

The Digital Future of Human Systems Integration

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SUMMARY

Digital Engineering is becoming more recognised as system development is increasingly utilising more digital tools, and enhancing the use of the concepts of Digital Threads and Digital Twins. Human Systems Integration (HSI) needs to develop its place in this evolving digital engineering ecosystem, and therefore an understanding is required of how digital tools and workflows are developed to deliver enhanced HSI and Human Factors Engineering in the future. This paper initiates a dialogue on how the development of Digital HSI can be initiated and the necessary tools and workflows identified.

KEYWORDS

Human Systems Integration, Digital Engineering, Human Factors Engineering

Introduction

The media is full of descriptions of our digital future, from improvements in holiday bookings to AI taking over occupations. Although automated and potentially autonomous systems are developing at an increasing rate, there is a need to understand how the human integrates with such systems as they become increasingly complicated and complex, or rather how the system needs to integrate with the human(s) to deliver the required capability. Such systems are developed with a diverse range of digital tools that support the different engineering domains, e.g. mechanical, electrical, electronic and software. As an overall capability increasingly becomes a 'Systems of Systems', and the use of Modular Open Systems Architecture blurs the lines between the engineering domains (i.e. the systems are no longer disparate, but rather their performance is based on the interaction of multiple engineering domain sub-systems), the complicated / complex interaction between the multiple sub-systems necessitates the need for a way of understanding how the systems are designed and operate, particularly the integration of human(s) within the system.

From a high-level perspective, this paper takes a defence related perspective to examine the designs and development workflow from the initial capability requirement, through Mission Engineering (ME) and Systems Engineering (SE), and how the humans fit within a design process that involves the use of digital tools. Human Systems Integration (HSI) and Human Factors Integration (HFI) are well recognised processes that have supported HF in systems for a number of years with the use of Policy (JSP 912), Standards (DEFSTAN 00-251) and technical guidance held within the MOD DE&S HFI Management System (HuFIMS). As the digitisation of the design and assessment processes advance, a solution is required that effectively describes and illustrates the capability and functions of the human(s) within the system. This paper examines the future of some aspects of digitised HSI from a UK defence perspective, but is also applicable to the wider engineering community. The term HSI is used throughout the paper as if focuses on the human operating as an integral part of the system.

Digital Engineering

The term Digital Engineering (DE) is becoming increasingly recognised, an example being the establishment of the Digital Engineering Centre within the MOD DE&S organisation. Digital tools have been developing for a while, e.g. Computer Aided Design (CAD), Finite Element Analysis, etc., but there has more recently been a move to be more integrated. The increasing use of PLM (Product Lifecycle Management) software brings together multiple engineering artifacts, but this doesn't integrate the design process, rather the management and organisation of the product / component information. DE is typically associated with the development and use of concepts such as Digital Twins, Modelling and simulation, etc., with the aim of accelerating project delivery, at reduced risk, and often using a spiral development methodology.

As part of DE, there are lots of good digital tools, but they are typically disparate and need to be joined up with an effective workflow, allowing the movement of data and information through the project lifecycle, without losing important aspects of the design and functionality. An enhanced digital workflow should provide better integration of the different engineering disciplines, and specifically the HSI/HFE. The workflow(s) should also utilise the reuse of digital assets, e.g. standardised Digital Human Models (DHM) – utilising the appropriate anthropometry and adorned with the correct clothing and equipment.

The concept of the Digital Twin has proliferated, but has a multitude of definitions depending on the application. Relatedly, the concept of the Digital Thread may be a more useful term to describe the application of data and digital tools to provide the continuity of a concept from inception, through design and manufacture. Once a system is fielded and delivering data it may be defined as the 'digital twin' and deliver an effective through life support capability.

Mission Engineering

Mission Engineering (ME) has recently come to the fore, although it has existed in other forms for a while. Within the capability lifecycle it lives at the start, being involved with the high-level capability requirement, operational analysis, and concept. From a DE perspective, ME typically utilises sequence diagrams to illustrate the timeline of the proposed capability. The use of the sequence diagrams provides the opportunity to directly link to the Systems Engineering (SE) System Model (SysML) sequence diagrams. This use of sequence diagrams provides the facility to embed the human related functions within the capability, prior to embedding within the system design with additional detail.

