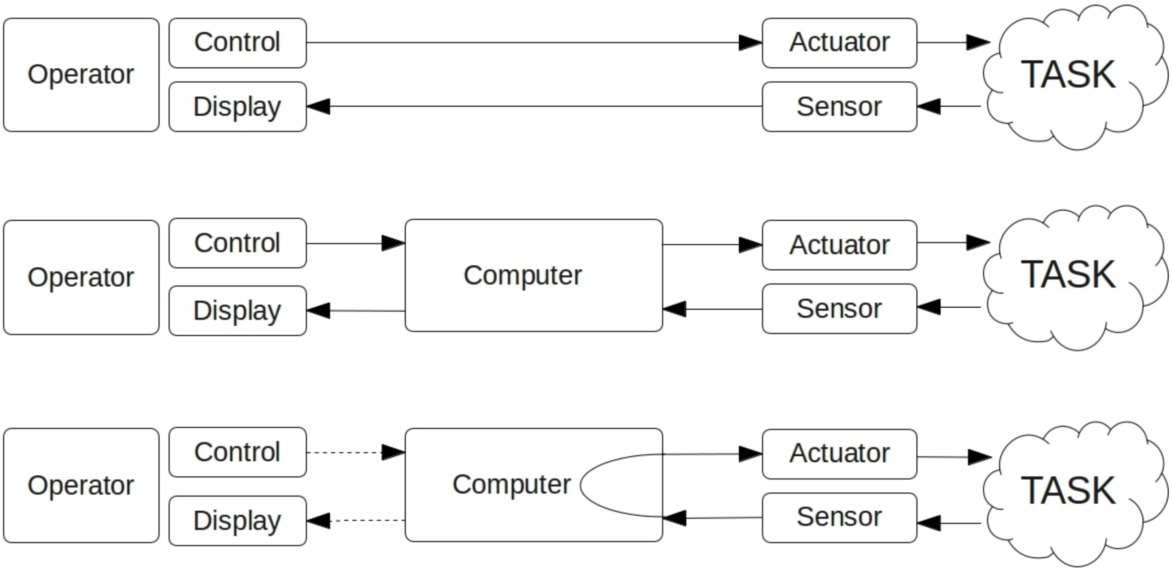

Figure 1: Representation of three levels of automation of a computerized control task (Source: adapted from Parasuraman Sheridan and Wickens 2000)

Such a classification makes it possible to explicitly specify the allocation of functions between humans and machines. It has a significant bearing on the content of the supervision and control task and partly determines what the human operator will have access to, in order to build their mental representation of the process. Moreover, the classification (despite its age) is a reflection of the drawbacks of automation, as it is generally the case that the greater the extent of automation, the more difficult it is for an operator to detect a loss of situation awareness. This makes the effects on the control and supervision task all the more severe. In view of the consequences of a loss of situation awareness, it makes sense to address the issue of the drawbacks of automation in some detail. This discussion may eventually help the operator find an answer to the key question of control and supervision, namely, ‘Why is the system doing what it does?’ (Boy 2005), which is the focus of the following sub-sections.

The following sections present and discuss six HMI-related drawbacks resulting from the automation of systems. They draw heavily upon the work of Abbott, Slotte and Stimson (1996) who provide an extensive discussion of automation issues, particularly aboard modern aircraft. Although the six examples given here do not originate from the oil and gas domain, it is worth noting that the two domains have many common features. The eDrilling operator is just as remote from the process as the pilot of a fly-by-wire aircraft. In both situations the control cues have changed, the system has become more complex and autonomous, and anticipation is a key issue. With these similarities in mind, it is assumed (in the absence of a full demonstration) that the difficulties found in eDrilling are comparable to those found in traditional HMI-critical domains.

2.1 Remoteness of Control

Modern interfaces tend to separate operators from direct contact with the process they are controlling. Activity becomes symbolic: rather than direct physical information the process is controlled by a set of parameters. This can be seen in nuclear power station control operations, air traffic control (Figure 2) and train traffic control (Crawford et al. 2010) for example.

