Capturing Variability in Human Capability in Mission Models for Human Autonomy Teams

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ABSTRACT

Autonomous functions are rapidly making their way into all stages of human problem-solving. As a matter of fact, they can easily be envisioned as independent and equal team-members in a plethora of domains within the foreseeable future. The Human-Autonomy-Team (HAT) is a concept for describing collaboration between human operators and machine-based elements – a paradigm-shift in which machines no longer are mere tools, but rather helpful partners in complex problem-solving. HAT has gained attention in the defense domain where research efforts are spent on a wide spectrum of perspectives. This paper presents work-in-progress and sets out to investigate how to prepare for models that can describe the dynamics between humans and autonomous systems by introducing reliable approaches to modelling the inevitable variability in human capabilities. The ultimate goal is to enable mission autonomy, which involves agent-agnostic, independent decision-making in dynamic, operational environments that are challenging to predict. In other words: this work aims to lay the foundation for planning the unplannable through effective models.

1.0 INTRODUCTION

The integration of Human Autonomy Teams (HATs) is transforming defense industries by combining the strengths of human operators with the advantages of autonomous systems. AI and autonomy are enabling a change in the role of machines from mere tools into versatile team members. To achieve the full potential of HATs, the work presented here argues that it is crucial to account for the variability in human capabilities within mission planning and execution. Therefore, this paper delves into the vast task of capturing variability in human capability within mission models for HATs. The aim is to initiate the exploration of how mission models can adapt to cognitive, physical, and emotional variability among human team members, with the objective to contribute to enhanced performance, safety, and adaptability. This analysis aims to contribute to the development of mission models that are robust and effective in diverse operational contexts based on strong teaming between human operators and machine-based agents.

To say the least, human behavior is notoriously challenging to model and simulate in algorithmic and computer-based environments due to its unpredictable nature [1]. It is worth noting that fact as this work ultimately strives to treat any member of an HAT in an agent-agnostic manner, i.e. to have the capacity to disregard of whether the team-member is human or machine-based. Therefore, this research is in the midst of formulating capability-centered models to describe team-members, rather than deriving capabilities from assumptions of the agent-class. Subsequently, one of the main challenges include finding an approach to modeling necessary elements of human input such that it is useful without being neither prohibitive nor too coarse. Modeling and simulation of HATs is considered a key capability for future defense systems [2] and current literature indicates its significant impact on competition in the defense sector overall [3].

1.1 Human Autonomy Teams

HATs represent a fundamental paradigm in contemporary human-machine collaboration, where humans work alongside autonomous systems to accomplish complex tasks and missions. The core attribute of HATs is the combination of human involvement as part of independent autonomous functions through collaboration on compound missions. This concept has been around since the 1990's, but has gained more attention since the late 2020s', as suggested in a comprehensive literature study on the topic by O'Neill et al. [4]. O'Neill et al. also discuss the challenges in the delineation of HATs, as there seems to be a lack of a commonly accepted definition in academia and industry. However, there are several sources that address the topic as such, and e.g. Rich and Sidner [5] have written that "We take the position that agents, when they interact with people, should be governed by the same principles that underlie human collaboration", which suggests a shift in the underlying assumptions of the roles of machines.

A distinct starting point for the work presented here is that HATs involve human participation as integral team members and collaborate with autonomous systems, contributing with unique cognitive and decision-making abilities. Autonomous systems and independent functions, which may include robots, drones, or AI-driven software, operate alongside humans to perform tasks autonomously or semi-autonomously. Further, HATs are assumed to emphasize collaboration between humans and autonomous systems as near equals, though humans are given priority as authorities. These entities share information, responsibilities, and tasks to achieve common objectives. In addition to that, HATs are intended here to typically be tasked with complex missions or objectives that require a combination of human and machine capabilities, such as search and rescue, space exploration, or medical procedures – although this work is limited to aerospace and defense - that ideally draw on the strong suits of each team-member class.

1.2 Significance of Human Autonomy Teams

As suggested above, HATs leverage the strengths of both humans and autonomous systems. Humans are presumed to provide cognitive flexibility, creativity, and ethical decision-making, while autonomous systems offer precision, endurance, and data processing capabilities. In high-risk environments, HATs can help mitigate human exposure to danger. Autonomous systems can perform tasks that are hazardous to humans, such as bomb disposal or disaster response. In addition, HATs can potentially enhance task efficiency and productivity by combining the rapid processing capabilities of machines with human judgment and adaptability. Another vital theme is that of scalability as there is potential in scaling up HATs to adapt to mission complexity. To address this task, additional autonomous systems or human team members can be integrated to meet changing requirements.

