Human Machine Teaming and Human Centred Design

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ABSTRACT

Human Machine Teaming (HuMaT) systems are expected to become increasingly important and common in the UK military domain as a result of changes in both technology and the Battlespace; however the role of the human user is expected to be retained, though it may change. HuMaT systems are sociotechnical systems where needs and behaviours may be emergent and hard to predict from previous systems behaviours, therefore framing formal requirements prior to design can be difficult and sometimes counterproductive. The complex and variable nature of interactions within Human Machine Teams (HMT) means that traditional technology centric design processes do not easily support them, if the best use is to be made of both human and technology actors then a process more focused on user goals and constraints is required. This paper outlines the considerations for applying a Human Centred Design (HCD) process to developing HuMaT systems and how HCD addresses the challenges presented by a technology centric process.

KEYWORDS

Human Machine Teaming, Human Centred Design, Weapon System, Design Process

Introduction

Robotic, Intelligent and Autonomous Systems (RIAS) and other AI are expected to become prevalent in the Battlespace in the coming decades, driving down response times and increasing the amount and type of data to be managed while still requiring human inputs into complex yet robust decision making (DCDC JCN, 2018; Lele, 2009). Human Machine Teaming (HuMaT) is a response to such changes providing the most effective way of managing them and delivering objectives within challenging operational environments. This paper is concerned with the implications that this move towards HuMaT will have for the design process, in particular for how high risk systems within the UK Defence Domain are designed, developed and evaluated. It considers the implications of the formal implementation of Human Centred Design (HCD) for Military HuMaT systems, i.e., a mix of people and technology, whose combined actions might result in the use of lethal force. It is assumed that human actors will hold final authority in all such instances. However, many of the issues raised will also have relevance to other systems where the possibility of lethal outcomes are not a factor in design.

A Human Machine Team (HMT) has both humans and technology based systems working together to deliver a common set of goals and supporting effects. The difference between more conventional technology and human operator control based relationships is that in HMT both the users and technology are considered to be, and treated as, ‘agents’ or ‘actors’ within the team (Figure 1), both with an ability to act with a level of autonomy, and who work collaboratively with interdependence.

The move towards HuMaT is driven by current and expected changes in the operational environment and the factors that shape it (DCDC JCN, 2017; 2018). These changes are in part a result of developments in the technologies deployed, their capabilities, and the options and risks they introduce (Lele, 2009). It is in these circumstances that system risks rise and human oversight becomes more pressing, often with the human operator being the 'last minute decider' making complex and high risk decisions in short timescales sometimes from a position of relatively low situational awareness.

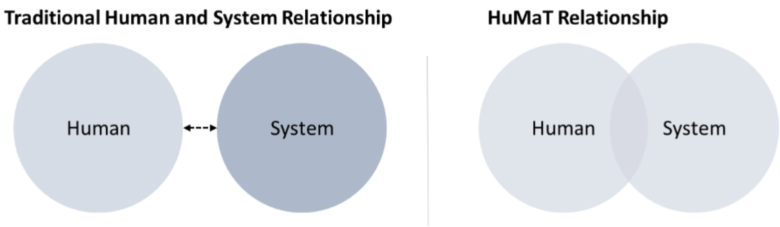

Figure 1: Human and System relationship vs. the envisaged relationship in HuMaT.

HMT are essentially sociotechnical systems (Badham et al., 2000; Appelbaum, 1997) where technologies rarely deliver their potential if they run contrary to, or fail to 'fit', the 'socio' systems they are embedded in. They measure success and failure by the degree to which the team achieves its goals and avoids undesired outcomes rather than by meeting some static performance or technology based requirement (Baxter, 2011). Most pose challenges for conventional design models in that they are usually complex, interconnected and responsive in ways that technology based systems rarely are; the socio context coupling the technology to a wider system that is generally dynamic with a range of possible behaviours in any context (Baxter and Sommerville 2010, Sommerville, I, 2004). As a result they, like HuMaT:

- often exhibit non-linear behaviours,
- have emergent behaviours and properties that may prove to be key factors in their performance,
- seek flexibility and responsiveness rather than efficient repetitive activities,
- may involve significant numbers of implicit assumptions,
- are connected in complex ways that mean optimisation of one element without regard for the others may damage overall team effectiveness.

