Human Systems Integration

The Drilling Systems Automation Roadmap Human Systems Integration section provides an in-depth knowledge base of the attributes required to effectively transition humans manually operating drilling systems into the future, when they supervise automated systems.

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Functional Description

Human Systems Integration (HSI) is a critical component in improving driller performance but one that has been overlooked across much of the drilling and completions industry. It is an expertise that incorporates multiple facets that cover the interaction between humans and machines and incorporates Human Machine Interface (HMI), Human Factors Engineering (HFE), training, organization and more. As a science, HSI was developed in 1940s designs of military systems to fit human operators, and has been applied in many industries, particularly those that critically rely on human control and human interaction with automation at any level. Led by aviation, the application of HSI to these industries provides lessons for its application to drilling operations.

Human Systems Integration (HSI) in drilling automation is a relatively new concept that promises to improve the application and acquisition of automated technology. HSI is a completely user-centered process that calls out the necessity of addressing multiple domains, or areas, early in technology development and acquisition, to avoid the pitfall of waiting until the end of the design process to incorporate human-centered practices.

By intent, the presence of humans working on drilling rigs diminishes as drilling automation matures. Most industrial automation experts agree, however, that a completely autonomous system without direct human interaction is not a practical goal.[1] This means that the role of humans at the well-site will not disappear but will change dramatically as tasks and responsibilities are systematically shifted to automated machines and remote operating centers. During this transition, addressing the needs of drilling personnel through HSI is imperative to ensure both the safety and the efficiency of drilling operations.

HSI is a bottom-up approach that begins with defining operator requirements. As tasks are transferred from human responsibility to an automated system, HSI ensures that the human interface meets the requirements and information processing limits of the user at each stage of the transition. Complex tasks, involving much environmental uncertainty, impact the industry, which causes the level of uncertainty to dictate different functional requirements for automated technology and a higher level of supervisory control by humans in the system.

In the military domain, HSI as a concept has been heavily relied upon to ensure that force protection systems are designed around the functional requirements of the military personnel the systems are meant to protect. For the purposes of the drilling automation roadmap, critical areas to be addressed include manpower, personnel, training, safety and occupational health, and human factors engineering—the practice of designing products, systems or processes to take proper account of the interaction between them and the people that use them. Organizational factors are a related area that address the highly variable interests and requirements of stakeholders in drilling operations.

Identifying *manpower* requirements begins with determining the benchmark number of people required for present-day drilling operations and whether the current pool meets those needs. It must then be determined how evolving automated technologies will impact this pool. And finally, a workforce development plan must be created that includes personnel preparation, recruitment, hiring, retention and training specifications.

The area of personnel calls for matching the requirements of technology with the knowledge, skills and abilities (KSAs) of the workforce. Automation provides an opportunity to bridge gaps that exist between workforce KSAs and present-day drilling technology. Automation that emulates exceptional performers turns average or inadequate drillers into exceptional drillers by assuming challenging tasks. Automation also can offset knowledge gaps when an insufficient number of experienced and trained personnel are available to run drilling operations because of the high turnover rate of drill site personnel and today's anticipated wave of retirees (the so called "big crew change").

The most powerful and sophisticated automated system can fail if personnel are not properly trained on how to interact with it. Training personnel to handle emergency or rare operational conditions is imperative and one major concern is that automation may result in skill degradation as personnel become increasingly removed from the tasks they once conducted manually.

Newer personnel face the challenge of not fully understanding the operation that the automated system is accomplishing. This lack of a mental model constrains personnel's ability to diagnose problems. Therefore, training that promotes the correct mental model of the system is important. Simulator use on a regular basis is helpful, especially as a training tool for emergency situations and cross-skill needs.

From an HSI perspective, safety and occupational health refer to the immediate physical safety of personnel in the workplace. The HSI approach includes adopting a safety management system for personnel, process, and technology and equipment, and a system to encourage personnel to report potential areas of improvement. While automation is a means to reduce rig personnel, it remains important to identify barriers and hazards to safe operations and processes and strategies to remove barriers and mitigate hazards.

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Human Factors Engineering (HFE) focuses on ensuring that the human-machine interface adheres to user-centered design practices. Good HFE practices greatly reduce the potential for human error. These practices also promote operational efficiency by reducing operator-system interface time. HFE can use embedded knowledge, which is made up of indications in the layout that provide operational cues regarding its appropriate use. De-cluttering information display screens and control panels can simplify operator decision and response time. Re-designs can promote situational awareness and communicate the intent of the automation and the uncertainty to ensure the operator has the correct mental model of operations. System feedback can combat complacency and provide important cues regarding operational limits that must not be approached. HFE also can address skill degradation and operator distrust.

The HSI approach also includes developing a plan to overcome barriers created by organizational factors. These barriers may include industry business models that are embedded in the tradition of modern-day operations that have the potential to stall research and development efforts even when a substantial advantage is demonstrable.

Stakeholders who require that automated technology necessarily enhances the safety and operational performance of personnel and is not solely for the sake of achieving autonomous operations are likely to be more successful with implementation.

Multiple levels of handover from a human control to autonomous control were defined many years ago in a classic exposition on the ten levels of automation. Those ten levels have since become the accepted standard in the application of industrial automation.[2] Later work reduced these ten levels to eight, providing some simplification for assigning Drilling Systems Automation (DSA) applications.[3]

Performance targets

Levels of Human and Systems Interaction

This roadmap uses a definition of automation that emphasizes human-machine comparison and defines automation as a device or system that fully or partially accomplishes a function that was previously, or conceivably may be partially or fully, carried out by a human operator.[1] This implies that automation is not an all or none proposition, but may vary across a continuum of levels, from the lowest level of fully manual performance, to the highest level of full automation. Several levels between these two extremes have been proposed in which a 10-point scale was defined with the higher levels representing increased autonomy of computer over human action.[2] These defined levels have become accepted by all types of industries for automation application and are applicable to drilling systems automation.

In more recent work, an 8-level range has been defined that extends from low levels of automation, level 1, to high levels of automation, level 8, providing a relevant and simplified scale for DSA adoption. The DSA levels include:

1. The computer offers no assistance and the human must do it all
2. The computer suggests alternative ways to do the task and the human selects from those suggestions and executes the task
3. The computer selects one way to do the task, which triggers five possible scenarios including:
    - the human executes that selection
    - the computer executes that suggestion if the human approves
    - the computer allows the human a restricted time to veto before automatic execution
    - the computer executes the suggestion automatically necessarily informs the human
    - the computer executes the suggestion automatically and informs the human only if asked.
4. The computer selects the method, executes the task and ignores the human.

This classification of human interaction covers a sequence of cognitive functions in a human-machine system. The scale refers mainly to automation of decision and action selection or to output functions of a system. However, automation may also be applied to input functions, i.e., to functions that precede decision making and action. The model was expanded to adopt a simple four-stage view of human information processing.[1]

The successive cognitive function stages of information acquisition, information analysis, action decision, and action implementation are usually automated to different levels from manual through various degrees of automation to fully automated. The best degree of automation is seldom the same at the various stages. In this roadmap, these stages are outlined in Figure 1 and better defined in Table 1.

