EMESRT

Earth Moving Equipment Safety Round Table

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HUMAN FACTORS IN DESIGN GUIDE

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enquiries@emesrt.org

DOCUMENT CONTROL

1. REVISION HISTORY

REV	DATE	DESCRIPTION	PREPARED BY	CHECKED BY	APPROVED BY
0.1	August 2024	Document developed	Robin Burgess-Limerick, Tony Egan, Adam Ferris, Eve McDonald	Robin Burgess-Limerick, Tony Egan	Tony Egan
1.0	September 2024	First published	Robin Burgess-Limerick, Tony Egan, Adam Ferris, Eve McDonald	Robin Burgess-Limerick, Tony Egan	EMESRT Advisory Group

2. DISCLAIMER

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3. CONDITIONS OF USE

EMESRT has an ambition to reduce the Health and Safety risks from operating and maintaining mobile earth moving equipment. This is achieved by sharing leading practice information that can be referenced by users and designers when seeking to reduce the level of risk to personnel. Connecting through a community collaboration of; end users, OEM's, researchers, and third-party suppliers it allows a deep understanding of the problems needed to be addressed to support industry level improvement.

3.1 TRANSLATIONS

This Guide was developed and reviewed in English only. If the Guide content, in part or in its entirety is translated, only the English version published by EMESRT is the approved version.

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TABLE OF CONTENTS

1.0	OBJECTIVE	4
2.0	SITUATION AWARENESS	5
3.0	HUMAN-CENTERED DESIGN	12
4.0	DESIGNING FOR SITUATION AWARENESS	14
5.0	HUMAN READINESS LEVELS	16
REFERENCES		19

1.0 OBJECTIVES

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1. Describe a human-centered design process to support developers and sponsors of new technology related to vehicle interactions
2. Outline the importance of evaluating human factors, people and processes, that impact on the successful integration of technology in work systems, including mobile plant equipment
3. Provide accompanying information on human factors to complement the surface and underground functional performance scenario storyboards

"... design process to support developers and sponsors of new technology.

2.0 SITUATION AWARENESS

Situation awareness is the primary human factors concept relevant to the prevention of unwanted vehicle interactions. A three level model of situation awareness (Figure 1) was defined by Endsley (1987) as:

> the perception of the elements in the environment ... the comprehension of their meaning, and the projections of their status in the near future.

Situation awareness refers to that portion of a person's knowledge pertaining to the state of a dynamic environment (Endsley, 1995). It is separate from decision making and subsequent task performance. Operators may make poor decisions or engage in wrong actions based on accurate situation awareness; however, even the most highly trained and motivated operator will make poor decisions if their situation awareness is inaccurate or incomplete.

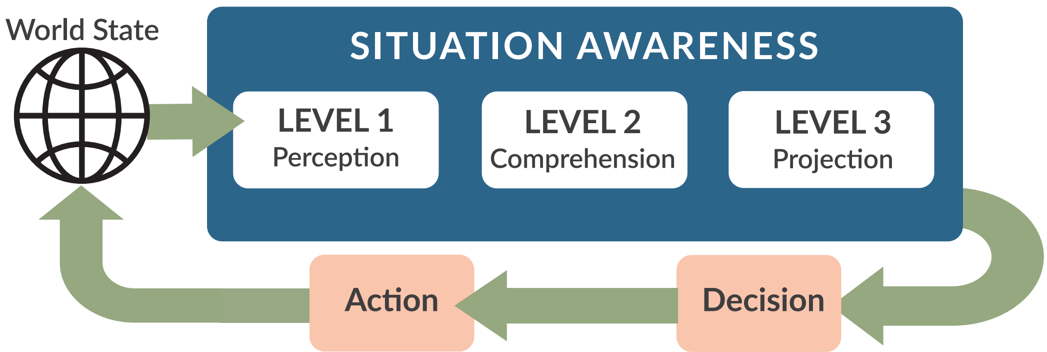

Figure 1: *Three level model of situation awareness (Jones, Connors, and Endsley, 2009).*

The first step in achieving accurate situation awareness is to perceive the state of relevant elements in the environment. In the case of the operator of mobile equipment, this includes the location and motion of other vehicles, the environmental layout, and the dynamics of the operator's vehicle. This perception of the elements of the current situation is defined as **Level 1** situation awareness.

The next step in the situation awareness process is for the operator to synthesise the **Level 1** elements into an understanding of the significance of those elements in the light of the operator's goals (including avoiding unwanted vehicle interactions). Comprehension of the current situation is defined as **Level 2** situation awareness.

