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An Initial Review on Human-centered Design and Evaluation Methodologies of Autonomous and Automated Machines and Equipment (AAM&E)

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Abstract: Automated or autonomous machines are increasingly being implemented in the industrial work environment, and has great potential to alleviate workers' safety and health risks in the hazardous workplaces. A global talent crisis and an imminent skilled labor shortage are affecting both developed and developing economies. Moving toward autonomous or automated machines solutions may help ease the skilled operators' shortages in the various industry. This study aimed to review and synthesize human-centered design and evaluation methodologies for autonomous and automated equipment or machines in occupational and industrial settings, and discuss the challenges and limitations regarding the current AAM&E design and evaluation methodologies. This preliminary review was based on the result of general keywords search of six databases: APA Psycinfo, PubMed, Web of Science, ScienceDirect, ProQuest, and Scopus. We followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline and checklist for systematic review preferred reporting items for systematic reviews and meta-analyses (PRISMA) checklist & flowchart were used to evaluate methodological quality (PRISMA, 2021). We reviewed and summarized the design and evaluation (and assessment) methodologies for autonomous and automated equipment or machines in various occupational and industrial settings, while addressing the limitations and weaknesses of the existing AAM&E design and evaluation methodologies.

Keywords: Autonomous, Automation, Machines and Equipment, Occupational, Industrial, Human Centered Design, Evaluation, Methodology

1. Introduction/Background

Automated or autonomous machines are increasingly being implemented in the industrial work environment, and has great potential to alleviate workers' safety and health risks in the hazardous workplaces (Burgess-Limerick, 2020; Edet et al., 2022). A global talent crisis and an imminent skilled labor shortage are affecting both developed and developing economies. Moving toward autonomous or automated machines solutions may help ease the skilled operators' shortages in the various industry (Choi & Borchardt, 2022). Younger workers, who lack the skills and experience of their veteran peers, can benefit from the technology being deployed on jobsites. Autonomous applications can also provide employment opportunities to a new workforce such as wounded veterans with physical disabilities, creating a value-added job for someone who wants to work but may face challenges in physically operating a machine (Jurgens, 2021).

International Organization for Standardization (ISO) 17757 (2019) defines autonomous operation as "the mode of operation in which a mobile machine performs all machine safety-critical and earth-moving or mining functions related to its defined operations without operator interaction. The operator could provide destination or navigation input, but is not needed to assert control during the defined operation." ISO 17757 (2019) defines that autonomous machine as "a mobile machine that is intended to operate in autonomous mode during its normal operating cycle" (ISO 17757, 2019; Tiusanen et al., 2020). ISO 18497 (2018) provides documentation to assist in communicating the safety requirements, means of verification and usage information to ensure an appropriate level of safety for self-propelled machines and equipment with highly automated operations (ISO 18497, 2018).

Human-centered design (HCD), as a definition and approach, can differ depending on the perspectives of those implementing the process (Demirel & Duffy, 2013). Regardless of viewpoints, however, HCD uses techniques to support and stimulate involvement in product development and interaction with the goal being to continuously improve product characteristics depending on needs, abilities, and limitations of users. Recent emphasis on HCD has been promoted by the International Organization for Standardization (ISO), which updated its ISO 9241-210 standards around ergonomics in 2019, "approach to systems design and development that aims to make interactive systems more usable by focusing on the use of the system and applying human factors/ergonomics and usability knowledge and techniques" (ISO, 2020, np). For the last decade, HCD has become a commonly used process in the development of many products, receiving much attention from occupational safety practitioners. When determining root causes of workplace incidents, poor or inadequate design is often a major factor (Horberry & Burgess-Limerick, 2015). HCD is a process that aims to make equipment and systems more usable and acceptable by focusing on end users and how they may respond based on work tasks and environmental factors at play (Gulliksen et al., 2003). HCD requires the involvement of users and stakeholders throughout the design and development of intended outputs. Research has documented an array of HCD considerations in the design of medical equipment, road vehicles, and consumer products (Rouse, 2007). An essential principle of HCD is having an explicit understanding of the user before designing an appropriate solution and then tailoring those solutions for the end user. The needs, wants, and limitations of users and stakeholders should be given attention at each stage of the design process in order to appropriately fit the equipment, system, or interface to individual workers (Steiner, 2014).