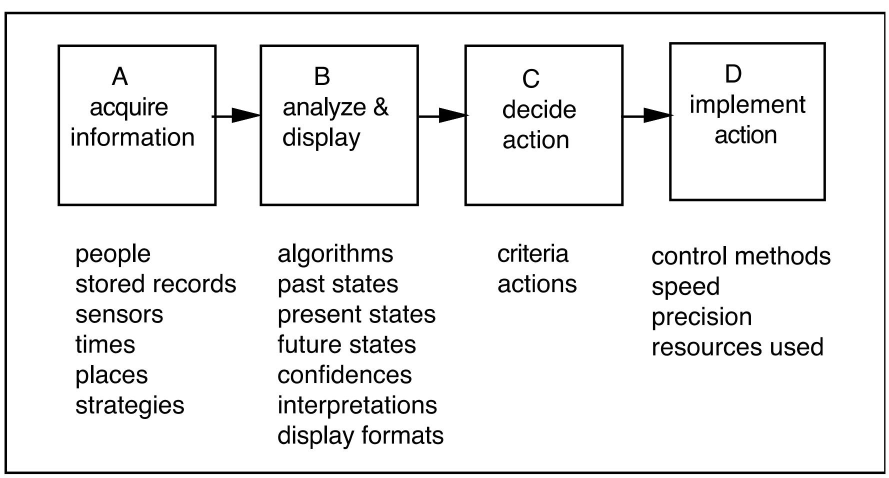

Figure 1: Stages of Cognitive Function Interaction between Humans and Automation[1]

The first stage of cognitive function refers to the acquisition and registration of multiple sources of information. This stage includes details on how the data was sensed through any initial processing, locations and time stamps amongst other information critical to data definition. The second stage involves processing of the retrieved information through a working memory. This stage includes all aspects of analysis and display prior to reaching the point for decision making. The third stage is where decisions are made based on previous processing. The fourth and final stage is implementation, which must include the aspects of the control method to affect the decision.

The standard auto driller simply controls the slack-off weight at surface and equates it to a weight-on-bit (WOB). These traditional systems do not acquire, analyze and decide action. In contrast, sophisticated ROP optimization systems acquire and analyze the data, and take decisions with a high degree of automation providing a full spectrum automation system. This four-stage cognitive function model is a means by which to categorize the many components of human information processing. The tasks at each stage involve interdependency with other stages and require coordination between the stages, including feedback and anticipatory feed-forward loops.

This model for information processing applies to humans and has its equivalent in a series of cognitive functions that can be automated. Consequently, this cycle is synonymous for human and automated control although caution must be used with this analogy. The model is a simplification of information processing but cannot completely identify all the complex information processing tasks carried out by a human. If this cycle was fully synonymous with human control, all the intricate tasks carried out by the human would have to be identified and programed into the automation to assume those tasks.

The cognitive cycles can be easily adopted for simple, repetitive tasks in predictable environments but when complex decisions are required using expert operators in uncertain conditions, the model needs further articulation. The supervisory role of skilled humans will remain critical to successful DSA application in uncertain environments in the near term.

This cycle of cognitive functions can be transferred from manual to automated control at the various levels described above with some modifications to the intentions that these levels originally applied to deciding action. Figure 2 shows two alternative applications of automation and how a particular system can involve automation of all four dimensions at different levels. A system (A), for example, could be designed to have moderate to high acquisition automation, low analysis automation, low decision automation, and low action automation. Another system (B), on the other hand, might have high levels of automation across all four dimensions.

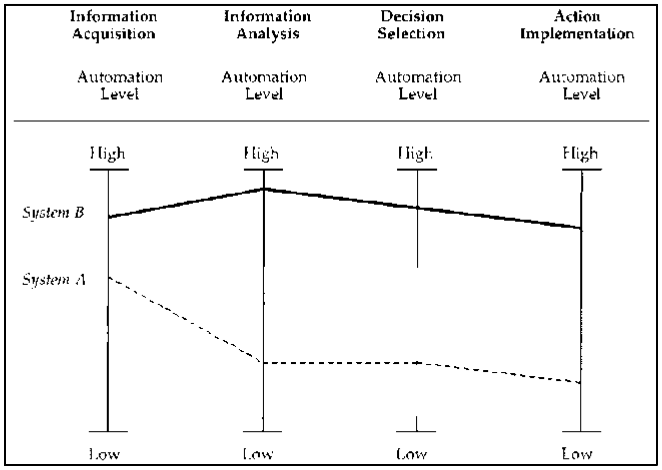

Figure 2: Alternative Applications of Automation[1]

Figure 3 illustrates the spectrum for the next generation air traffic control system in the USA. [3]

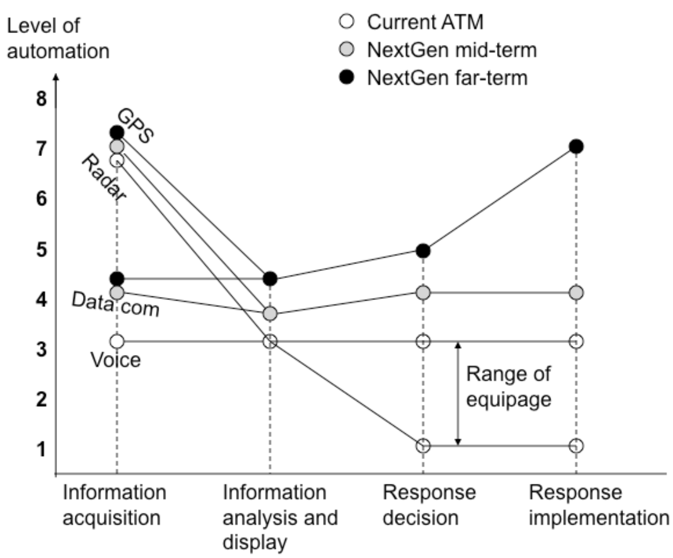

Figure 3: Estimated levels of automation in NextGen automation

This model can be adopted for Drilling Systems Automation (DSA) based on the further distinctions developed in the following section and using the same definitions created earlier in this report. These definitions include:

- Acquisition of Information—Automation of information acquisition applies to the sensing and registration of input data. These operations are equivalent to the first human information processing stage, supporting human sensory processes.

- Analysis of Information—Automation of information analysis involves cognitive functions, such as working memory and inferential processes. This includes analysis by algorithms and prediction.
- Decision—Decision and action selection from among decision alternatives. Automation of this stage involves varying levels of augmentation or replacement of human selection of decision options with machine decision making.
- Action—Implementation refers to the actual execution of the action choice. Automation of this stage involves different levels of machine execution of the action choice and typically replaces the hand or voice of the human.[1]

Levels of Automation Taxonomy

Levels of Automation Taxonomy (LOAT) is a matrix of human information processing and systems functions against levels of automation. It provides a framework to identify the best levels of automation in a given context and to determine a logical transition of manual to various levels of automated operations, which, when combined with the application of HSI, defines the steps of the progression. The path to a LOAT suitable for adoption for drilling systems automation has been laid out by the Single European Sky ATM (Air Traffic Management) Research (SESAR). It is grounded on the seminal work by Sheridan and Verplanck—the first to introduce the idea of automation levels—and on the subsequent work by Parasuraman, et al, which defines four cognitive functions to be supported in a human-machine system as described in the previous sections. [1, 2]

The four cognitive functions are based on a staged model of human information processing that can be translated into equivalent system of cognitive functions—information acquisition, information analysis, decision and action selection, action implementation—for automated systems. This LOAT is designed through the following principles:

- An automated system cannot have one overall level of automation. A statement about a level of automation for a system always refers to a specific cognitive function being supported.
- One automated system can support more than one cognitive function having different levels of automation.
- The description of each automation level follows the reasoning that automation is addressed in relation to human performance. The automation being analyzed is not just a technical improvement but has an impact on how humans are supported in accomplishing their task.