Guidance on ME and the associated architecture has been developed by the US Department of Defense [2023, 2025], and the inclusion of HSI within ME has been highlighted in the recent development of an ME Competency Framework [Moreland, Irwin, & Baker. 2025] where the recommendations include;

'Ensure HSI Integration and Operational Context Early in ME Practice, Prioritize HSI and mission context, soliciting end-user input during early design and evaluation phases, and expand M&S tools to capture operator behaviour and intent.'

The proposed ME Competency Framework include the following HSI statement:

Human Systems Integration and Operational Context

Human Systems Integration (HSI) and operational context cognition are pivotal competencies in ME. These competencies ensure that mission systems are designed and implemented with the human operator in mind, accounting for

human capabilities, limitations, and broader operational environment in which these systems are deployed. By focusing on human capabilities and operational realities, ME strives to create systems that are not only technically advanced but also intuitive, efficient, and resilient in the face of human challenges.

Systems Engineering

The Systems Engineering (SE) V-model provides an established development process framework for the system design (recognised by the MOD DE&S), and the ability to understand and visualise the complexity of how the systems, and systems-of-systems operate. HSI is a recognised part of SE, as illustrated by the INCOSE HSI Working Group who hold regular workshops and conferences.

The SE SysML activity and sequence diagrams provide a method of visualising the system functionality. The diagrams typically have a limited representation of the human's role within a systems functionality, although more recently there has been work to address this. Within the SysEng process there are numerous digital tools that support the design activities, these include Computer Aided Design (CAD), Digital Human Models (DHM), requirements management, SysML, simulation (e.g. Finite Element Analysis, Computational Fluid Dynamics, etc.), synthetic environments, etc. These tools currently sit as disparate tools that are joined by human engineers. Model Based SE (MBSE) provides a framework for illustrating the human interaction within the system. This is a relatively new concept, e.g. the use of the SysML sequence diagrams for the HF task analysis [Dobbins et al. 2022], and is supported by a DE&S HuFIMS technical guide [2025].

Human Systems Integration & Human Factors Engineering

Human Systems Integration addresses a range of human related aspects, of these HFE may be viewed as being the domain most strongly related to SE. The increasing use of digital tools within the SE process means that HSI / HFE have no choice but to become digital, without which they will become increasingly left behind in the design process and importance hierarchy. In addition to HFE, the increasing adoption of automated / autonomous systems means that other HSI domains, e.g. Personnel, will be increasingly engaged as the end-users will need different skills from those needed to operate current/legacy systems.

For HF SRs to become integrated within the system design they need to have features, functions and performance that can be embedded within the digital system. These need to be recognisable and measurable. For example, the use of DHMs embeds the human operator within the CAD models where their space requirement is easily recognised and accounted for. Similarly human functions need to be embedded in the SysML sequence diagrams, in sufficient detail, so that they become 'real' and accounted for throughout the system design and assessment.

Currently DE appears to have limited application to the non-HFE HSI, although digital information management will play an increasing part of the overall capability, as well as the utilisation of digital products such as simulation for personnel talent identification and selection. But the development of tasks-specific simulation can utilise / re-use the appropriate functionality from the systems digital version.

Digital Tools and an Example Thread / Work Flow

An example of the use of digital tools within a design process is shown below in Figure 1. Currently these are mainly disparate tools, shown in red text, where information is currently manually transferred and translated between them to deliver the work flow.

also have the appropriate joint articulation to support the design of seating, reach to controls / handles, etc. Similarly, the DHM head and eyes provide the required vision envelopes for the design of windows and display screens.

It is essential that the file format of the DHM integrates seamlessly with the PA CAD software. Experience demonstrates that the advertised capability of file format translation software often does not work as advertised, leading to frustrations with ineffective/inefficient workflow.