The final stage in the process is the prediction of the likely state of the situation in the near future. In the case of a mobile equipment operator, this means the probability of an unwanted vehicle interaction. This projection of the future state is defined as **Level 3** situation awareness.

Loss of accurate situation awareness is a common cause of unwanted vehicle interactions. There are a range of ways in which a loss of situation awareness can occur.

In some situations, visibility restrictions prevent the mobile equipment operator from perceiving the layout of objects in the surrounding environment (Figure 2). The role of a collision awareness system in this situation may be seen as providing additional information to supplement the information available to the operator through direct sensory perception.

***Figure 2:** Still taken from a simulation trial conducted as part of ACARP project C24028 in which an approaching light vehicle is continuously obscured behind the A pillar of a haul truck cab as the vehicle approach a T intersection. In some situations, visibility restrictions prevent an operator from perceiving presence of another vehicle through direct vision alone. In this trial, an interface being trialled alerted the participant to the light vehicle's presence and braking was initiated prior to the light vehicle being visible.*

In other situations, adequate sensory information may be available to an operator but they might not attend to it (e.g., Figure 3). This situation highlights the role that selective attention plays in maintaining situation awareness during the operation of mobile equipment. An operator is continually presented with dynamic patterns of light and sounds. The initial stage of situation awareness and perception, involves the selection and processing of these sensory stimuli to gain a moment-to-moment awareness of the elements in the surrounding environment. Humans have limited capacity to process information and "attention" is required for both the selection and processing of stimuli as well as the subsequent stages of situation awareness (Kahneman, 1973). This attentional capacity varies, particularly with arousal levels.

Figure 3: *A simulation of a stationary light vehicle located in front of a stationary haul truck. The view from the operators seat (lower panel) includes visibility of the light vehicle flag in the bottom right of the windscreen.*

Humans also only possess fine-detail vision in a small part of the visual field. Where the operator looks, and which stimuli are selected for processing continually changes. Although selective attention can be brought under conscious control, for an experienced equipment operator the process is usually subconscious.

There are both top-down and bottom-up influences on selective attention. For example, expectations based on prior experience, or training, direct attention to locations likely to be important depending on the situation (top-down). "Bottom-up" influences on selective attention include stimuli in the environment that attract attention such as sudden movement or appearance of an object. The role of a collision awareness system in this situation is to direct an operator's attention to the critical aspect of the visual environment to allow them to maintain accurate situation awareness (Ho & Spence, 2008).

A third category of situations in which a loss of awareness occurs is "looked but did not see" events or "inattentional blindness". In such situations, the sensory information required is readily available, however operators do not accurately comprehend the situation. Investigations of on-road accidents have suggested that this form of loss of situation awareness is perhaps the most common cause of collisions (Hole, 2007).

The fatal collision between a haul truck and a light vehicle that occurred at the Glencore Ravensworth mine in 2013 provides a tragic example. The investigation report describes the situation illustrated in Figure 4:

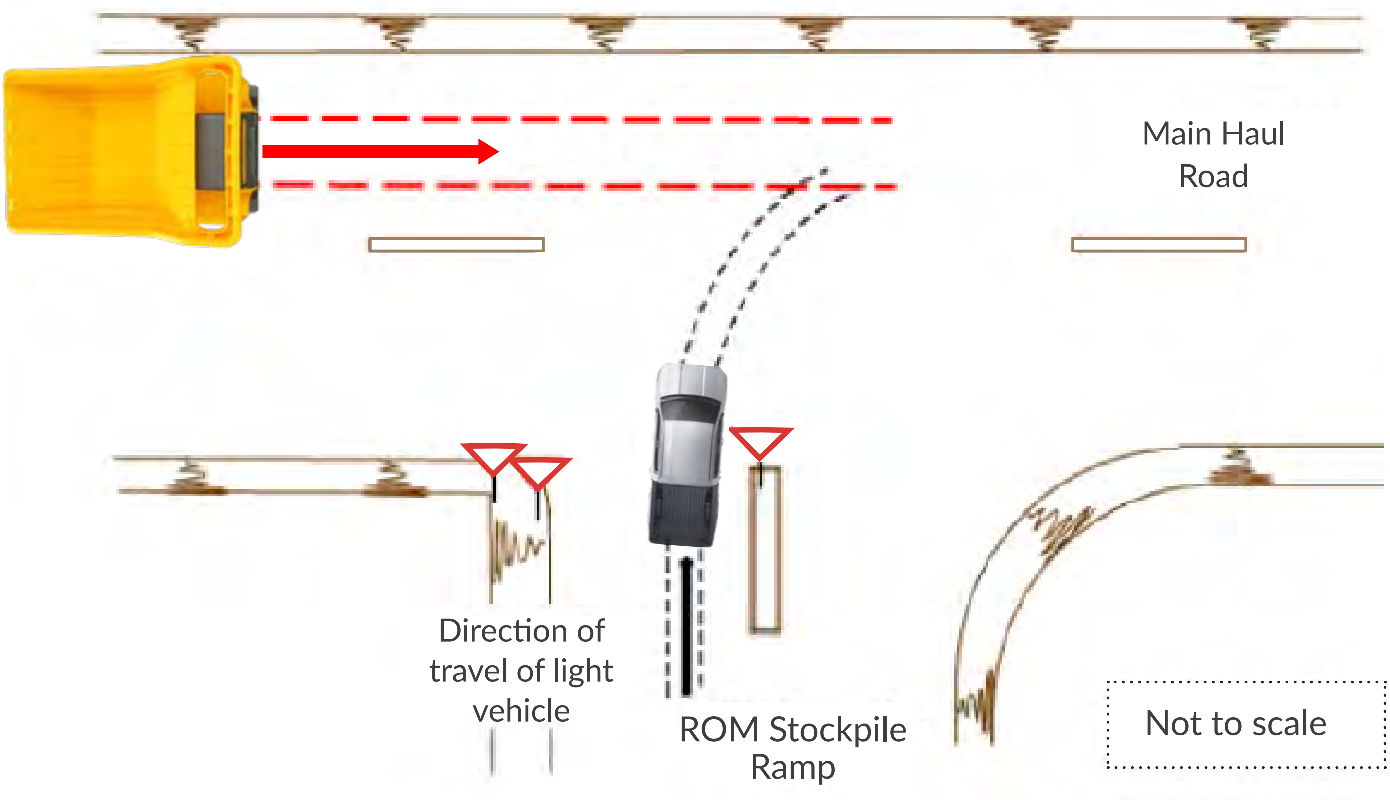

Figure 4: Schematic representation of the 2013 fatal collision at Ravensworth.

From the truck operator's point of view, the scenario is similar to the situation illustrated in Figure 2. The investigation report concluded that the driver of the truck was aware of the presence of the light vehicle but lost sight of it prior to the collision. Visibility of the truck was not obscured for the light vehicle operator, however the environmental conditions presented a perceptual challenge (Figure 5). It is likely that Ms Forshaw "looked, but did not see" the oncoming truck.