Simply designing automation to take over the role of a human operator can potentially hamper technology innovation. Viewing automation in this way constrains how a process is viewed. Replacing the human in the loop requires understanding of the process itself and, if it can be done altogether differently in a way that would improve the safety and efficiency of operations. There is a balancing act between technology development and the role of the human operator.

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Interdependent maps have been created for the field of aviation that are applicable to other automation endeavors, specifically drilling systems automation. These maps combine the eight levels of automation with the four functions in the control loop to create a matrix that defines the Level of Automation Taxonomy (LOAT) for each of the control cognitive functions that enable mapping of human-to-automation handover. [4] These maps are directly developed from the combination of Sheridan's levels of automation and Parasuraman's information processing model. [1,2]

The juxtaposition of the two forms the matrix. SESAR populated the cells of the matrix with aviation specific examples involving both the pilot of the craft and the controllers on the ground to demonstrate the model's practical application.[4] This, in turn, demonstrates its utility for drilling systems automation in which the driller functions in relationship to remote support.

This DSA roadmap intentionally applies this LOAT methodology to the drilling industry to describe transitions from manual to full automation involving an operator supervising the machine (pilot/driller) and the remote operations centers feeding back directions and information (air traffic control/remote operations center). This methodology makes available an LOAT that provides a sound basis for the oil and gas industry to develop the transition from human to more automated control and recommendations for HSI application to DSA. HSI ties directly into the LOAT by providing the methodology to analyze and implement a transfer of roles from the human to the system in a managed manner, which itself will impact the rate of adoption of greater degrees of automation.

The LOAT from SESAR is designed to classify the level of automation of both airborne and ground automated systems supporting the activities of pilots' and air traffic controllers', respectively. [4] In this LOAT, all automation levels start with a default level '0' corresponding to manual task accomplishment and increase to full automation. Automation level 1 is based on the principle that the human is accomplishing a task with 'primitive' external support, such as initial control in place of the traditional driller's brake, which is not automation. This LOAT is applicable to many industrial operations and is particularly suited to drilling operations. The LOAT shows how DSA can be mapped out for Systems of Interest (see Systems Architecture section) across the matrix. Specific Systems of Interest can be mapped to demonstrate the potential advancement through the levels within the LOAT while accounting for HSI, sensor development, communications technology improvement and more.

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From INFORMATION to ACTION →

INCREASING AUTO ↓

A Information Acquisition	B Information Analysis	C Decision and Action Selection	D Action Implementation
A0 Manual Information Acquisition	**B0 Working Memory Based Information Analysis**	**C0 Human Decision Making**	**D0 Manual Action and Control**
The human acquires relevant information on the process s/he is following without using any tool.	The human compares, combines, and analyses different information items regarding the status of the process s/he is following by way of mental elaborations. S/he does not use any tool or support external to her/his working memory.	The human generates decision options, selects the appropriate ones and decides all actions to be performed.	The human executes and controls all actions manually.
A1 Artefact-Supported information Acquisition	**B1 Artefact-Supported Information Analysis**	**C1 Artefact-Supported Decision Making**	**D1 Artefact-Supported Action Implementation**
The human acquires relevant information on the process s/he is following with the support of low-tech non-digital artefacts.	The human compares, combines, and analyses different information items regarding the status of the process s/he is following utilising paper or other non-digital artefacts.	The human generates decision options, selects the appropriate ones and decides all actions to be performed utilising paper or other non-digital artefacts.	The human executes and controls actions with the help of mechanical non-software based tools.
A2 Low-Level Automation Support of Information Acquisition	**B2 Low-Level Automation Support of Information Analysis**	**C2 Automated <u>Decision Support</u>**	**D2 Step-by-step Action Support:**

The system supports the human in acquiring information on the process s/he is following. Filtering and/or highlighting of the most relevant information are up to the human.	Based on user's request, the system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed.	The system proposes one or more decision alternatives to the human, leaving freedom to the human to generate alternative options. The human can select one of the alternatives proposed by the system or her/his own one.	The system assists the operator in performing actions by executing part of the action and/or by providing guidance for its execution. However, each action is executed based on human initiative and the human keeps full control of its execution.
A3 **Medium-Level Automation Support of Information Acquisition**	**B3** **Medium-Level Automation Support of Information Analysis**	**C3** **Rigid Automated Decision Support**	**D3** **Low-Level Support of Action Sequence Execution**
The system supports the human in acquiring information on the process s/he is following. It helps the human in integrating data coming from different sources and in filtering and/or highlighting the most relevant information items, based on user's settings.	Based on user's request, the system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user.	The system proposes one or more decision alternatives to the human. The human can only select one of the alternatives or ask the system to generate new options.	The system performs automatically a sequence of actions after activation by the human. The human maintains full control of the sequence and can modify or interrupt the sequence during its execution.
A4 **High-Level Automation Support of Information Acquisition**	**B4** **High-Level Automation Support of Information Analysis**	**C4** **Low-Level Automatic Decision Making**	**D4** **High-Level Support of Action Sequence Execution**
The system supports the human in acquiring information on the process s/he is following. The system integrates data coming from different sources and filters and/or	The system helps the human in comparing, combining and analysing different information items regarding the status of the process being followed, based on parameters pre-	The system generates options and decides autonomously on the actions to be performed. The human is informed of its decision.	The system performs automatically a sequence of actions after activation by the human. The human can monitor all the sequence and can

highlights the information items which are considered relevant for the user. The criteria for integrating, filtering and highlighting the relevant information are predefined at design level but visible to the user.	defined by the user. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user.		interrupt it during its execution.
A5 **Full Automation Support of Information Acquisition**	**B5** **Full Automation Support of Information Analysis**	**C5** **High-Level Automatic Decision Making**	**D5** **Low-Level Automation of Action Sequence Execution**
The system supports the human in acquiring information on the process s/he is following. The system integrates data coming from different sources and filters and/or highlights the information items which are considered relevant for the user. The criteria for integrating, filtering and highlighting the relevant info are predefined at design level and not visible to the user (*transparent to the user* in Computer Science terms).	The system performs comparisons and analyses of data available on the status of the process being followed based on parameters defined at design level. The system triggers visual and/or aural alerts if the analysis produces results requiring attention by the user.	The system generates options and decides autonomously on the action to be performed. The human is informed of its decision only on request. (Note that this level is always connected to some kind of ACTION IMPLEMENTATION, at an automation level not lower than D5.)	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can modify or interrupt it during its execution. *Ex. 1) Implicit initiation of an electronic co-ordination with adjacent sector as agreed exit conditions (according to Letter of Agreement) cannot be met anymore after changes to the a/c trajectory (route or flight level) has been made.*
		C6 **Full Automatic Decision Making**	**D6** **Medium-Level Automation of Action Sequence Execution**

		The system generates options and decides autonomously on the action to be performed without informing the human. (Note that this level is always connected to some kind of ACTION IMPLEMENTATION, at an automation level not lower than D5.)	The system initiates and executes automatically a sequence of actions. The human can monitor all the sequence and can interrupt it during its execution.
			D7 **High-Level Automation of Action Sequence Execution**
			The system initiates and executes a sequence of actions. The human can only monitor part of it and has limited opportunities to interrupt it.
			D8 **Full Automation of Action Sequence Execution**
			The system initiates and executes a sequence of actions. The human cannot monitor nor interrupt it until the sequence is not terminated.