1.3 Research Objectives

The primary research objective presented here is to define methods for and initial results of capturing variability in human capability within mission models for HATs. Addressing human capability variability in mission planning for HATs is arguably of critical significance, as it directly shapes mission success and adaptability in complex, dynamic environments. Recognizing the diverse cognitive, emotional, and physical capabilities of human team members and their interactions with autonomous systems allows for tailored task allocation, optimized human-machine collaboration, and the flexibility to adapt to evolving mission conditions. This approach is anticipated to enhance mission outcomes while ensuring that HAT systems remain agile and responsive, which are deemed crucial attributes in achieving success in defense and autonomous mission contexts. A secondary objective is to address the limitations of modeling and simulation techniques available today to capture the dynamics between humans and machines in an HAT. As such, an interesting question becomes: How can models describe HAT missions for planning and execution such that they capture the complex nature of unpredictable environments and creative, agent-agnostic, problem-solving?

2.0 DECISION-MAKING UNDER PERFORMANCE VARIABILITY IN AGENTS

There are intricate challenges and strategies associated with decision-making on all the various temporal levels of military ordering under performance variability in agents. As agents – both humans and computer-based - encounter dynamic and uncertain environments, understanding how they adapt and choose actions becomes essential for their successful deployment. Through exploration of the underlying principles and methodologies, with subsequent modelling, this work aims to shed light on the mechanisms that enable agents to navigate the complexities of performance variability and make informed decisions.

2.1 Performance Variability

2.1.1 Cognitive Variability

Effective decision-making is a cornerstone of mission execution within HATs. Cognitive factors, such as information processing, risk assessment, and cognitive biases, significantly impact the quality and timeliness of decisions. Team members' ability to make sound decisions collectively influences mission success, and deviations from optimal decision-making processes can lead to mission failure. In HATs, cognitive variability among human team members adds a layer of complexity. Variations in cognitive styles, expertise levels, and the ability to manage information may lead to divergent decision preferences and strategies within the team. Recognizing and accommodating this variability is arguably pivotal, as it enables mission planners to leverage diverse perspectives and expertise, fostering more robust and resilient decision-making processes. Furthermore, understanding and monitoring cognitive variability can help identify potential decision-making bottlenecks and vulnerabilities within the team, allowing for targeted training and support interventions to mitigate risks.

2.1.2 Emotional Variability

Emotional variability is also part of the holistic human capability within the context of mission planning, encompassing elements such as stress, resilience, and motivation. These factors add to the cognitive landscape that may significantly impact the effectiveness of mission execution. A significant amount of literature on Human Factors indicates how stress levels, emotional resilience, and motivation dynamics influence human operators' decision-making and performance, e.g. [6], [7] and [8]. As an example, stress may impair cognitive function and lead to suboptimal decisions in high-pressure situations, as argued by Clayton et al. [6]. Conversely, emotional resilience and motivation may act as force multipliers, bolstering an operator's ability to overcome challenges and maintain mission focus.

Furthermore, emotional variability has direct implications for mission outcomes and team cohesion within HATs. The emotional state of individual team members can arguably influence their interactions, collaboration, and overall effectiveness, which is further discussed and modelled below. Eduardo et al argue for how a team composed of emotionally resilient and motivated members may exhibit higher levels of cohesion and adaptability, potentially leading to more successful mission outcomes [9]. Conversely, fluctuations in emotional states, such as heightened stress, can undermine teamwork, communication, and coordination, thereby impacting the mission's overall success, as suggested by e.g. Shouhed et al [10]. Hence, understanding emotional variability and its interplay with mission planning ought to be included in developing strategies that harness emotional strengths while mitigating emotional vulnerabilities,as argued by the author. By considering emotional and cognitive modeling and adaptive mission planning techniques, mission planners would possibly better equip teams to handle the challenges posed by HATs, ultimately aiming to improve mission outcomes and team cohesion.

2.2 Cognitive Factors and Decision-Making in HATs

Decision-making within HATs involves a complex interplay of cognitive factors that significantly influence the outcomes of missions [11]. These cognitive factors encompass various aspects. First and foremost, information processing is fundamental. HATs rely on the assimilation and processing of vast amounts of data and information from both human team members and autonomous systems. Effective decision-making hinges on the team's ability to sift through this information efficiently and identify the most relevant and actionable data. Secondly, risk assessment plays a role in the ability to determine consequences of actions. Given the diverse and dynamic nature of missions, risk assessment is a critical cognitive factor. Team members must evaluate potential risks associated with different courses of action and make informed judgments about the acceptable level of risk, especially when human safety is at stake. Further, cognitive biases are also necessary to consider. Human decision-makers are susceptible to cognitive biases, which can distort their judgment and lead to suboptimal decisions. Recognizing and mitigating these biases is crucial within HATs to maintain objective and rational decision-making, as implicitly suggested by Krausman et al. [11].