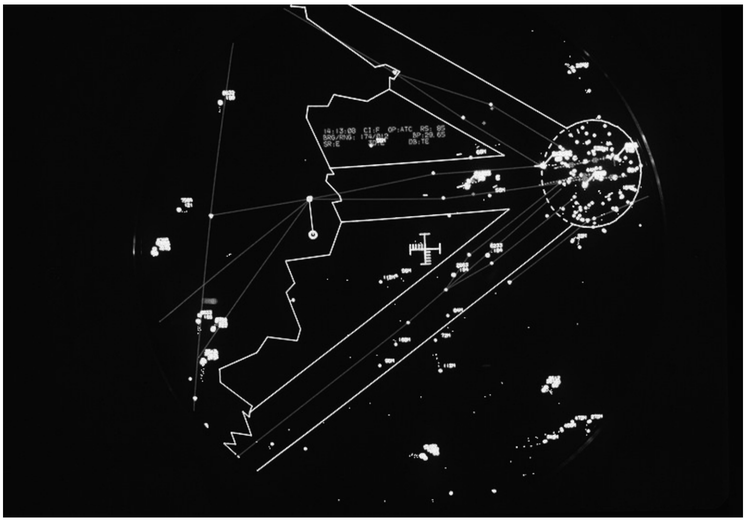

Figure 2: Air traffic control display of the aircraft corridors at West Berlin airport in 1989 (Source: Wikimedia Commons)

The fact that processes can only be indirectly manipulated means that performance control relies on the operator having an accurate mental representation of a symbolic set of information. This symbolic representation is not necessarily a source of mishaps *per se*. However, it can become a challenge for operators when control and supervision tasks switch from being direct and analogue, to indirect and symbolic.

In the context of Integrated Operations, remote operations are only marginally implemented. The current situation may be due to a lack of feedback from experience and insufficient technological maturity. As the technology is deployed more extensively, it is reasonable to expect that remote operations will become common practice.

2.2 Change of Control Cues

Automation does not simply mean that a machine performs part of a task. It also changes the nature of the work carried out by humans and what they use as control cues. In aviation, for example, the mechanical commands that controlled surfaces such as flaps were replaced by electronic commands. Consequently, pilots were no longer physically connected to these control surfaces by cables and pulleys and they no longer received the haptic feedback provided by vibrations. This was a significant change as pilots lost a direct cue about airflow over the wings of their aircraft. The shift to electronic commands proved to be such a handicap for pilots that simulated vibrations had to be built back into modern control columns.

The problem of changes in control cues that follow the introduction of remote or indirect control technology is not unique to aviation. It was also shown to be an issue for high-temperature furnace operators when steelworks factories implemented process control rooms. Operators lost direct cues related to the temperature, colour and texture of the molten metal. Later, the move from electro-mechanical to digital displays caused a similar change in the control rooms of nuclear power plants (Figure 3). Before the introduction of digital displays a change in a parameter would cause a dial to click, thereby providing auditory information that something was happening. With digital technology, these sounds disappeared, which meant that operators could only supervise changing control parameters by sight.

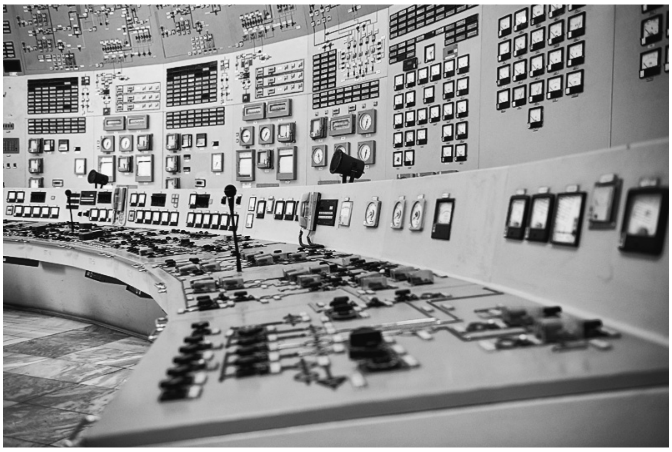

Figure 3: A set of electro-mechanical panels in a nuclear power plant control room (© 2009 Yovko Lambrev. Creative Commons)

2.3 Opacity

Automation (especially computerisation) has made it difficult for the operator to track the controlled process. The situation is analogous to a black box. To take the example of Babbage’s difference engine (Figure 4) it is clear that the various cogwheels, levers and drums work together to produce the result of a computation. However, once digitised into a pocket calculator (Figure 5) the process is no longer visible.