Table 1: SESAR developed LOAT – reproduced with permission[4]

This LOAT is fully relevant to DSA and provides a sound basis to make the transition from human to automated control across the information to action spectrum in a managed manner.

Current Situation

Levels of Automation Taxonomy for Drilling Systems Automation

The LOAT described previously creates a methodology for DSA to address multiple aspects of automation application including:

- Transferring operations from the driller, directional driller, drilling engineers and others to automated systems
- The breadth of the application of automation
- The extent to which this automation will replace human operation in drilling operations
- The various locations of automation in drilling operations, from the rig at the driller's console to the remote-control center and remote center of excellence.[5]

However, the transfer from human to automated system will require:

- An HSI plan that fully addresses the human–system interaction in all states, ensuring that the human and the automated systems function successfully
- Improvements in sensors such that the automated system can fully trust the verified and validated data and not rely on human judgment to determine the actual situation
- The modelling and simulations have known quantities that the system can trust and apply in place of the human's ability to be judgmental when recommendations appear unrealistic.

The LOAT provides a foundation for the drilling industry to understand the transition from human to automation, and for companies providing services within the drilling industry to provide technology and services that deliver value at the most suited human–automation level within this foundation.

The LOAT matrices in Tables 2a and 2b demonstrate how a summarized version can be adopted to track the transition of any system from monitor, to advice, to automation in a more comprehensive manner.

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	A	B	C	D
LEVEL	INFORMATION ACQUISITION	INFORMATION ANALYSIS	DECISION AND ACTION SELECTION	ACTION IMPLEMENTATION
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium-Level Automation	Medium-Level Automation	Rigid Automated Decision Support	Low-Level Support Action Execution
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 2a: LOAT Tabulation – Summarized version

	A	B	C	D
LEVEL	INFORMATION ACQUISITION	INFORMATION ANALYSIS	DECISION AND ACTION SELECTION	ACTION IMPLEMENTATION
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium- Automa **Monitoring**	n-Level ation	**Advising**	**Automating**
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 2b: LOAT Tabulation – Monitoring, Advising, Automating Transition

This mapping indicates that the standard auto driller operates from a set point and therefore is not a smart system (Table 3a). These auto drillers are essentially machine feed systems similar to those used in metal working and do not react to a change in the formation being drilled. As auto drillers advanced, the level of automated processing was first applied to the cognitive functions of acquisition, analysis and action selection, which is the advisory mode shown in Figure 3b that leaves the choice to implement to the human. The automation process applied to Systems of Interest, such as rate of penetration and wellbore steering, transitioned to closed-loop automated control after the human supervisors gained confidence in the advisory output (Figure 3b). This staged approach provided the opportunity for the implementer to give feedback on the output of the advisory system, which led to improved functionality and, ultimately, to the user gaining increased confidence in the system, and to close the automation loop and step back to supervisory control.

	A	B	C	D
LEVEL	**INFORMATION ACQUISITION**	**INFORMATION ANALYSIS**	**DECISION AND ACTION SELECTION**	**ACTION IMPLEMENTATION**
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low-Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium-Level Automation	Medium-Level Automation	Rigid Automated Decision Support	Low-Level Support Action Execution
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 3a: LOAT Tabulation Example – Early Auto driller – Simple Feed Mechanism

LEVEL	A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium-Level Automation	Medium-Level Automation	Rigid Automated Decision Support	Low-Level Support Action Execution
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 3b: LOAT Tabulation Example – Advisory Auto Driller

LEVEL	A INFORMATION ACQUISITION	B INFORMATION ANALYSIS	C DECISION AND ACTION SELECTION	D ACTION IMPLEMENTATION
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium-Level Automation	Medium-Level Automation	Rigid Automated Decision Support	Low-Level Support Action Execution
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 3c: LOAT Tabulation Example – Advanced Auto Driller

This advanced auto driller LOAT shows how the system has become "smart" in its information acquisition and analysis, thus delivering more value in the action implementation. The increased level of automation in the information acquisition, information analysis, and decision and action selection stages of the process has delivered a 40% improvement in drilling performance, which demonstrates the real opportunity to deliver value by increasing the automation levels automation through all four stages of interaction. [5]

	A	B	C	D
LEVEL	INFORMATION ACQUISITION	INFORMATION ANALYSIS	DECISION AND ACTION SELECTION	ACTION IMPLEMENTATION
0	Manual	Memory Analysis	Human Decision	Manual Action and Control
1	Artifact-Supported	Artefact-Supported	Artefact-Supported	Artefact-Supported
2	Low Level Automation	Low-Level Automation	Automated Decision Support	Step-by-step Action Support
3	Medium-Level Automation	Medium-Level Automation	Rigid Automated Decision Support	Low-Level Support Action Execution
4	High-Level Automation	High-Level Automation	Low-Level Automatic Decision Making	High-Level Support Action Execution
5	Full Automation	Full Automation	High-Level Automatic Decision Making	Low-Level Action sequence Automation
6			Full Automatic Decision Making	Medium-Level Action sequence Automation
7				High-Level Action Sequence Automation
8				Full Automation

Table 4: LOAT Tabulation Example – Managed Pressure Drilling (MPD)

This Managed Pressure Drilling (MPD) draft LOAT illustrates how the automation processes information and makes corrections when the system is operated at a high level of automaton (Table 4). Other options reduce the levels of decision and action selection and action implementation to a more manual operation in lower cost MPD applications. The LOAT tabulation provides the means to view various levels of MPD automation when comparing their costs and benefits.

Problem Statement

Barriers to Successful HSI

Human Factors Engineering (HFE) is gaining attention and application within oil and gas drilling. Process safety has gained attention after several major incidents showed the gap between personal and process safety practices. Industry focus has been on human behaviors, especially when the humans are under stress, and not on the human-machine interfaces. Some work has been undertaken for offshore driller control cabins, but the proliferation of screens clearly shows that a tidy and effective aircraft display quality solution has not been achieved. Various HSI areas, such as HFE, are being adopted in drilling operations, but HSI is not being systematically employed to drive the development of technology that involves humans in the loop.

Need for HSI

The risk of automation failure resulting from the human operating incorrectly in a monitoring or supervisory capacity because the human is unable to react to the information and signals provided by the system is large. Simply applying automation without due consideration of the humans interfacing with the system will result in perceived automation failures that are, in fact, human failures.

Successful automation will be applied to Systems of Interest such that effective value is generated from the application in a defined loop. The transition through the LOAT for any subsystem or system development will require proper evaluation of the human role before and during transition to higher levels of automation to the final automation state.