HCI / HMI Wireframe

The HCI / HMI wireframes are developed from the HF Analysis, where the digital display / controls provide an interface to the system, supporting Situation Awareness, OODA Loop, etc. The wireframes may be built using software that is typically used for UI/UX. This may initially be relatively easy to use to build prototypes, but it may not effectively support the required workflow. The wireframe tool must consider the workflow into the subsequent process, i.e. the SysML Activity and Sequence Diagrams, and the Simulation / Synthetic Environment. Utilising Synthetic Environment software that includes the ability to model HCI / HMI functionality provides a seamless link between the wireframes and simulation, where an assessment of the system functionality can occur – providing progressive assurance evidence for the V&V process – inputting to the system requirement database.

Although digital representations of HMI / controls can be produced within the wireframes, it may be more appropriate to rapid-prototype physical controls to interact with the wireframes.

SE System Model

The SysML is often referred to as the Single Source Of Truth, of which the sequence diagrams provide an intuitive illustration of the system functionality, including the human tasks. The input of the results of the HF Analysis to the SysML embed the required HF functions into the system. This embedding importantly ensures that the human aspects have parity with other engineering requirements. An important workflow element is moving the SysML functionality into the Synthetic Environment. This is essential to ensure that the simulation-based assessments are using an exact replication of the SysML.

The linking of the HCI / HMI wireframes to the SysML is also important as the sequence diagrams need to replicate the functions the humans have via the HCI / HMI.

Computer Aided Design (CAD)

The CAD model(s) are most obviously recognised for the PA, but they also include physical aspects of the electrical and electronic systems. The integration of the DHM into the overall PA CAD model should follow an HCD process (e.g. ISO 9214-210, Human-Centred Design for Interactive Systems), where the system is designed around the human – both spatially and functionally.

A workflow requirement is for the PA / DHM model to be imported / integrated into the synthetic environment. Typically, the models won't be 'rigged' to articulate, and this needs to be added into the simulation. The importing needs to transfer only enough PA detail to effectively operate the simulation. There is a lot of detail in the PA model that is not required for the simulation, e.g. connectors, nuts & bolts, welds, etc.

Simulation – Synthetic Environment

The system functionality, embedded in the SysML and the sequence diagrams, is transferred and replicated in the simulation / synthetic environment – this is currently a laborious manual task, with

the inherent risk that errors are made in the coding of the system functions within the simulation. The ability to export the SysML functionality directly into the simulation is essential.

Whilst the synthetic environment provides the digital recreation of the system and the environment it is intended to operate in, the assessment of the system functionality requires both physical and digital interfaces for the human(s) in the loop to interact with. Physical interfaces may utilise real / COTS interfaces, if not, new interfaces need to be designed and produced – this may be via the use of rapid prototyping, e.g. 3D printing.

The assessments undertaken using the simulation provide progressive assurance against the SR compliance Measures of Performance – feeding the results into the Requirements Management Tool.

The simulators also provide the first step to the development of the systems training capability. It may also provide crew training for de-risking the assessment on the first prototype systems / platforms, as well as informing the training capability SRs.

A Future View of Digital HSI

The description above of HSI related digital tools and their use in a design / development process illustrates both the opportunities and requirements to effectively undertake HSI in an increasingly digital engineering ecosystem.

To start this digitised journey, a definition of Digital HSI needs to be established, but recognising that HSI is a multi-factorial concept, and therefore work is required to establish a roadmap to help set the direction of travel. This starts with agreeing where we are now, identifying the actors within the ecosystem that capability-development and HSI operates in, and developing a plan for the future development roadmap. This paper may be considered to primarily focus on the HFE domain, but it does subsequently link to other HSI domains such as training and aspects of personnel.

Questions regarding this development, and directions of travel include, but are not limited to:

- How to improve the representation of the human within the SysML, with an improved ability to understand / visualise their role and tasks / activities, and therefore identify the capabilities required, particularly in relation to increasing automation/autonomy – e.g. situation awareness, decision making, human-machine teaming, etc.
 - Is this providing a better representation of the human and their functions/actions within the system? This could be achieved by providing more detail within the SysML Sequence Diagrams.
- How to improve the effectiveness of the digital thread – how are the digital tools linked so the design ‘flows’ through the process.
 - Software programs may have successfully operated as standalone tools, but today they need to operate within a larger ecosystem that allows data to seamlessly flow between tools, without losing any of the relevant details.
 - Vendors of suites of software tools may suggest that this is possible, but this results on ‘lock-in’ situations that may not / doesn’t deliver the required outcome.
- The ability to link the SRs and their compliance MOPs to the system design.
 - Currently this is a manual process, but if the system was able to understand its target performance, then this would support an enhanced iterative design process.