The requirement HCD analysis stage involved identifying and understanding the set goals (what it is and why it is needed), roles and demographic information of the user, and environmental conditions that may affect the interface (Endsley et al., 2003). Technological analysis on the other hand, involved evaluating the various tools and technology available to determine which one is most suitable for the intended user (Edet et al., 2022). The development of an autonomous industrial machine should include the design of an interface that will enable humans to interact with the machine to perform supervisory functions. The literature on remote supervision has noted that the role of the human supervisor in an autonomous system includes setting tasks, allocating resources, monitoring the execution of tasks, and intervening in emergencies that exceed the capability of the autonomous machine (Edet & Mann, 2022). The design of the human-automation interfaces by which information is conveyed to people within the system becomes a critical concern (Lee & Seppelt, 2012). Combining data into meaningful information though the design of visual interfaces with emergent properties that correspond to system relevant parameters is one approach that may be helpful, as is placing information in a meaningful context and/or integrating automation-related information with traditional displays. Other options are to create human-automation interfaces that predict future states of the system and/or to provide information through multiple sensory channels (Burgess-Limerick, 2020).

1.1 Study purpose

This preliminary review aimed to synthesize human-centered design and evaluation methodologies for autonomous and automated equipment or machines in occupational and industrial settings, and discuss limitations and weaknesses of the current AAM&E design and evaluation methodologies.

2. Methods/Procedures

This preliminary review was based on the result of general keywords search of 6 databases: APA Psycinfo, PubMed, Web of Science, ScienceDirect, ProQuest, and Scopus. We followed PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guideline and checklist for systematic review preferred reporting items for systematic reviews and meta-analyses (PRISMA) checklist & flowchart were used to evaluate methodological quality (PRISMA, 2021). The Initial search results/hits with the keyword combinations by search engines/databases were as follows: (autonomous OR automation) AND (equipment OR machine) AND (industrial OR industry) AND (assessment OR evaluation OR criteria) AND human* AND (design OR method); (autonomous OR automation) AND (equipment OR machine) AND (industrial OR

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industry) AND (assessment OR evaluation OR criteria) AND ("human factors" OR ergonomics OR "human centered") AND (design OR evaluation OR method). Inclusion/criteria used were: journal articles in English (including review papers); title evaluation for relevance; abstract evaluation for relevance; human-centered design/user-centered design; design methodology; evaluation/assessment methodology; human machine collaboration or interaction; human systems interaction; occupational and industrial.

3. Results

Initial searches of the databases produced a total of 955 results. After articles screened on title and abstracts, 69 paper were excluded. The full texts of the remaining 50 unique studies were reviewed for appropriateness, which resulted in an additional 19 studies being excluded, and resulted in a total of 31 studies published between 2001 and 2022 were selected for this preliminary review study. Of these papers, 22 reports on studies related to design methodology, and only 9 studies were on evaluation/assessment methodology of AAM&E in occupational and industrial settings. Table 1 provides sample papers of design methodology in autonomous or automated machine or equipment and their findings, recommendations and relevant technique or methodology.

Table 1. Sample Studies on Design Methodology in Autonomous or Automated Machine or Equipment

Author (Year)	Title	Purpose	Type	Industry	Findings	Recommendation	Relevant Technique
Feuerriegel et al. (2021)	Interface Design for Human-Machine Collaborations in Drone Management	Design of human interface for drone/UAV management, with a focus on autonomy due to latency in information exchanges	Immersion interface design based on iterative process	UAV and Emergency / Disaster Response	Immersive interface reduces cognitive load on the operator while improving task performance. A well-designed interface can help overcome lag / latency between the aircraft and the user	Further research on real world drone operations.	Immersion – Virtual Environment (3D) Experimental design - NASA Task Load Index Interface view for real-time flight monitoring, UVA control, and sensing UAS traffic management.
Burgess-Limerick (2020)	Human-Systems Integration (HIS) for the Safe Implementation of Automation	Review HSI in procurement of automated systems in in mining.	Review	Mining and Quarry Operations	Automation to a mine/quarry should include a human centered design process to encompass operations and employee tasks.	Safety related questions are necessary for mine operators during the implementation of automation	Human-systems integration (HSI) core domains: staffing, personnel, training, human factors engineering, safety, and health.
Roth et al. (2019)	Function allocation considerations in the era of human autonomy teaming	Review approaches to function allocation in the context of human machine teaming with technology that exhibits high levels of autonomy (e.g., unmanned aerial systems).	Review	General/ Broad	Four key activities: (1) analyzing operational demands & work requirements; (2) exploring alternative distribution of work across person & machine agents; (3) examining interdependencies between human and autonomous technologies; and (4) exploring	The function allocation methods and frameworks identified through this literature review process provide a solid foundation for making function allocation decisions for these more autonomous technologies	Function Allocation Methods (MABA-MABA ("Men are better at, Machines are better at"; LOA (Levels of Automation); CTA/CWA (Cognitive task analysis/Cognitive work analysis); Co-Active Design)