Traditional drilling systems that interface with the human operator have been poorly designed in the operational controls themselves or in the displays. For example, the graphics used by many companies today to display data versus depth are in the form of "squiggly' lines. These diagrams are mimicking the plots created by the geolographs from the 1950s, which were drum systems with paper charts wrapped around them and pens held in arms that were moved by potentiometers. Simply displaying what was possible with 1950s technology is not the optimal method to activate humans to take correct actions. Displayed data from automated systems must be totally and immediately comprehensible to ensure that the human overseeing the system is fully aware of the situation and able to step in as needed.

Critical Success Factors for HSI

Human Machine Interface - Design of Drilling Consoles

Best practices for applying HSI principles to the consoles used by drillers, directional drillers and other operators at varying levels of automation are critical to success for DSA. Drilling displays were essentially nonexistent when drilling was undertaken by a driller on a traditional brake system. The driller often stood in the open air on the drill floor connected mechanically to the machinery he controlled. The displays were simple and based on the primary measurements available. The introduction of large format dial gauge displays that showed the string weight and the deduced weight on bit was a major step forward. These readings, supported by pressure gauges showing real-time pump pressures and drillstring rotational speed, became the primary reference for the driller when drilling a well.

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While still largely mechanized, drilling equipment is now often controlled electronically by means of software. The evolution of drilling control allows for a migration of mechanical controls on a driller's console that were once operated by hard controls to "soft" controls that may be embedded in a human-machine interface (HMI) screen. Modern-day control systems afford the opportunity to implement increasing levels of automation that may accomplish multiple distinct drilling processes with singular input from drilling personnel. However, the ease with which increasing levels of automation may be accomplished should not be considered license to proceed without first weighing the benefits of automation against the effect automation will have on the safety and efficiency of operations.

Automation is being introduced into drilling operations with existing personnel. As such, it is imperative that the interaction of drilling personnel with present-day drilling technology be benchmarked and to define the core job roles of these personnel. This information can be used to define key performance parameters (KPPs) from a human factors perspective so that as automation evolves, baseline KPPs are established against which safety and efficiency of new automated technologies can be measured. The focus of the description of HSI is on the role of the driller. However, all job roles that involve drilling operations need to be considered when applying HFE principles to optimize drilling systems automation technology.

When benchmarking driller performance, it is necessary to conduct a series of task analyses that will yield information regarding the specific tasks a driller performs with each operational task. Task analysis describes the actions and or cognitive processes used to achieve a task objective.[6] Task analysis provides structure, which enables the description of how activities fit together, the implications of which may be for products design. This is a very powerful methodology when considering the design of interfaces to products and how users interact with the products and processes through these interfaces.

Drilling can be divided into two general areas of operation, drilling the bore hole (including casing and completion), and surface operations required to perform the drilling operation, such as pipe handling, well head installation and BOP rig up. From these two main areas of operation, a task hierarchy may be developed that specifies not only the physical interaction of the driller and the rig controls, but also the cognitive steps or thought processes that the driller must engage to accomplish each physical task.

Task analyses result in work flows that can be specified for sublevels of operations. Making a connection is a common process in pipe handling operations. A driller will repeatedly conduct a series of steps that involve a repetitive interaction with controls, such as torqueing drill pipe with an iron roughneck. Creating workflows for tasks at this level of operation also creates a means to identify candidate processes to be automated. Use cases, described in the Systems Architecture, provide a means to articulate these work flows within a tool used to develop automated processes.

Automating simple, repetitive tasks can improve the driller's experience with the console through workload management. Mapping work flows enables the prioritization of tasks to be automated, while reserving complex tasks that require significant decision-making from the driller for lower levels of automation in which set point inputs remain with the driller. Sophisticated auto drillers elevate the role of the driller to supervisory controller.

In addition to using task analyses to define work flows, attention to the layout of system indicators and controls with which the driller interacts is within the purview of HFE. The key reason for including it in the design of controls is that HFE emphasizes the driller's needs based on basic human factors design principles. HFE design principles are based on nearly a century of basic physiological and psychological research that demonstrates humans perceive, understand and respond to information better when it is presented in ways that cater to the limitations of human information processing.

For example, the visual system is primed to recognize an object when it is grouped with related items according to function. Therefore, grouping related controls near each other improves the efficiency with which a driller can identify the control he needs to activate. Grouping by function also aids in preventing inadvertent activation of unrelated controls. Grouping related controls such as those associated with the blow-out preventer (BOP) in a manner that reflects the actual physical layout of the valves on the equipment also helps the driller to visualize the controls and to preserve his mental model of the operation the equipment is performing.

Maintaining the driller's mental model of operations is particularly important as automation is introduced into drilling operations. A mental model refers to an operator's understanding of the physical execution of operations by the equipment that is performing them. When there is a one-to-one correspondence between control activation and the action of the equipment, as is typical in mechanical operations, the mental model of operations is typically preserved. However, when there is a one-to-many correspondence between control activation and the action of the equipment, as may occur with automation, the mental model of the operator becomes vulnerable.

As the mental model breaks down, the operator becomes less adept at troubleshooting and developing operational strategies as well as more prone to experiencing operational errors; in effect, the driller becomes less effective. Therefore, the benefit of automating a process, which in many cases can vastly improve the safety and efficiency of operations, must be weighed against compromising the operator's mental model.

When benefit from automating a process is evident a significant effort is required to design an interface, or driller's console, that embeds knowledge into its design and preserves the driller's mental model. Embedding knowledge into the design of the drilling system is an acceptable mitigation strategy to prevent the degradation of the driller's mental model and can be achieved through intuitive interfaces as well as through visualizations and simulations of operations embedded in HMIs. Ultimately, the most effective means of ensuring a driller's mental model of operations is through well-designed training programs using simulated operational scenarios.

The experience cycle of drillers has changed from manual operations as basic training to cyber systems for control. Training has advanced to include simulated operations, primarily for surface equipment. The advent of drilling systems automation will require that the drillers and other key operating personnel, such as directional drillers and mud engineers, are provided with intuitive consoles and not simply controls that mimic capabilities of legacy (manual) systems.

The term supervisor implies that the human in the new role acts with respect to the automation in much the same way as does a supervisor of human workers by setting goals, initiating action, monitoring, intervention in case of abnormalities, and learning from experience.

Lessons Learned from Industry

Many lessons can be learned from adopting experience from other industries that are more advanced in automation application, especially those with critical safety issues, high horsepower and significant load handling capability. One example of experiences to be adopted is the four stage, multi-level Next Generation Locomotive Cab (NGLC) Phase III—Industry Cab Workspace Design Standards (Figure 4). The NGLC is a proven method for human machine integration in terms of control layout and displays. Because this interface is critical to both manual control and the advanced automation state of human supervisory control, the drilling industry must develop this early in the adoption of automation. Failure in this interface, at any level from manual to fully automated, will be catastrophic in many measures, including safety, machine failure and ultimately loss of well control.