Figure 4: Charles Babbage’s difference engine (Source: Friendly & Denis 2001)

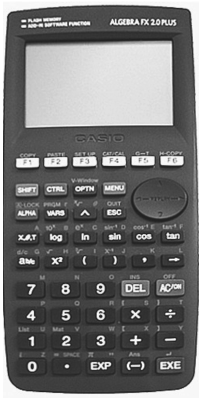

Figure 5: A pocket calculator
(© Volker Urban. Creative Commons)

Without prior knowledge of the internal design of the calculator, only the input interface (the keyboard) and the output interface (the monitor) provide the user with information from which they may be able to infer how calculations are actually done. The same is true for any machine or system that relies on digital technology. This opens the door to automation ‘surprises’, a term which refers to decisions taken by machines that are not consistent with the understanding that crews or operators have of the control task. Such an event took place in 1995 aboard a Boeing 757 aircraft approaching Cali airport (Columbia). The crew keyed the first letters of a navigation beacon into the flight management system (FMS). Unknown to the crew, the FMS wrongly self-completed the name of the beacon. Consequently, the aircraft turned towards the incorrect beacon, located on a trajectory that did not follow the original descent path. By the time the crew detected that they were on an incorrect heading and corrected their trajectory, they were in a mountainous area and the aircraft ploughed into a mountain. Everyone on-board perished in the crash (ACRC 1996).

2.4 Complexity

As automation becomes more extensive, complexity increases (see Rauterberg 1996 for a definition). This not only means that there are more functions, but also that the number of possible interrelations between functions increases. For example, the control unit of modern car engine receives a large amount of digital information (e.g. engine load, engine speed, composition of exhaust gases). This information is used to control the functioning of the engine (e.g. by adjusting the composition of the fuel/air mixture).

These automated functions operate without intentional input from the operator (the driver). They also have cross-compensation capabilities, which mean that a manual change to one of them will not necessarily change the overall state of the system (i.e. the functioning of the engine). Such features are efficient under nominal conditions. However, in the case of failure where there is a need for manual tweaking, or in an emergency situation, the complexity inherent in the system makes adjustment difficult. First, greater complexity makes it increasingly difficult to diagnose the cause of a failure as more functions create more possible failure combinations. Secondly, a manual override can be made impossible by design (e.g. it can be impossible to repair an engine control unit without physically taking it apart.

2.5 Mode Confusion and System Autonomy

A mode is a pre-programmed, selectable set of instructions that configures the behaviour of the system it controls. Modes make it possible to streamline an interface by assigning more than one function to a given control and they are paramount in modern control and supervision systems. In aviation for example, the same device enables pilots to manage descent speeds in two different ways (Figure 6), which has the advantage of triggering several actions at once, thereby facilitating interactions with the system. However, as Sarter and Woods (1995) have pointed out, system autonomy can make it difficult to interact with modes as it can cause modes to change indirectly. An example of this from the aviation industry is a system-generated change in a flight parameter (as opposed to a manual intervention by the pilot) that triggers a mode awareness issue affecting the crew.