All of which have the capacity to radically change assumptions about what is needed from military systems, what behaviours they must accommodate, how they must support human actors and how they are deployed and used. As a consequence, new scenarios, new roles and types of use are likely with each one resulting in challenges for the design process both in terms of what activities are included and when and how the process is managed.

HuMaT and the Design Process

Historically the acquisition process within the defence domain has been technology centric utilising a waterfall engineering process. Though HCD techniques have been used, often extensively, the background has remained one with a concentration on equipment and the associated formal requirements that were often derived when the context of use was still uncertain. In such cases configuration of the 'system' when deployed is seen as stable and any changes are managed to minimise disruptions and unpredictable behaviour, this may result in a focus on what is considered the usual rather than the exception. As a result, the conventional process tends to act to limit flexibility and capacity for change, both in terms of the design process and the resulting roles of the human and technology actors. The well scoped and predetermined parameters, and the assumption of stability, allow little room for the frequent and rapid re-configurations that may be required in a sociotechnical system and that forms a characteristic of HuMaT (DCDC JCN, 2018).

This is particularly the case where the design cycle requires the early agreement of formal requirements and where most design and verification activities are focussed upon satisfying them. Such a process does not readily accommodate the emerging needs and context driven nature of HuMaT as it tends to lead to:

- a concentration on the early derivation of requirements, often before the context, problem space, and the user roles in it are fully understood, these are then captured in a contractual document making them hard to change,
- a rigid flow of those early derived requirements into design irrespective of the degree of knowledge and uncertainty at the time the requirements were derived,
- difficulties in adapting to conflicting information that emerges from consultations and other stakeholder inputs later in design that might challenge the requirements set, and
- the discarding of preliminary and early development work undertaken as part of research and exploration of user needs.

This in turn shapes expectations about the HMT relationships and shared actions and goals that may not be valid and which are not sufficiently tested.

It can also have implications for expectations and assumptions about the roles and responsibilities involved. This includes the skills that may be present and where and how the actors interact with others inside and outside of the team, including the wider organisation it is embedded in (Appelbaum, 1997). Some of this has been known for some time (Mumford (1983), Norman (1993), Eason (1997), Suchman (1987)), and more recent work has elaborated it (Baxter and Sommerville 2011).

The sociotechnical nature of HuMaT needs a process that is exploratory and flexible, that can cope with the associated uncertainty and related progressive shaping of requirements, primarily but not exclusively lower level requirements, and iterations of design. This requires far more of the design process to be dedicated to understanding the non-technical elements of the overall system, including the operational environment, the context of the goals and related tasks, the range of actors in the team and the social and communication dynamics involved.

The configuration of the team, and how tasks and responsibilities are allocated within it, are determined by the operational context and related factors such as doctrine, resource availability and appetite for risk. However, the objective of HuMaT remains consistent regardless of configuration or context; that the human and technology actors work in a collaborative manner, (DCDC JCN, 2018). In this context the role of the operator relative to the control loop becomes ever more sensitive to faulty assumptions and gaps in knowledge. As a result, more effort and time within the design process needs to be allowed to develop an understanding of the social structures, the context of use and its drivers and constraints. Such a process would have implications for the relationship between concepts, design and development and the degree to which design activities can proceed in a linear fashion. It also has consequences for the level of priority and resource granted to the various activities during the process of design and development. However, the relationship between a sociotechnical design process and specific design activities and outcomes is very involved and a detailed discussion of it is necessarily excluded in a paper of this length.

One of the most significant considerations will be assurance and verification, because an agreement between developer and customer of a systems' fitness for purpose will still be required. However, if requirements emerge as design progresses then traditional planning for formal verification will need to be revised. If the process places less emphasis on formal requirements, then the concept of a verification phase of design can be questioned and new approaches to acceptance will have to be agreed, not least because of the increasing importance of the concept of trust between the human and technology actors.