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					the function allocation trade-space.		
Edet et al. (2018)	Remote supervision of autonomous agricultural sprayers: The farmer's perspective	Determine info needed for farmers for autonomous ag machines with remote supervision	Survey / Questionnaire	Agriculture	Farmers are willing to accept autonomous sprayers. The systems must be able to adapt for safety and variable soil and field conditions. The interface must be portable.	-Easy interface access and live feeds of the sprayer & its environment. -Increase the situation awareness of the user (farmer).	Questionnaire
Joe et al. (2015)	Function allocation for humans and automation in the context of team dynamics	Present how social factors can have a negative effect on performance of human only teams and human/automation teams	Evaluation	General / Broad	Autonomous function allocations must consider capabilities of individuals and social factors that affect teamwork	Human Factors Engineering should reconceptualize how function allocation to address individual and social interactions.	Function allocation (FA) considering both the individual cognitive and computational capabilities of humans and automation, and social factors that affect teamwork.
Edet et al. (2022)	Design and Evaluation of a User Interface for an Autonomous Agricultural Sprayer	Describe design and evaluation of a user interface for remotely supervised autonomous ag sprayer	Review of literature	Agriculture	A user interface was designed for an autonomous sprayer. The evaluation identified various improvements for the user interface.	Improvements to the interface to allow the user to resolve issues prior to stopping a machine.	Requirement analysis for the design of an automation interface. Heuristic and cognitive evaluation. Usability evaluation

4. Discussion

This paper reviewed and summarized the design and evaluation methodologies for autonomous and automated equipment or machines in various occupational and industrial settings, while addressing and improving limitations and weaknesses of the existing AAM&E design and evaluation methodologies.

Autonomous equipment offers significant benefits with respect to efficiency, cost savings, and safety. These machines are poised to have a profound impact in the off-road environment, upsetting and defying current models in relation to the size of the equipment and the role of the dealers and OEMs, as well as impacting the individual operator (Jurgens, 2021). Adopting technology such as robots and autonomous equipment in workplaces is unavoidable because workers entering the workforce have grown up using tablets and smartphones throughout their entire life, and the younger workers are going to expect technology to help them perform their jobs (Jones, 2020). Moving toward autonomous solutions may help ease the skilled operators' shortages in the various industry (e.g., construction). Using machines autonomously improve productivity, and machines use less fuel and move more efficiently, which prolongs machine life, reduces maintenance, and prevents unnecessary wear and tear. By automating some tasks, skilled workers can work on more complex tasks or move to areas where human skills are needed most. Equipment automation also allows jobsites to run beyond normal operating hours (e.g., at night) and perform tasks in parallel so they can be done more quickly. Autonomous machines can alter the economics of machine design, facilitating the increase of smaller machines. Robotic and autonomous systems can reduce occupational injuries and free workers from conducting dangerous tasks that conventional construction methods have reached their limits and that automation and robotics technologies have the potential to address the productivity challenges of high-risk industry like construction (Delgado et al., 2019).