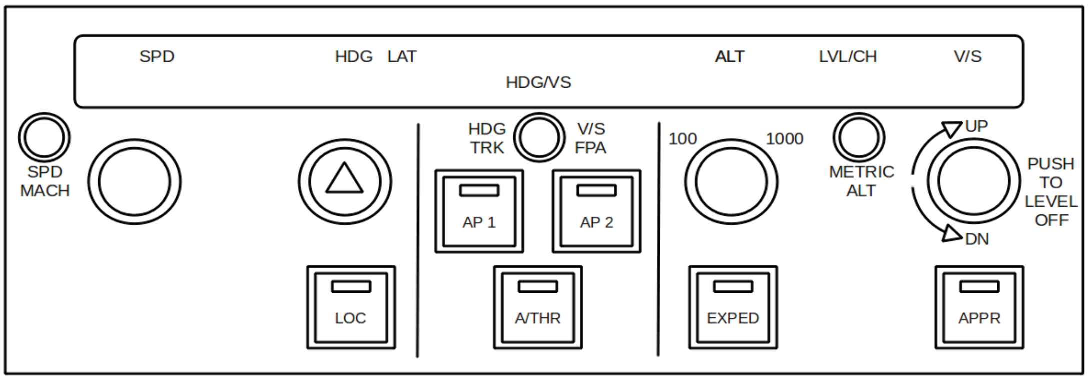

Figure 6: The control interface to the Flight Control Unit of an Airbus A320

The crash of an A320 aircraft on Mont Sainte Odile in 1992 (METT 1993) and the accident involving an A300 aeroplane in Nagoya, Japan (AAIC 1996) are both examples of incidents where the wrong mode was selected. Consequently, in both cases the pilots could not understand why the aircraft was not behaving as expected. Both of these accidents resulted in a total loss of life, although both aircraft behaved exactly as designed. This paradox is known as ‘controlled flight into terrain’. This term highlights both a) the absence of technical failure as the cause of the accident and b) the importance of the consistency between the operator’s mental model and the actual flight situation.

2.6 Anticipation

In dynamic control situations such as driving a car, anticipation is required in order to foresee a range of possible future states, and prepare control plans and strategies. In particular, the speed of motion, the complexity of the control task and external conditions determine the extent of the anticipation envelope. For example, when driving at high speed the information used by the driver as input to the control task has to be extracted far ahead of the position of the vehicle, in both time and space. The same applies to high-tempo control and supervision tasks. This is true to such an extent that the proficiency of operators in controlling such tasks can be indirectly assessed by their ability to predict future system states.

This section has addressed a number of the drawbacks related to the automation of process control and supervision tasks and has demonstrated how HMI performance can degrade as a result of these issues. This list of drawbacks provides the input for the prototype HMI assessment method described later in this chapter. The following section discusses the main features and operational environment of eDrilling.

3 Remote Control and Supervision in IO: eDrilling

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4 An HMI Assessment Prototype Method

This section presents the prototype method, which consists of four steps:

1. select the system functions to assess;
2. develop assessment questions on the basis of the drawbacks of automation;
3. assign scores and produce a graphical representation; and
4. assign the set of scores to a risk class.

4.1 Select the System Functions to Assess

HMI assessment uses advanced models and methods to evaluate situations such as the effect of location on a given display (Xiaoming et al. 2005) or information searching performance (Ha & Seong 2009). Here, we will only address a few of the many possible assessment dimensions.

Parasuraman, Sheridan and Wickens (2000) and Parasuraman and Wickens (2008) propose that the functions of automated systems can be divided into four classes, namely: information acquisition, information analysis, decision selection and action implementation. In each of these classes the extent of human-machine collaboration is distributed over a spectrum that ranges from low to high, as shown in Figure 8. Automation levels for the four function classes refer to the material presented at the beginning of the section on the drawbacks of automation.

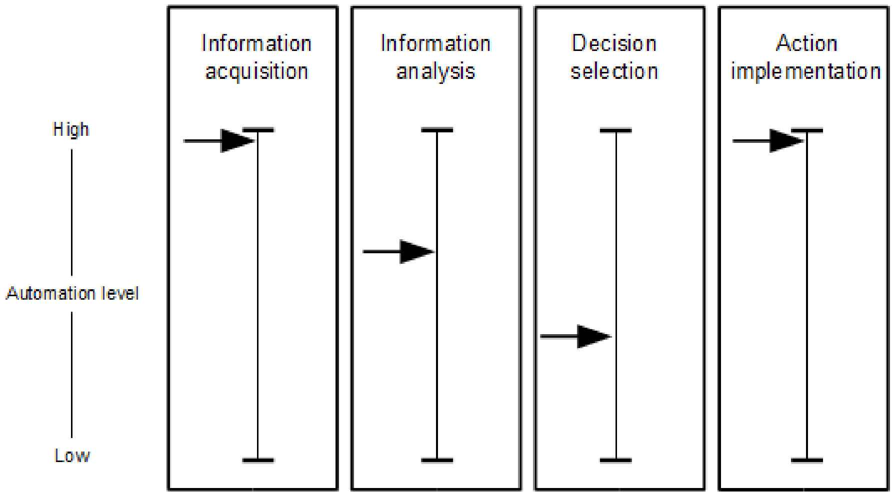

Figure 8: Recommended automation levels for eDrilling
(Source: adapted from Parasuraman, Sheridan and Wickens 2000)