Given the desired ‘partnership’ of humans and technology within HuMaT it is not surprising that one of the important themes in forward looking strategy and doctrine initiatives, (DCDC JCN, 2018), is how much the human actors, and our society, are prepared, able and willing to trust machines/systems. Too little trust leads to delays and a level of risk aversion that may prevent objectives being met, while too much trust leads to bias that can result in very significant errors and failures of oversight. The development of trust is complex involving a range of factors (Hoff and Bashir 2015), too complex for discussion here, but trust without bias is essential for effective HuMaT. Where bias is a possibility then it needs to be understood, justified, and accepted as tolerable, not doing so risks delivering systems that are vulnerable to errors particularly where ambiguity or uncertainty levels are high. SME comments made during our HuMaT research suggested that stakeholder trust in complex systems, rather than reliance upon them, is best developed through experience including that gained during the design process; this latter allows the development of an understanding, and discussion, of strengths and weakness in the system while change is still possible.

In HuMaT design human operators and their goals need to be at the centre of military systems development with every technical decision being taken in the context of the goals, activities and relationships of the overall team, while retaining a fluid approach enabling the process to re-focus and reconfigure as these mature or change. This requires a design approach that is holistic, considers all conditions and the interactions between technology and human actors as well as human to human interactions, and gives them equal weight. After an initial review of possible models, it was considered that Human Centred Design was most compatible with UK military customer needs and preferences, however other models may be preferred for HuMaT in different domains.

Human Centred Design

ISO 9241-210: 2019 describes the HCD process. HCD is not a new process, and is described within the mandated Human Factors Integration process used within UK defence, but its use has been within the context of a design process that has remained largely technology centric and linear. This is in part because of the nature of the systems themselves, i.e., systems with the capacity to enact activities involving lethal force. The emergence of HuMaT requires its role and implementation, be reviewed.

The HCD process may vary with the size, scope and nature of the system but it has three defining characteristics, all of which fit well with the needs of HuMaT;

- frequent consultation, with an early and on-going focus on users,
- an empirical approach involving measurement,
- iteration.

Here development is cyclical rather than linear with iterative cycles of research, design, test, measure and redesign being its key pillar, (Maquire, 2001; Preece et al., 2002). This allows faulty assumptions to be teased out and errors spotted and corrected before a significant investment has been made in an inappropriate design. This is particularly necessary in HuMaT where:

- assumptions drawn from current systems may no longer be valid,

- assumptions regarding the re-use of equipment and processes may be untested or unjustified,
- the configuration of the team may change regularly,
- the roles of the various agents may be context dependent and subject to rapid change,
- the stakeholders may be drawn from different groups, dispersed, and using different support systems.

Possibly the most important characteristic of HCD for HuMaT is that all design decisions are taken in the context of both individual users, the whole HMT and the context of use. Keeping this context in mind can be difficult and some of the tools of HCD aim to support this awareness as well as exploring how the resulting system might be used.

In HCD, stakeholder response to the emerging design and the information that underpins is measured from early in development with stakeholders being consulted and their response captured and documented for comparisons with later iterations. This input is usually based on the outputs of interactions with simulations and prototypes of design when they are available and always before the design concept has been finalised.

The use of HCD does not preclude the assumption that user needs, goals and activities are capable of being characterised at the start of design, or that they can be described even where they are complex. HCD methods have previously been used in situations where some level of formal requirements have already been determined and where assumptions around goals, needs and context are broadly stable. In any HCD, some of the user and stakeholder needs identified may be formalised as traditional requirements and will need to be managed as such. Even for HuMaT, it would be expected that a number of system level requirements derived from known goals and needs would be agreed prior to design and would remain broadly stable.

In HuMaT systems, the HCD process would be expected to start in concept or pre-concept phases therefore before any formal requirements were agreed, though a need and associated goals will have been identified and articulated. In addition, high level, generic, requirements for complex HuMaT systems can be identified, however these concentrate on the key needs and dependencies of a HuMaT system and should be tailored for each specific development. This refining of generic HuMaT requirements can fit within a HCD process as part of regular design iterations.