Next Generation Locomotive Cab

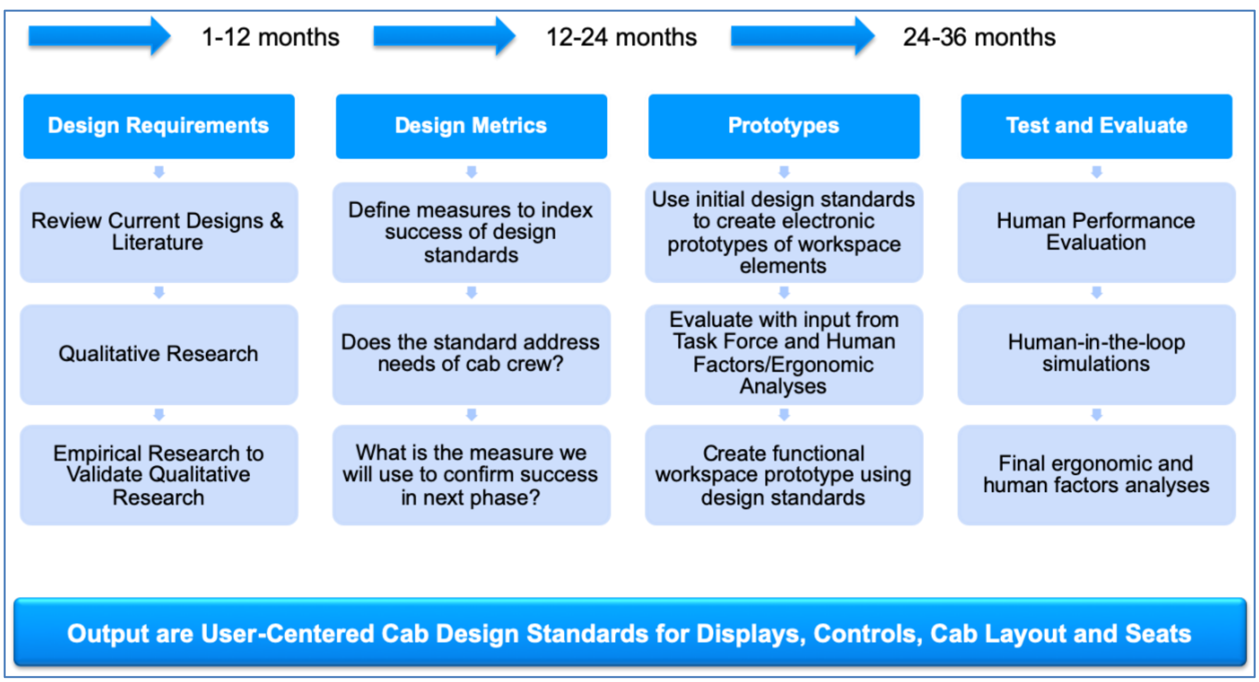

Figure 4: NGLC Phase III—Industry Cab Workspace Design Standards (Source: A DiFiore)

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Mining

Rio Tinto is a leader in autonomous mine application through their Mine of the Future™ program. In Western Australia, the company has significant autonomous activity with remote control in open cast mining. These are networked to synchronize activity in the pit and include:

- Autonomous mining trucks that combine GPS-based localization with object detection.
- Autonomous drills that drill the bench for blasting and accumulate data for shot loading
- Autonomous trains that run 1,300 km to the coast for shipping the ore.

One lesson from mining and car manufacturing is that when robots do the work the process stops improving. Toyota is now seeking improvements to their processes by replacing some robots with humans on the factory floor. Rio Tinto is also working to integrate humans into the robotic mining systems to seek improvements. Improvements in non-deterministic environments found in many systems in drilling requires adaptive expertise for which the human is best suited.

Machine Intelligence

Artificial Intelligence (AI) and Machine Learning (ML) is unlikely to be significantly adopted as a key component of DSA in the time frame to 2025. Although AI is being trialed in the processing of wellbore data to assist in automated geosteering, many systems addressing uncertainty will continue to rely on the human capability for adaptive problem solving and discovery, which is required in non-deterministic environments.

Consequently, the human must be designed into the process to support non-deterministic systems and to find improvements in deterministic systems. This results in a focus on how the system will communicate its state to the human so that the human can help during unanticipated situations or to improve known situations (from performance data).

Development of DSA will require recognitions of the expert humans' roles such that they can solve the complex problems manifested by uncertainty. Machine intelligence applications in DSA are likely to evolve by supporting a small set of human experts in cooperative problem solving.

The economics of the DSA solution will be driven by the ability to successfully plan how to wrap autonomy around the remaining human roles, which must be defined in terms of the humans' nature (skills, rules, knowledge, and expertise) and tasks. This can lead to lower costs, higher efficiencies and overall improved system performance.

Humans in the Loop

Alonso Vera, of the NASA Ames Research Institute, presented his list of thoughts on the human role in automation to the SPE DSATS/IADC ART Symposium held in Ft Worth in March 2016. Vera told his audience that:

- Humans will remain important components of complex systems
- Use human adaptive experience as much as possible

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- Use human perceptual system as much as possible in interactions with big data sets
- Robotics are progressing faster than AI

Vera's thoughts correspond well with drilling systems automation:
- drilling systems automation is a complex system consequently humans will remain important
- placing human adaptive experience in DSA can be critical to success
- humans working with the robots will remain valid before AI is capable to fully step in

Way Ahead

The impact of human systems integration on the development of drilling systems automation is critical to its success and a huge body of knowledge is available to drilling organizations to help them in this area. Some key aspects are depicted in Figure 5 as the transition occurs from manual to autonomous across the four cognitive functions. The impact on human performance must be assessed and compensated to avoid failure in implementation. Reliability of automation and the costs of the outcome of decisions and actions taken by the automated system require an evaluation of human oversight to reduce risks of failure and adverse financial consequences.