The following eDrilling recommendations can be derived from the four function classes:

- *Information acquisition should be highly automated*. Sensors integrated into an information technology system make it possible to quickly extract a wide range of data with a lower failure probability than humans are capable of.
- *Information analysis should be collaborative*. Automation should be used to narrow down the set of alternatives, but leave the final decision to humans.
- *Decision selection should usually be done by humans* although computers can assist humans in knowing the consequences of their actions (this is a current feature of eDrilling).
- *Implementation of actions can be almost entirely automated* with humans playing a supervisory role.

The work of Fitts (1951) demonstrated that machines and humans have different capabilities, and identified what these different capabilities are. Therefore, it is unsurprising that the degree of automation should vary across functions. The above classification shows that HMI is most critical in *Information analysis* and *Decision selection*. It therefore follows that an HMI assessment of these two classes of functions would be useful.

4.2 Develop Assessment Questions from Automation Drawbacks

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The six drawbacks of system automation and their related eDrilling assessment questions are shown in Table 1. It should be noted that the six generic drawbacks have been modified in order to generate two distinct types of questions, namely:

- Questions assessing HMI performance: *Can this situation occur? Is this problem present?*
- Questions assessing safety: *Can this drawback affect a safety-related task? To what extent does eDrilling provide a way to recover from this drawback?*

Table 1: HMI drawbacks and corresponding questions

Drawback	**eDrilling assessment questions**
Remoteness of control	*HMI performance*
	Can the operator accurately mentally represent what is happening at the rig? Are there cases where the operator’s mental model can differ from what is happening at the drilling site? Can the operator detect that their mental representation is not consistent with what is happening at the drilling site? Are there safety-critical consequences when the operator’s mental representation is not consistent with the reality at the drilling site?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by issues related to remoteness of control? To what extent can eDrilling help the operator readjust their mental representation?
Change of control cues	*HMI performance*
	Are there any discrepancies between analogue and eDrilling control cues? Can analogue cues be simulated by the eDrilling system? Is the eDrilling system able to control last-generation rigs and handle technological conflicts? Is the eDrilling system able to tolerate different levels of expertise? Can eDrilling support the transition from classical drilling to remote drilling? Might the operator confuse the control cues used in the analogue task and those used in eDrilling?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by the issue of cue change? To what extent can eDrilling assist in recovering control that has been lost due to missing cues or cue confusion?

Opacity	*HMI performance*
	Is there drilling-related information that is needed by, but not available to the operator? Is there information available in the physical drilling workplace that should also be available in the eDrilling system but is not? Does eDrilling feed all needed information back to the operator? Can automation mask situations that can develop into problems? Can there be eDrilling decisions that might surprise the operator?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by opacity issues? To what extent can eDrilling assist in recovering control that has been lost due to opacity issues?

Complexity	*HMI performance*
	Does the interface support the understanding of the internal and logical functioning of the eDrilling system? Are there interdependent control parameters in the eDrilling system? Can these interdependencies overwhelm the operator’s processing capacity? Do system functions interact, or are there parameters that can cause control to be lost? Is the system so cognitively demanding that the operator can become complacent?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by complexity issues? To what extent can eDrilling assist in recovering control that has been lost due to complexity issues?

Mode confusion & autonomy	*HMI performance*
	Does the interface support an understanding of the functioning of modes? Can modes change automatically? Are automatic mode changes announced to the operator? Is there potential for mode confusion on the part of the operator? Is full manual control available? Can the degree of autonomy/automation of eDrilling be adjusted by the operator? Can eDrilling take action without operator feedback? Can eDrilling override a human action without operator feedback?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by mode confusion and autonomy issues? To what extent can eDrilling assist in recovering control that has been lost as a result of mode confusion or autonomy issues?