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However, the introduction of automation that places humans into supervisory roles can lead to degradation of manual control skills. Introducing automation can also change the type and extent of information available to equipment operators by removing them from direct contact with the process being controlled. Locating the system supervisor (control room operator) remotely from the automated components may reduce the sources of information that can be used to monitor the system, and in particular, to detect and diagnose the causes of departures from normal operation (Sheridan & Parasuraman, 2005). Both the change from manual control, and the reduced information directly available to the people involved, potentially leads to loss of situation awareness, and consequential delays in responding in the event that a human is required to take action in response to the system being perturbed beyond its normal operating range. The need to maintain situation awareness is increased with the addition of automation, rather than being diminished, because supervisors must maintain awareness of the functioning of the automated components as well as information about the base system (Endesley, 2011). One interface design strategy typically employed is the provision of auditory and/or visual alarms which signal the supervisor to direct their attention to a potentially abnormal situation. However, if the system frequently alarms when action is not actually required, then it is predictable that such nuisance alarms will increase the probability that abnormal states will be ignored, with potential safety consequences (Burgess-Limerick, 2020). Interfaces are also used by humans to provide input to direct the actions of the automated components. Errors in these inputs have potential to lead to adverse safety outcomes if not detected and corrected. Errors could include inaccurate information about roadway or dump location, for example. Timely validation of supervisory input is an important aspect of interface design. Input errors may also be caused by a control room operator's confusion between different operational, or control, modes. At the same time, the span of control of an individual is likely to be increased when placed in an automated system in a supervisory role. Delays in receiving feedback resulting from actions, including errors, may be increased, and when combined with a reduction in the number of operators, the probability of error detection and correction is potentially reduced (Burgess-Limerick, 2020). One dimension of the human response relates to the trust people have in the automation technology (Hancock et al., 2011). People in the system may come to over-trust the automation, either failing to note and respond to automation failures (particularly when such failures are rare) or altering behavior in ways that reduce the intended safety benefits of automation. For example, the introduction of pedestrian proximity detection technology interlocked with the braking systems of underground coal haulage equipment may lead to operators and/or pedestrians over-trusting the technology and taking less care to avoid interactions, with potentially fatal consequences (Burgess-Limerick, 2020). The notion of trust and trust development needs to be considered in the early design of autonomous machines. Trust as a design requirement is a new item in the requirement list and needs to be described more thoroughly.

The deployment of automated and fully autonomous machines demands new styles of interaction and collaboration on a site. Especially, the capabilities as well as the intentions of the machines need to be clear to the human collaborator (Frank et al. 2019; Ruvald et al. 2018). Observations and interviews at construction sites supported the understanding and development of trust among human teams. Nonverbal communication, experience, the stable formation of the team, and a comprehensive understanding of the work task supports the inter-team trust development and its maintenance (Frank et al., 2019). In addition, a rule-based framework, applied at all sites, serves as an entry point into the trust development because new team members can rely on the "dos and don'ts" and that everyone follows the same company-wide rules. Similar to the development of trust between humans, the trust development between a human and an autonomous machine or robot can be facilitated. Transparency, constant feedback, reliability, and durability exposed by the autonomous system support the development of trust on the human side (Frank et al., 2019). Observations and the predictability of the machine behavior can be seen as a high influence factor as well. With respect to the assigned work task on a construction or mining site, the workflow of the machine and human worker has to be maintained throughout the operational period. Facilitation systems are required to ensure safe and efficient collaboration and side-by-side working of humans and autonomous machines within the same work area (Frank et al., 2019). Associated issues such as implementation are acceptability of automation to operators, loss of situation awareness, deskilling, and operator behavioral changes based on different levels of automation. It is suggested that a user-centered design approach could overcome the issues with a parallel focus on system automation rather than component automation (Frank et al., 2019). Endsley et al. (2003) recommended that an automation interface should be human-centered rather than machine-centered if one is to achieve optimum productivity and safety while using the interface: autonomous equipment offers significant benefits with respect to efficiency, cost savings, and safety; using machines autonomously improve productivity, and machines use less fuel and move more efficiently, which prolongs machine life, reduces maintenance, and prevents unnecessary wear and tear. Autonomous machines can alter the economics of machine design, facilitating the increase of smaller machines. Robotic and autonomous systems can reduce occupational injuries and free workers from conducting dangerous tasks. However, it is warranted to invest more research on development and validation of methodological framework for designing and assessing autonomous or automated equipment or machines in occupation and industrial settings.

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