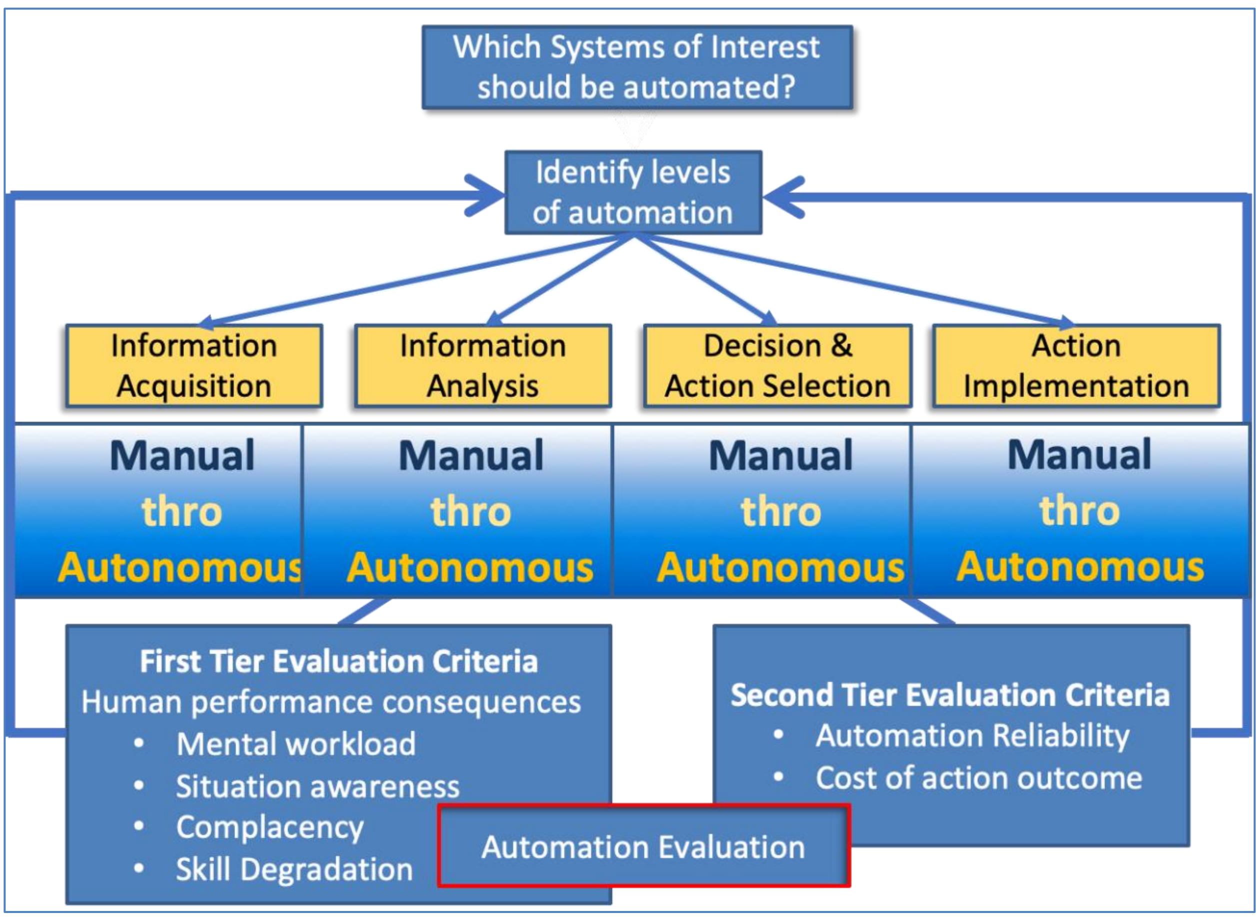

Figure 5: Linkage of Humans to Automation Progression (Source: A DiFiore)

Human Systems Integration – Background & Best Practices

Human Systems Integration (HSI) is a user-centered process that calls out the necessity for addressing multiple areas early in technology development and acquisition. Ensuring proper HSI at the outset of drilling systems automation maximizes return-on-investment (ROI) and avoids costly redesign efforts that may occur when developers? wait until the end of the design process to address good human-centered practices.

The military relies on HSI to map the functional requirements of force protection systems to personnel that the systems are meant to protect. The Air Force Human Systems Integration Manual details specific responsibilities and tasks for HSI subject-matter experts (SMEs).[7] For the purposes of drilling systems automation, the critical SME areas are manpower, personnel, training, safety and occupational health, and human factors engineering. Another area not traditionally included in the HSI process is organizational factors. Given the highly variable interests and requirements of stakeholders in drilling operations, considering organizational factors presents an opportunity to address higher level barriers to the integration of drilling systems automation technology.

The HSI process begins with an analysis of user-centered requirements. It may seem counterintuitive to consider human requirements given that autonomous operations transfer the responsibility of a task from a human operator to an automated system. However, most experts in industrial automation agree that human interaction in most industrial applications of automation is required, albeit in a different role depending upon the level of automation.[1]

Automation in drilling operations will be evolutionary with less complex, deterministic tasks introduced early in the timeline. Complex tasks involving much environmental uncertainty will impact the industry later as the innovation of technology evolves. During this transitory period, addressing the HSI needs of drilling personnel is imperative to ensure both the safety and the efficiency of drilling operations. The following descriptions of relevant SME areas in HSI provides content discussion regarding how these areas can be considered during the evolution of drilling systems automation technology.

Manpower

Manpower refers to the number of people working or available for work or service. A key goal of drilling automation is to eliminate hazardous jobs through autonomous operations that remove personnel from the drill floor and drill site when possible. Elimination of hazardous jobs will reduce the workforce and keep people out of harm’s way while also reducing operational costs, particularly in the offshore environment where staffing is costly.

A reduction in the workforce is also beneficial based on current staffing challenges in drilling operations. Anecdotally, the industry reports difficulty hiring and retaining adequately trained drilling personnel as well as not having enough personnel to support current operations. Automation through remote operations will help bridge this personnel gap and foster a cross-crew collaborative operational environment.

The HSI approach for identifying manpower requirements includes determining:

- The benchmark number of people required for present-day drilling operations
- Whether the pool of current employees and candidates is sufficient for present-day drilling operations
- How near-term, intermediate, and long-term automated technologies impact the pool of drilling personnel employees and job candidates
- A near-term, intermediate and long-term workforce development plan including personnel preparation, recruitment, hiring, retention and training specifications.

Personnel

While manpower refers to the sheer number of individuals in the workforce, personnel in the HSI approach addresses how individuals within the workforce are qualified for a specific job or career. At present the industry is defining benchmark personnel roles in drilling operations through competency modeling. This effort is imperative for defining automation priorities. As previously mentioned, simple, deterministic tasks are candidates for near-term automated implementation. Competency models along with cognitive and job task analyses can identify core job competencies as well as performance that qualify an employee as an exceptional performer.

The HSI approach tor identifying personnel requirements includes determining:

- Plan for updating competency models as automated technology is introduced
- How personnel roles will change with the introduction of automation
- How cross-skilling—training for multiple job roles—can be used to meet operational requirements
- How new recruitment strategies, such as targeting former military personnel, will fulfill personnel needs
- Education and training requirements for personnel in the near-, intermediate and long-term implementation of automated technology.

Training

Training is an inherently important HSI component. The most powerful and sophisticated automated system may fail completely if personnel are not properly trained to properly interact with it. Training focuses on addressing and mitigating human performance limitations introduced by new automated technology. Crucial to implementation is a pilot test of the technology in a representative sample of operations. This involves adopting prototype automation on a small scale to obtain personnel and stakeholder feedback. The lessons learned can then be used to further improve training protocols prior to full-scale roll out.

Training personnel to handle emergency or rare operational conditions is also imperative when implementing automation. Automation can result in skill degradation as personnel become further removed from the tasks they once conducted manually. Newer personnel, who may have never conducted manual operations and enter the workforce after automation has been adopted, face a different challenge of not fully understanding the operations that the automation is accomplishing. This lack of a proper and well-developed mental model constrains the employee's ability to later diagnose problems when they arise. Development of training methods that promote the operator's correct mental model of the system is therefore an important requirement.

The HSI approach to identifying training requirements includes determining:

- If current training programs are adequate for existing job roles and how they need to be modified to accommodate near-, intermediate and long-term plans for introducing autonomous operations
- How training programs need to be modified to ensure that skills and mental models of drilling operations remain intact
- Training needs for a cross-discipline approach
- How to utilize simulators on a regular basis to train for emergency situations.

Safety and Occupational Health

Safety and Occupational Health from an HSI perspective refer to the immediate physical safety of personnel in the workplace. The oil and gas industry is a leader in promoting personnel safety. The introduction of automated technology will highlight not only the need to address personnel safety but the importance of addressing process safety as well.