Anticipation	*HMI performance*
	Does the operator understand the eDrilling system sufficiently well to predict the behaviour of the system? Does eDrilling match or extend the operator's anticipation span? Is the data needed for anticipation easily accessible to the operator? Do the anticipation span and the type of data used in eDrilling accord with the operator's way of working?
	Safety
	To what extent are safety-critical eDrilling tasks unaffected by anticipation issues? To what extent can eDrilling assist in recovering control that has been lost as a result of anticipation issues?

4.3 Assign Scores and Produce a Graphical Representation

How the assessment is scored depends on the questions that have been developed. For the purposes of this example, the following scoring system has been arbitrarily chosen:

- Questions assessing HMI performance can score between 0 and 2 (where 0 degrades HMI performance and 2 supports HMI performance).
- Questions assessing safety can score between 0 and 10 (where 0 is detrimental to safety and 10 is acceptably safe).

In this scenario, the scores for safety-related questions have been given greater weight. This reflects the emphasis that the prototype method places on safety. When the scores for individual questions are combined, each drawback is given a compound score. Taking *Complexity* as an example:

Table 2: Example of assessment scores for Complexity

HMI performance	***Score***
Does the interface support the understanding of the internal and logical functioning of the eDrilling system?	2
Are there interdependent control parameters in the eDrilling system?	1
Can these interdependencies overwhelm the operator’s processing capacity?	2
Do system functions interact, or are there parameters that can cause control to be lost?	2
Is the system so cognitively demanding that the operator can become complacent?	2
TOTAL	9/10

Safety	***Score***
To what extent are safety-critical eDrilling tasks unaffected by complexity issues?	9
To what extent can eDrilling assist in recovering control that has been lost due to complexity issues?	7
TOTAL	16/20

COMBINED TOTAL	**85/100**

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4.4 Assign Scores to a Risk Class

The radar diagram can be used to assign the assessed system to a class of risks. This is done by deciding acceptability thresholds for each HMI dimension. For instance, the assessor can:

- set the lowest threshold for acceptability to 75, below which any single dimension causes the whole system to be rated as unacceptably risky;
- set a range between 76 and 90 where any single dimension causes the whole system to present acceptable risks; or
- set 91 as the upper threshold beyond which the assessed system is rated as safe.

These thresholds are not intended to determine what is acceptable or not. Rather, the aim is to show how management decision criteria can be implemented into the method. This is an important feature of a risk assessment exercise where the assessment is usually only one step in the decision-making process.

5 Discussion

This chapter has described how the drawbacks of HMI can be turned into assessment criteria and incorporated into a prototype method for HMI performance evaluation. It is important to note that the proposed prototype method is only a demonstration of an instance of the set of criteria. It does not address issues such as what the set of criteria should include in terms of issues to be assessed, and how it should be used. These points (and several others) are discussed in the following section.

5.1 Assets

The prototype method proposed here is different from a traditional technically-centred risk assessment exercise as it assumes that a significant proportion of the performance of control and supervision systems is the result of HMI. This position differs from established theory in that it suggests that under certain conditions HMI can cause breakdowns in complex, dynamic, automated systems. Moreover, assessments of interactions between humans and machine interfaces typically only deal with the physical dimension of HMI (see for example Xiaoming et al. 2005). The approach taken here emphasises that assessments must also target the cognitive dimension of the interaction.

The selected HMI assessment criteria and the method developed here can be applied to a wide range of interactive systems both within and beyond IO. The eDrilling scenario described here provided a test-case, which demonstrated the deployment of a method that can be adapted to virtually any system that distributes control and supervision tasks between humans and machines.

Although function allocation has been mentioned several times in this chapter, the question of which functions to automate (or not), to what degree, etc. has not been addressed. Function allocation is a discipline in itself that spans many technical domains (Beevis, Essens & Schuffel 1996). In the context of the general HMI assessment exercise it may require particular attention. For example, the assessment may look specifically at how functions are allocated between humans and machines, and how this allocation can be dynamically redistributed across tasks, under different time pressure settings, workload conditions, etc. More generally, any HMI evaluation should also include an assessment of how function allocation can support both performance and safety.

5.2 Limitations

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6 Conclusion

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