It may be that the number and nature of formal fixed requirements for a system will decline in a HuMaT scenario with more requirements emerging as a result of the HCD process itself, particularly lower level requirements. This is inescapable with HuMaT, where many features of the 'need' emerge as exploration of systems structures and possibilities are progressed. Where HCD is used there must be a willingness amongst the design team and customer to revisit and refine the proposed solution and the underpinning requirements frequently. Some of the 'needs' identified and captured as part of ongoing user consultations and engagements may not be translated into formal requirements at all to save effort and time. In these cases, 'emergent' requirements, whatever they are named, will need to have the same status or 'authority' as formal requirements.

This shift in how requirements are derived and managed in a HCD framework are likely to result in changes to the validation and verification process, but this should not be taken to mean that formal verification isn't required. However, verification of requirements, and the acceptance of the related design, may form a part of the iterative process rather than being a separate activity occurring once design is considered to be completed.

Moving away from the familiar technology centric waterfall approach to a full HCD process is in many ways a cultural as well as a process change, bringing new activities and changing the priority of others, introducing the requirement for new skills and perhaps resulting in the need or wish to deploy systems incrementally. Therefore, it is important that both the supplier and the customer understands the implications of doing so, and also the consequences of not doing so.

HCD Methods and Tools

While elements of HCD, particularly those such as task and use case analysis and those used in managing user and stakeholder involvement, have been used extensively in system development in defence, it is less common that all groups of stakeholders have been true participants in an integrated systems development process. In many instances, the use of HCD methods have been focussed on the 'how's' of interaction, primarily through the design of the Human Machine Interface or the physical characteristics of the equipment. As a result, user involvement may have been restricted to:

- small formal inputs into the development of a technology centric system, often made in design reviews or similar scheduled events,
- collecting SME and user comments on a specific design,
- embedding a single user, or small number of users, in the design team, which risks eroding their domain understanding and identification with the user community.

It should not be assumed that the development of a system used to plan or enact actions involving lethal force can be developed in exactly the same way as one that is not safety critical. In the defence domain, the balance of risk and the challenges and constraints of the operational environment are very different to many commercial systems and has consequences for the design process. This is particularly the case in HuMaT systems, where RIAS and other AI are drivers, though these may be considered equivalent in some scenarios. As a result, the use of HCD techniques will need to be modified to accommodate a context where:

- the negative consequences of undesired outcomes are such that the possibility of error needs to be minimised and safety consideration are considered paramount,
- system assurance and verification will need to be robust and rigorous,
- user skills are variable and functions (and possibly goals) may move between user and user groups,
- some actors in the HMT are technology based systems,
- goals are broad/unstructured and where the scope may be determined by factors not yet identified,
- goals may be met by a shifting range of methods (effects) and desired outcomes may change rapidly, and
- the goal itself may change with a context that cannot yet be defined.

The above, and the nature of the specific context of HuMaT, will have implications for the HCD tools used, how and when they are deployed, and for the number and type of stakeholders that need to be included. In addition, far more attention will need to be given to infrequent and exception events as it is at the edges of predictability, when ambiguity becomes more probable than certainty, that system performance starts to fail and humans need to take control.

Therefore, the HCD approach adopted needs to be able to address the levels of uncertainty seen in the developing operational context and the variability seen in HuMaT, and to better encompass situations that users have not yet experienced and may only experience infrequently. This may require the involvement of a wider range of stakeholders and consideration of more marginal and complex scenarios than has been the case in the past. This raises a number of questions around:

- the degree to which conventional HCD as it has previously been used can support the design and development needs of HuMaT,

- the implications of not using it,
- which of the HCD tools currently available are best suited to the emerging conditions and design processes, and
- the implications of using a HCD tool that has a poor ‘fit’ to the context or complexity of the situation.

HCD methods are focussed on four things:

- understanding stakeholder goals,
- exploring the relationship between the goals and the supporting effects, tasks and activities,
- investigating how design can support both goals and the associated tasks, and
- evaluating the degree to which a proposed design provides the required level of support.

