Case Study: Visual Engineering to Support Human Factors Assessments in the Nuclear Industry

Laura Poad, Samantha Hilton and Ben Gafner

Amentum

SUMMARY

This case study presents how modern Visual Engineering (VE) tools, such as Virtual Reality (VR), digital human modelling and interactive simulation, have been used to support traditional Human Factors (HF) assessments within the Nuclear Decommissioning Industry. The case study demonstrates a real-world example of how Visual Engineering tools have been integrated into existing HF processes and aims to provide practical, evidence-based insights and transferable lessons to HF practitioners interested how Visual Engineering technologies can benefit HF practice.

KEYWORDS

Visual Engineering, Virtual Reality, 3D Computer Aided Design, Digital Human Modelling, Nuclear Decommissioning, Human-System Integration, Ergonomics, Engineering Design

Introduction

The case study is a nuclear decommissioning facility which requires the safe retrieval, inspection and transport of legacy waste containers, involving intricate interface management and manually intensive operations in confined spaces. HF has been integrated into this project from Concept Design to ensure that operator capabilities have been considered and claims made on operators are adequately supported by the design.

In this case study, it was identified that existing 3D designs were limiting and there was a risk of HF issues not being identified until later on in the project. Human Factors worked with engineers to develop a cohesive immersive environment using digital human models, aligning with the user population, to conduct early user testing, evaluating operator reach, visibility, workflow and safety risks long before physical prototypes were to exist.

This case study is well-suited for the theme of "Adapting to the Future" as it will provide attendees with a clear real-world example of how Visual Engineering tools have been used to encourage a proactive, visually driven design approach to HF integration, which helped elevate existing HF processes.

Method

An immersive environment was developed by the HF and VE team to visually represent task sequences. The method of using VE to support HF assessments was as follows:

Task and Error Analysis: Task sequence design documentation was used as an input to capture different tasks, allowing user postures and user-system interactions with the proposed design in the store environment to be considered. The HF team performed virtual walkthroughs and identified the Performance Shaping Factors affecting task completion, which became integrated into human error analysis, identifying potential operational risks and communicating HF optimisations of the design back to designers.

Ergonomic and HMI Assessments: Human modelling ('Manikins') was used in the immersive environment to represent the target user population and accurately visualise postures, reach distances and positioning required to achieve tasks. Use of the VR headset and controls allowed the HF team to perform user testing and capture data measurements. This information was used to assess compliance against client ergonomic standards, assess whether the anticipated user population could safely and reliably operate the equipment in the given environment, and strengthen ergonomic and HMI assessments.

Design Reviews: Visual Engineering tools supported multidisciplinary teams in collaborating around a shared virtual environment to conduct design reviews. These tools enabled visualisation of HF issues to provide all stakeholders with a shared position of HF risks, making HF issues easier to identify, communicate and resolve. The iterative approach reduced rework, improved ergonomic quality and accelerated design decisions. This process was able to take place early in the design phase providing an efficient, integrated design solution to be progressed to build and commissioning.

Results

Integration of VE into the HF programme of work provided a number of benefits to strengthen existing HF approaches:

Early Identification of HF Risks: Risk associated with critical tasks were able to be appropriately managed where it was the As Low As Reasonably Practicable (ALARP) solution through proposed HF adjustments to design, supporting the principles of defence in depth and hierarchy of controls.

Examples:

A lifting clash was identified during a VR walkthrough which would not have been easily identified in static 3D modelling. The design team rapidly simulated this scenario using the animation model which confirmed an access oversight. This issue was resolved through design changes, however if left unresolved, would have surfaced during test rigging or commissioning at a significantly higher cost and programme risk.

VR modelling allowed for the design to be considered at an integrated level which identified a number of hazards e.g. finger traps present in the operator-system interfaces and compromised postures of a range of users whilst interacting within the environment, which may not have been considered until testing of the full design at a later stage of the project.

Collaboration Across Stakeholders: Use of VE allowed for a shared position between HF and designers on what user-system interaction looked like. VE became a communication tool between stakeholders on the project to support regular and informal design reviews to key project milestones such as Hazard Operability Studies including all stakeholders across the project. This encouraged HF integration to be filtered through to each stakeholder through visualisation of the operator's role, increasing awareness of HF as a discipline.

Examples:

The iterative nature of performing VR walkthroughs with designers allowed for modifications to the design to be proposed and adjusted in models in real time to explore changes. Management of HF *issues on the HF Issues Register became more streamlined as next steps to design could be immediately communicated, understood by all stakeholders present and appropriately actioned.*

Active demonstration of HF risks could be visualised across the project and communicated on a broader level through the use of Mechanical Sequence Diagrams which used images from VR walkthrough sessions and visualised the operator-system interactions for input into project-wide meetings. This provided awareness of the key HF risks across the project and supported stakeholders in identifying potential HF risks and reaching out to the HF team.

HF Assurance of Design: By visualising each task step within the Tabular Task Analysis, conclusions on human error analysis could be more readily understood by HF verifiers for the project.

Example: The HF verifier for the case study was able to use VR to gain an understanding of the environment prior to verification activities. This led to the identification of Learning From Experience opportunities to be fed back into design at an early stage.

Speed of Analysis: The transition from the designer's CAD model to the VE software was accomplished with speed through the team-set up allowing for direct collaboration with the Visual Engineering Team. This streamlined workflow enabled the rapid creation of an interactive environment that accurately reflected the existing building.

Example: The designers visited site with the Visual Engineering team and collated images of the existing facility. By integrating detailed CAD geometry alongside this cloud point data, the environment supported early and meaningful exploration of HF considerations such as lighting conditions, sightlines and spatial constraints. As a result, design implications could be evaluated in context without an immediate requirement for a site visit, reducing time and cost while still enabling informed, data-driven decision making.

Integration of VE into the HF programme of work in this case study was limited by:

Validation of Manikins: While digital human models enable efficient evaluation of reach, clearance and posture, their accuracy is depending on the underlying anthropometric datasets and implementation within the software. As the VE software was not a HF-specific software, human body measurements were extracted and manually inputted from HF documentation and there is a risk that certain percentile representations may not fully reflect real-world variability, affecting the reliability of ergonomic conclusions drawn from the simulation. Validation and verification of manikin models would strengthen HF conclusions made using VE.

Operational and Environment Assumptions: Although cloud point data and detailed CAD models improved realism, transient conditions such as temporary obstructions, wear and tear of the existing facility or dynamic lighting changes have not been captured. User interactions within the virtual environment may also not fully replicate human behaviour, particularly under operational stress or constrained movement. Finally, sensory factors such as noise, temperature and tactile feedback are not represented and limit the completeness of HF assessments. This still necessitates later in-person validation. Iterative refinement as new data becomes available, targeted site visits to confirm assumptions and close collaboration including operatives would strengthen the environment in being appropriately contextualised.

Conclusions

This case study demonstrates that application of VE tools can be used alongside existing HF methods and processes to adopt an early-stage risk mitigation approach to HF integration in design. While this paper focuses on the benefits of using VE alongside HF methods, the HF team recognise that it is an emerging technology and as such there are inherent limitations**.** The HF team identified some further developments of the tool to strengthen the application of VR to HF assessments, for example, validating the anthropometric dimensions of Manikins used and validating operational and environmental assumptions not able to be directly captured within the VE software.

Furthermore, this case study demonstrates how the use of emerging technology can be used to derisk projects, evidencing the value which can be achieved through cross-discipline collaboration.