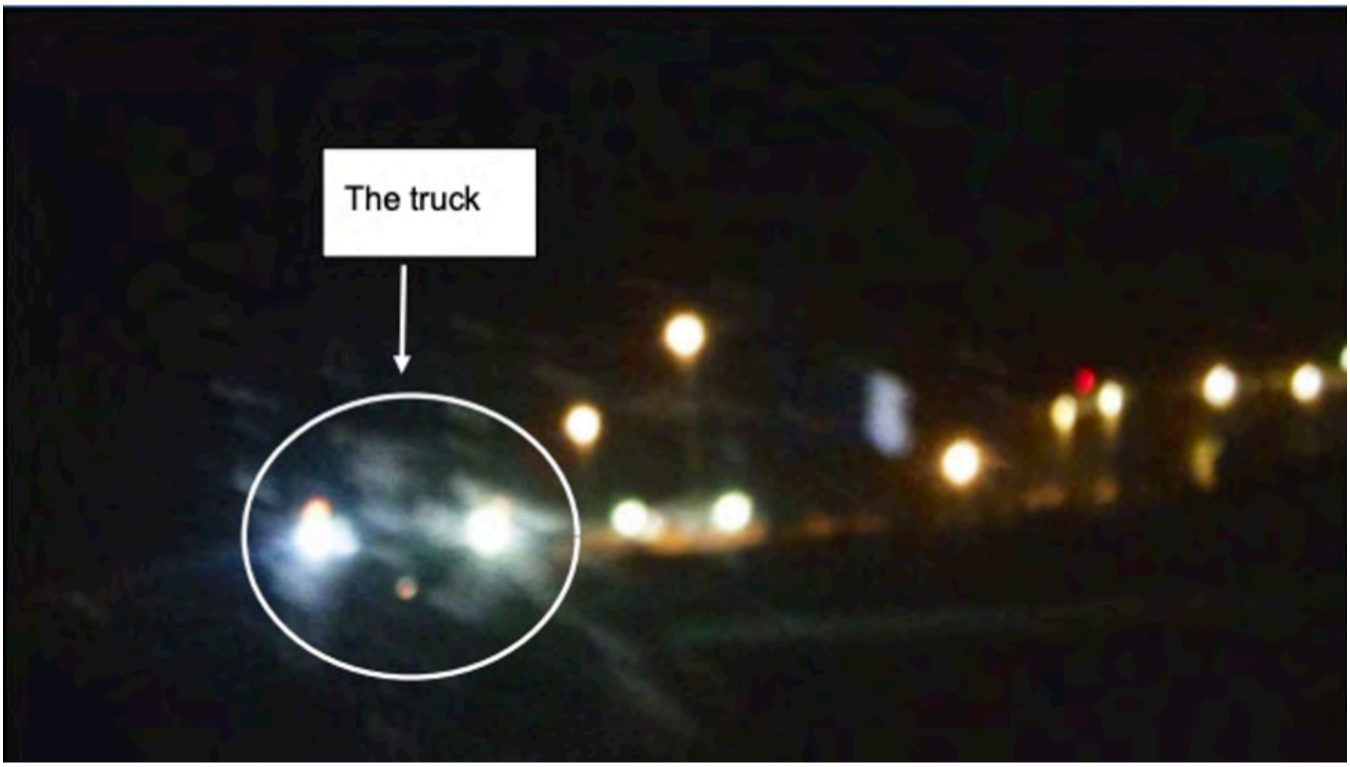

Figure 5: *Screenshot from video taken by investigators from inside a light vehicle travelling through the intersection.*

Traffic accidents associated with such "looked, but did not see" losses of situation awareness are typically framed as a consequence of driver distraction or failure to pay attention (Recarte & Nunes, 2009). An alternate understanding comes from understanding the implications of Kahneman's description of system 1 and system 2 modes of thinking for the situation (Kahneman, 2011). **System 1** "operates automatically and quickly, with little or no effort and no sense of voluntary control", while **System 2** operates when attention is allocated to "effortful mental activities". **System 1** is fast, automatic, effortless, and operates on the basis that "what you see is all there is".

Kahneman notes that driving a car on an empty road is an exemplar activity reflecting **System 1**, while consciously directing attention to a particular aspect of the environment is a function of **System 2**. **System 2** requires continuous exertion of effort. While both systems are always concurrently active, **System 1** is a fast, automatic and effortless system; it is habitual, and common when arousal levels and attentional resources are low.

For example, an experienced mobile equipment operator repeatedly driving the same route in the early morning primarily operates in **System 1**. Instances of inattentional blindness leading to loss of situation awareness may be understood as the "overuse of a strength" in that the driver continues to rely upon the efficiency of **System 1** in circumstances in which this is no longer functional. The aim of a collision awareness system is to prompt the operator to engage the attention of **System 2** when required by the situation.

3.0 HUMAN-CENTERED DESIGN

Human-factors engineering encompasses human capabilities and limitations in system design, development, and evaluation. In collision awareness technology, this is particularly important in the design of the interfaces through which operators interact with the technology.

ISO 9241-210 Ergonomics of human-system interaction Part 210: Human-centered design for interactive systems provides principles for human-centered design of computer-based interactive systems that will be relevant to many technology projects, namely:

a. The design is based upon an explicit understanding of users, tasks, and environments

Designers should consider the complete range of users and others who may be affected by the technology. ISO 9241:210 suggests that a failure to adequately understand user needs is a common source of system failure.

b. Users are involved throughout design and development

Active involvement of users throughout the design process is critical. The nature and frequency of involvement will vary depending on the project; however, the effectiveness of the user involvement will be proportional to the extent of direct interaction with technology designers.

c. The design is driven and refined by user-centered evaluation

The risk of system failure is reduced by incorporating user feedback on preliminary designs into progressively refined solutions. User-centered evaluation is a key part of final acceptance testing, and ongoing feedback from users provides input into subsequent design improvements.

d. The process is iterative

Effective utilisation of user feedback implies that multiple iterations of the design process enables progressive refinement of specifications and prototypes.

e. The design addresses the whole user experience

The effectiveness of the specific technology is only one aspect. Other aspects include the users' responses to the technology, and aspects of the implementation of the system such as training or wider impacts of the technology.

f. The design team includes multidisciplinary skills and perspectives

Achieving effective human-centered design requires diversity of skills within the design team and requires human factors expertise, combined with engineering and software design. The involvement of users and other subject matter experts is essential to achieving a satisfactory human-centered design.