However not all HCD methods fit well with the design of HMTs for the UK defence domain. Our review of the needs of HuMaT developments and analysis of these against the main attributes and outputs of HCD tools, undertaken as part of other projects related to HuMaT and Operational activities, suggests that the HCD methods with a role to play are likely to be Cognitive Work Analysis (Bisantz & Burns, 2008 and Vicente, 1999.), Ethnography (Robson, 1993; Siverman, 2004), Goal Modelling (Preece et al., 2002), Personas (Maquire, 2001), Prototyping (Maquire, 2001), Scenarios (Gould et al., 1985; Preece et al., 2002; Alexander & Maiden, 2004), Task Analysis (Annett & Stanton, 2000; Naikar, 2013), Use Case analysis (Alexander & Maiden, 2004), and User Engagement (Robson, 1993; Preece et al., 2002). Most require specialist skills and practitioners with significant experience to make best use of them. Some HCD tools, such as use case and task analysis, can be used by less experienced people and those with more general expertise under supervision, but others such as Cognitive Work Analysis, Persona and Scenario development, User Engagement and Prototyping require Suitably Qualified and Experienced Person (SQEP) from Human Factors and Operational Analysis.

The way HCD methods are integrated into the design process may also need to be adapted for HuMaT. The timescales involved in developing an understanding of specific HuMaT context and the demands made on the supporting systems may have implications for how HCD, and wider design, is practiced. It may become necessary for some design activities to take place, at least in part, outside of the ‘project structure’ and to be developed in a more generic cross project manner. This ‘generic’ form of HuMaT understanding could be developed to support knowledge bases and design options servicing more than a single capability. In this case scenario based designs might be developed reflecting broad goals and objectives that can be tailored and incorporated into suitable capability based projects.

In response to a growing need in defence for more responsive, flexible and faster system development, we are now seeing a shift towards spiral development and agile engineering. Within ‘agile’ there is less of an emphasis on requirements and development is broken down into segments or ‘sprints’ the output of which is put before the ‘product owner’ who may be a user, other customer stakeholder or another member of the development team, for comment, before any further development or design work is attempted. This approach seems to be more aligned with HCD principles and may allow the two processes to be used together. If this can be achieved, then there is potential to reduce development timescales and unproductive design activity and to better manage risk and trap errors progressively.

Summary and Conclusions

HuMaT systems are expected to become increasingly important and common in the military domain as a result of changes in both technology and the Battlespace; however, the role of the human user is expected to be retained, though it may change. Increasingly human actors within HMTs will act as risk managers whose role may involve intervening at short notice when unexpected events occur, when Battlespace constraints require it, or when the technology actors involved are operating at or beyond their confidence limits.

HuMaT systems are sociotechnical systems where needs and behaviours can be emergent and hard to predict from previous systems behaviours, therefore framing formal requirements prior to design can be difficult and sometimes counterproductive. The complex and variable nature of interactions within HMT means that traditional technology centric design processes don't easily support them. If the best use is to be made of both human and technology actors, and their weaknesses be minimised, then a process more focused on user goals and constraints is required

HCD is probably the best suited to the development of sociotechnical systems, including HuMaT, as it has both the range and flexibility to cope with team based systems where requirements may not be determined and where emergent properties and behaviours can be expected. However, moving away from a techno-centric design process requires that both developers and customers understand the changes in activities, priorities and resourcing this involves and are willing and able to support a process that can feel unstructured and undisciplined to those who are unfamiliar with it. However, using HCD in a domain where the outcomes of undesired actions and inadvertent events may well be unacceptable is likely to require some modifications to the processes and expectations that have been common in its previous use.

There is a wide tool set already developed for use within HCD, and though not all of them fit well with HuMaT there is a sub set that supports its needs, or can be adapted to do so.

HCD also fits with agile processes and so may help reduce development timescales by allowing design and verification activities to proceed in parallel, reducing timescales to develop and deploy systems.

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