- The effective use of simulation to visualise and test the system, at all points of the design process, potentially providing a foundation of the system Digital Thread.
 - The use of human in-the-loop simulation is typically used towards the end of the system design process. It's use at the start of the process, i.e. to visualise the ME Sequence Diagrams will speed up the development process as the simulation can enhance the workflow with the different tools providing increasing fidelity as the maturity of the design increases.
- Improve the ability for active feedback loops within the system design, rather than having to manually follow the consequences of changes through the system.
 - This requires the digital tools to have a greater level of integration and an understanding of how the consequences of any changes cascade through the overall design.
- Improve the ability to identify the unintended consequences of design decisions early, i.e. have a better understanding of the holistic design of how the different pieces (sub-systems) fit together.
 - Some SysML software has the ability for emulation and can identify where flows through the activity and sequence diagrams don't work. The ability of the overall system to deal with multiple tasks (this may be via the interaction of multiple operators using multiple sub-systems) can be difficult to assess, particularly within a dynamic environment.
- Develop a roadmap for digital HSI. This is a multidisciplinary endeavour, e.g. HSI / HFE and SE SMEs working with the digital tool (software) developers to ensure the tools are fit for purpose, and provide the required digital thread with an efficient workflow.
- Reduce the barriers to entry for the use of digital tools and cross-disciplinary working. Some examples of this includes:
 - HSI / HFE SMEs need the ability to read, edit and produce SE SysML Activity and Sequence Diagrams.
 - PA CAD engineers need to understand how to manipulate DHMs appropriately within their platform/system models. Likewise, HFE SMEs need to understand the design constraints that the platform designs are working to (e.g. overall size constraints).
 - Simulation / Synthetic Environment builders need to be able to read and interact with SE engineers so that the SysML functionality can be effectively translated into the simulation.
 - Digital tools are often expensive and beyond the budget of smaller companies / projects. This also makes it difficult for new engineers to access the tools to become proficient in their use.

Conclusion

This paper describes the current situation regarding systems design, HSI, and the use of digital tools. It then highlights aspects of how HSI / HFE needs to move into the digital realm to engage in the development of digital threads and digital twins. Considering the digital tool workflow requirements, the greatest need is the ability to seamlessly link the SysML with the Simulation /

Synthetic Environment, i.e. the ability to transfer the Sequence Diagrams functionality to the simulation.

The paper should initiate and facilitate the dialogue to develop the concept of Digital HSI. It is expected that numerous aspects will be challenged, and new digital tools and workflows developed.

This paper has purposely not considered the use of AI within the development process. It is recognised that it will undoubtedly be utilised, as it already is in some aspects of system design. There will no doubt be a lot of marketing suggesting that AI can revolutionise the process, but we need to ensure that it is capable of achieving these claims and how it fits within the workflow of digital tools to deliver effective HSI.

References

- Dobbins, T., Meeks, R., Hespley, M., Howe, S. & Garland, K. (2022) Task Analysis Within the System Model - The Single Source Of Truth. Conference Proceedings; Ergonomics and Human Factors 2022. Chartered Institute of Ergonomics and Human Factors (CIEHF)
- Department of Defense (2023). Mission Engineering Guide. Version 2.0.
- Department of Defense (2025). Mission Architecture Style Guide. Version 1.0.
- Moreland, JD, Irwin, T, & Baker, R-A (2025) Mission Engineering Competencies Workshop: Roles, Responsibilities, and Skills. Centre for Mission Engineering (CME), Old Dominion University. <https://doi.org/10.25776/5tvq-2h29>
- MOD DE&S (2025) Human Factors Integration & Model Based Systems Engineering. Technical Guide 11.4. Version 1.