Table 1 provides examples of the activities that comprise a human-centered design process and the outputs of each activity.

Table 1: Human-centered design activities (adapted from ISO 9241-210).

ACTIVITIES		DETAIL	OUTPUTS
1	Understand and specify the context of use.	The characteristics of the users, tasks and organizational, technical and physical environment define the context in which the system is used.	Context of use description (e.g., user characteristics, tasks and goals, use environment).
2	Specify user requirements.	User requirements provide the basis for the design and evaluation of systems to meet user needs. This includes user interface knowledge.	Context of use specification. User needs description and requirements specification.
3	Produce design solutions to meet these requirements.	Potential design solutions produced based on the context of use description, the state of the art in the domain, design guidelines, and the knowledge of the design team.	User interaction specification. User interface specification Implemented user interface.
4	Evaluate the designs against requirements.	User-centered evaluation is a required activity at all HCD stages. Two widely used approaches are: inspection-based evaluation against usability guidelines, and user-based testing.	Evaluation results. Conformance test results. Long-term monitoring results.

4.0 DESIGNING FOR SITUATION AWARENESS

Interface design influences operators' situation awareness. The interface impacts on the operator's understanding of information that is critical to operations. This includes information accuracy and relevance to the situation (Endsley, 1995). Endsley & Jones (2012, 2024) have provided an approach to human centered design focused on situation awareness.

Interface design commences with describing situation awareness requirements through Goal-Directed Task Analysis. The goals and critical decisions associated with a job are described and the **Level 1**, **2** and **3** situation awareness needs associated with these decisions are then determined.

The designers' challenge is then to provide interfaces that organise information around the user's situation assessment needs and assist timely and accurate **Level 3** situation awareness.

General principles of designing for situation awareness have been developed (Endsley & Jones, 2012), including:

- Organise information around goals
- Present **Level 2** information directly—support comprehension
- Provide assistance for **Level 3** SA projections
- Explicitly identify missing information
- Support sensor reliability assessment
- Represent information timeliness
- Just say no to feature creep—buck the trend
- Ensure logical consistency across modes and features
- Don't make people rely on alarms—provide projection support
- Make alarms unambiguous
- Reduce false alarms, reduce false alarms, reduce false alarms
- Set missed alarm and false alarm trade-offs appropriately
- Use multiple modalities to alarm, but ensure they are consistent

Nuisance and false alarms are a significant failure mode that threatens the effectiveness of collision advisory warning technology. If auditory alarms trigger in situations in which no collision is imminent, an operator is unlikely to act as they should when they encounter a genuine collision threat. Guidance provided for on-road collision warning systems suggests that acceptable false alarm rates are less that once per week for the average driver (Campbell et al., 2007), although later advice (Campbell et al., 2016) noted that on-road truck drivers “will be likely to tolerate some level of annoyance with auditory warnings if they see clear safety benefits”.

The ill effects of “nuisance” alarms will be reduced if users understand the reason for the alarm. For example, if an alarm triggers while a haul truck is going around a switchback while another haul truck is present on the switchback then the operator understands and accepts the alarm, because the reason is evident. Unnecessary alarms that trigger without obvious cause give rise to subsequent response failures.

An attention getting alarm followed by a speech instruction is recommended. The aviation industry uses abstract “attensons”, combined with speech alerts and secondary visual displays.

Guidance regarding other human factors engineering details of interface designs for on-road collision warning systems (e.g., Campbell et al., 2007; 2016; 2018; Tidwell et al., 2015) may be relevant however mining operators must apply caution in their adoption.

5.0 HUMAN READINESS LEVELS

Judging the suitability of any new technology for deployment depends on an assurance that the technology will both function as intended, and that the use of the technology by humans in the system will have the intended outcome. Technology readiness levels are commonly used to describe the development of technology.

Human readiness levels are an analogous scale used to evaluate, track, and communicate the readiness of a technology for human use. The HFES/ANSI 400-2021 formalises these human readiness levels. Table 2 illustrates the concordance between technology readiness levels and human readiness levels.