The HSI approach to identifying safety and occupational health requirements includes:

- Adoption of a Safety Management System not only for personnel safety but also for process and technology and equipment safety
- Adoption of safety reporting system for operators to encourage personnel to report potential areas of improvement in process and technology and equipment safety
- Using automation to remove personnel from the rig when possible
- Identification of barriers and hazards to safe operations, and processes and strategies to remove barriers and mitigate hazards, which requires an environment in which operators are encouraged to admit errors and misunderstandings without a "blame game" being invoked.

Human Factors Engineering

Human Factors Engineering (HFE) focuses on ensuring that the Human-Machine Interface (HMI) adheres to user-centered design practices. Good HFE practices greatly reduce the potential for human error, which is a highly desirable outcome. These practices also promote operational efficiency by reducing the amount of time an operator needs to interact with the system interface. The design of the interface can utilize embedded knowledge, which are cues in the layout intentionally designed to provide operational cues regarding its appropriate use. De-cluttering information control panels and displays can also simplify operator decision and response time, which thereby promotes operational efficiency.

The HSI approach to identifying HFE requirements includes:

- Cognitive and job task analyses to determine near, intermediate and long-term automation priorities
- Plans for optimizing workload with adaptive automation
- Optimizing controls, information displays and visualization tools to promote situational awareness
- Plans to combat complacency
- Addressing skill degradation with embedded knowledge in the design of the HMI
- Addressing operator distrust by paying careful attention to system status messages, alarms and system reliability
- Communicating the uncertainty and the intent of the automation to the operator to ensure the operator has the correct mental model of operations.

Organizational Factors

Determining macro-level organizational requirements is paramount to an HSI approach. Barriers such as industry business models that are embedded in the tradition of modern-day operations have the potential to stall research and development efforts even when a substantial ROI is demonstrable.

An overarching goal for the introduction of any new technology is to promote and secure stakeholder buy-in. This is particularly true for drilling operations in the oil and gas sector due to the sometimes-competing goals of the service companies, drilling contractors and equipment suppliers. Securing buy-in should occur early in the HSI process and continue throughout the entire development and acquisition effort. Waiting until systems are fully engineered in a hardware/software sense before turning to HSI is a recipe for disaster.

During technology research and development, iterative design and evaluation are integral to ensuring that automated technology meets not only personnel needs but also industry stakeholder needs. Stakeholders require that automated technology necessarily enhances the safety and operational performance of personnel and is not realized for the sole sake of achieving autonomous operations.

The HSI approach to identifying organizational requirements includes:

- Defining stakeholders and their objectives and goals for automation, and identifying conflicting stakeholder goals
- Development of a stakeholder engagement plan
- Plan to overcome organizational barriers

HSI areas must be assessed and addressed as the level of automation of a drilling system or subsystem changes because they are not fixed.

Combining LOAT with HSI to Deliver Reliable Automation Uptake

The LOAT provides a tool to describe in matrix format distinct stages of transition from the manual to the highest levels of automation anticipated. HSI critical areas provide a means to analyze and plan for the transition of the human(s) in the stages of the LOAT such that the automation and human interdependence functions competently at all stages of the transition.

The advancement of automation in DSA is expected to occur in Systems of Interest because it is these systems that have the capability to improve results and deliver additional value. If these systems of interest are arbitrary in their adoption of automation and transition of the human role, the automation risks unplanned events. The impact of data attributes and operational uncertainties maps into the capability to transition in the LOAT (Figure 6). Adopting the LOAT, the IMS attributes, and the operation uncertainty in planning the role of humans and their competency transition is important for successful adoption of advanced drilling systems automation.

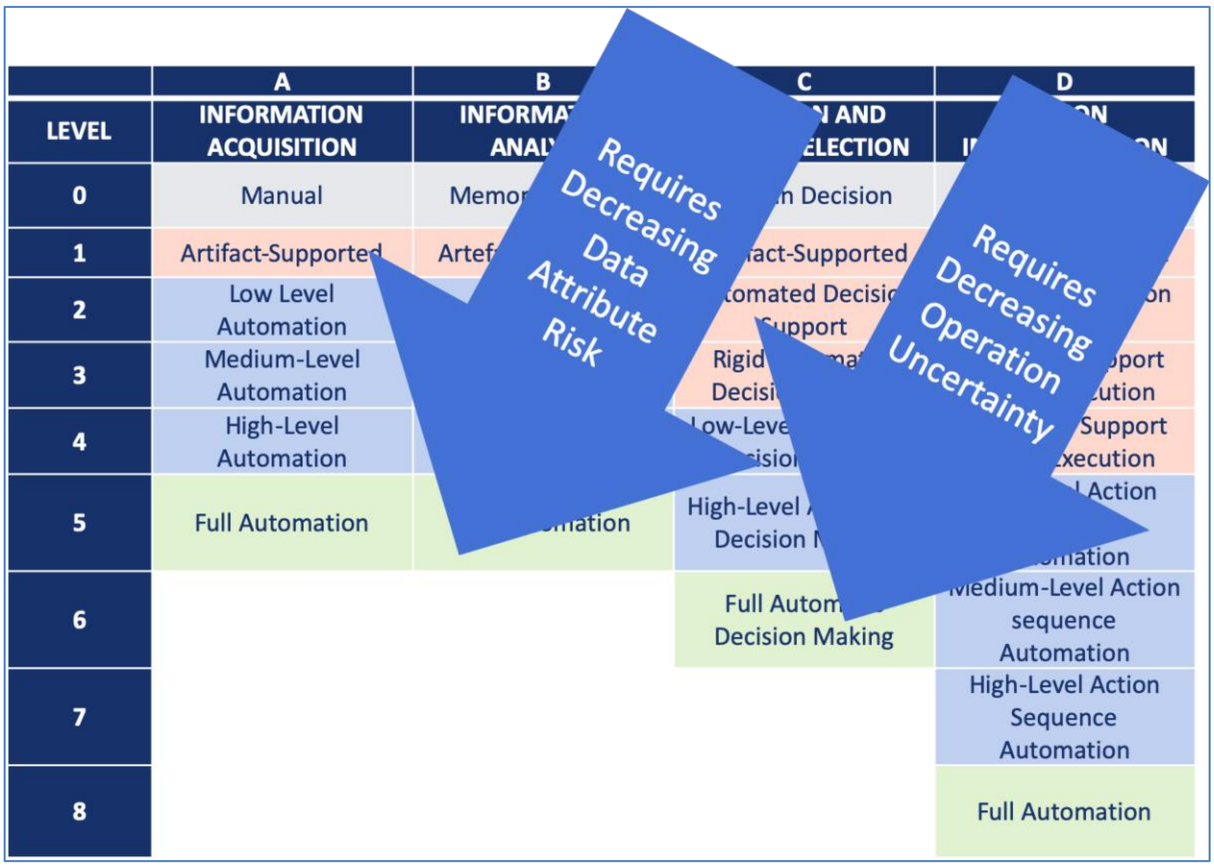

Figure 6: LOAT Capability to Map Data Risk and Operation Uncertainties

The application of this LOAT to the automation of directional drilling has been described and mapped to progress along the cognitive functions and levels of automation defined by the LOAT[8]. This application highlights the usefulness of the LOAT helping directional drilling automation implementers understand their current levels, provide a path forward, as well as manage expectations of potential implementers.

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