Table 2: Technological and human readiness levels (See, 2022)

	LEVEL	TECHNOLOGY READINESS LEVEL	HUMAN READINESS LEVEL
Production / Deployment	9	Operational use of deliverable	System successfully used in operations across the operational envelope with systematic monitoring of human-system performance
	8	Actual deliverable qualified through test and demonstration	Human systems design fully tested, verified, and approved in mission operations, using completed system hardware and software and representative users
	7	Final development version of the deliverable demonstrated in operational environment	Human systems design fully tested and vertified in operational environment with system hardware and software and representative users
Technology Demonstration	6	Representative of the deliverable demonstrated in relevant environments	Human systems design fully matured and demonstrated in a relevant high-fedelity, simulated environment or actual environment
	5	Key elements demonstrated in relevant environments	Human-centered evaluation of prototypes in mission-relevant part-task simulations completed to inform design
	4	Key elements demonstrated in laboratory environment	Modelling, part-task testing, and trade studies of human systems design concepts and applications completed
Research and Development	3	Concepts demonstrated analytically or experimentally	Human-centered requirements to support human performance and human-technology interactions established
	2	Concept and application formulated	Human-centered concepts, applications, and guidelines defined
	1	Basic principles observed and reported	Basic principles for human characteristics, performance, and behaviour observed and reported

Annex C of HFES/ANSI 400-2021 provides questions to evaluate the achievement of human readiness at each level.

For example, questions for **HRL level 1** include:

- Have key human behaviours, capabilities, and limitations been identified?
- Have preliminary usage scenarios for potential users been identified?

For **HRL level 2** the questions include:

- Have key human-centered design principles, standards, and guidance been established?
- Have usage scenarios been updated to include basic task descriptions for user roles?
- Has human performance on lacy or comparable systems been analysed to understand key human-technology interactions, human behaviour, and human performance issues?
- Have potential sources of human error and misuse been identified?
- Are appropriate metrics for successful human performance being identified?

For **HRL level 3** the questions include:

- Have human systems experts with requisite expertise been engaged and funded to support the design and development effort?
- Have usage scenarios been updated, based on human needs analyses for the proof of concept?
- Have cognitive task analyses and function and task analyses for each user role been completed?
- Have characteristics of the target population been specified?
- Are human capabilities, limitations, and needs being mapped to expected operational and system demands to identify human performance issues and system requirements?
- Have preliminary design features to accommodate human capabilities, limitations, and needs been investigated and recommended, based on the proof of concept?

For **HRL level 4** the questions include:

- Have task analyses been updated based on the developing prototype and optimised for human performance, using modelling and part-task testing?
- Has conformance of preliminary designs to human performance requirements, design principles, standards, and guidance been verified?

For **HRL level 5** the questions include:

- Have functioning prototypes of the human-system interface and simulations of mission tasks and conditions been developed to support assessment of critical human performance issues?
- Have task analyses been updated, based on prototype testing in mission-relevant part-task simulations?
- Have relevant human performance data been collected and evaluated to determine whether human performance metrics are successfully met, based on prototype testing in mission-relevant part-task simulations?
- Has conformance of system prototypes to human performance requirements, design principles, standards, and guidance been verified?

For **HRL level 6** the questions include:

- Has the full range of user scenarios and tasks been tested in high-fidelity simulated or actual environments?
- Has a system to track and resolve human systems issues after fielding been developed and evaluated in high-fidelity simulated or actual environments?
- Have relevant human performance data been collected and evaluated to determine whether human performance metrics are successfully met, based on testing in high-fidelity simulated or actual environments?

For **HRL level 7** the questions include:

- Has the range of user scenarios and tasks been tested with the final development system in an operational environment?
- Has the effectiveness of straties to address environmental constraints and impacts been evaluated with the final development system in an operational environment?
- Has conformance of the final development system to human performance requirements, design principles, standards, and guidance been verified?

For **HRL level 8** the questions include:

- Have task analyses been updated with the production system in mission operations?
- Has a system to track and resolve human systems issues after fielding been finalised and tested with the production system in mission operations?
- Has the effectiveness of straties to accommodate manpower, personnel, and training concerns been evaluated and successfully demonstrated with the production system in mission operations?
- Have human use issues been satisfactorily resolved, as evidenced by qualification of the production system in mission operations?

For **HRL level 9** the questions include:

- Are human systems performance data and lessons learned being documented for recommended systems improvements and future applications?
- Are human systems mitigations to improve performance in the fielded system being identified and implemented?
- Is user training for operation of the fielded system being evaluated for required modifications?
- Are potential upgrades to the fielded system being evaluated to address human systems issues and impacts?

Achieving satisfactory human readiness levels requires a human-centered design process during technology development. Conversely, assessing the human readiness levels through the questions provided by HFES/ANSI 400-2021 provides a means of evaluating the quality of the human-centered design process employed.

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