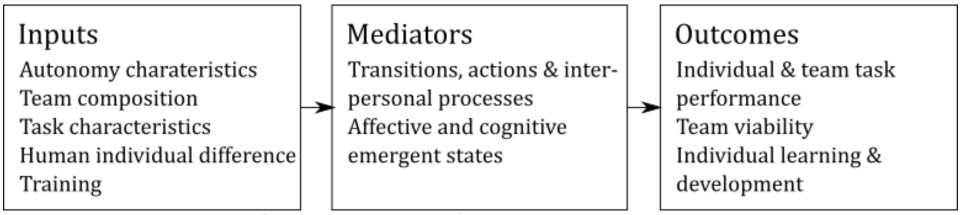

Figure 1 Central elements for Human Autonomy Teaming

O'Neill et al. [12] conclude that tasks included in HAT research typically are of the action variety. In contrast, tasks involving transition- and interpersonal-related processes are rarely considered (e.g. strategy, goal selection, conflict, motivation). However, they have large significance for human performance, as argued above. It is arguably suitable to model interpersonal processes separately, such that they can be independently tuned and evaluated when introducing their dynamics into HAT mission models. Figure 1 illustrates an initial suggestion of how to consider such processes as mediators between inputs and outcomes of tasks carried out by HATs in greater mission contexts.

2.3 Decision-Making Models in HATs

To better understand how decisions are made within HATs, various decision-making models are applicable, among which the Rational Decision-Making Model, as presented by e.g. Uzonwanne [13], and the Recognition-Primed Decision (RPD) Model, as presented by Klein [14], are two alternatives. Literature on using these models in the context of HATs is scarce, however, this research has initiated experiments to evaluate their effectiveness.

The Rational Decision-Making Model prescribes a systematic and logical approach to decision-making. It involves identifying the problem, generating alternative solutions, evaluating each solution's pros and cons, and selecting the most favorable option. While this model provides a structured framework, it may not always align with the fast-paced and dynamic nature of missions in HATs. The model assumes that objectives are clear and well-defined, that information is complete and accurate, and time and resources to evaluate all the possible alternatives and their consequences is unlimited [13]. This suggests that the framework may be useful for the planning stage at a high level in the temporal levels of mission ordering, and its application will be investigated further for those purposes.

The Recognition-Primed Decision (RPD) Model recognizes that in real-world scenarios, individuals often make decisions rapidly based on pattern recognition and intuition [14]. In HATs, where time is often limited, team members may rely on their expertise and experience to intuitively recognize and choose effective solutions. This model acknowledges that decision-makers draw upon their past experiences and knowledge to make sound judgments quickly and is therefore considered for possible applications in future research of this work for real-time instances of a mission model for HATs.

2.3.1 Notes on Collective Decision-Making in HATs

Effective mission execution within HATs depends not only on individual decision-making skills but arguably also on the team's ability to make collective decisions. Team members must communicate, share information, and reach a consensus on critical decisions. Factors like hierarchy, communication protocols, and information sharing mechanisms play a central role in ensuring that the decisions made by HATs are cohesive and aligned with mission objectives.

2.3.2 Notes on the Implications of Suboptimal Decision-Making

Deviations from optimal decision-making processes can be foreseen to have dire consequences for HAT missions. Suboptimal decisions can lead to mission failure, delays, resource wastage, and increased risks to human team members. Therefore, it is imperative for HATs to continually assess and refine their decision-making processes, considering the cognitive factors at play and the specific demands of the mission.

3.0 MISSION MODELLING WITH PERFORMANCE VARIABILITY

There are several possible approaches to modelling missions for HATs. The objective in the long run for this research is to enable mission autonomy of HATs on all temporal levels of mission ordering in the defense sector. However, the work is currently limited to providing an coarse, yet formal description of such missions and the context that they are to be executed in. This section thereby presents the initial results of a formal description of teaming, a delineation of the elements of interest in a mission model for HATs and the preliminary results of a formal ontology of HATs.

3.1 The Elements of a Mission Model for HATs

Missions are complex to describe in their entirety as they consist of several elements, such as intent with an underlying purpose and the corresponding break-down into tasks that are meant to create intended effect. Other crucial elements include, but are not limited to, rules of engagement, social and cultural components and overarching doctrines. A comprehensive mission model should ideally incorporate such mechanisms to ensure success with measurable effect. In the context of this research, human variability is to be integrated into such mission models to enable consideration of inevitable human traits that cannot be removed with e.g. training. This section discusses and presents results from research on mission modelling, that aims at including human variability.

3.1.1 Perception, Effect and Mission Success

Perception is considered a fundamental element in mission execution by providing individuals with information about the environment and the status of included system elements. The accuracy and reliability of perceptual processes directly affect the ability to assess situations, anticipate changes, and respond appropriately, in accordance with work presented by Gspandl et al. [15] among many others. The role of sensory modalities, including visual, auditory, and haptic perception, need attention in the context of HATs. Additionally, the integration of sensor data with cognitive processing influences situational awareness, which is significant for mission success, as argued above.

Another central element is evaluating the effect of HAT actions and mapping them to commander’s intent, for an reliable measurement of mission success, as argued by the author. For this purpose, a model for that mapping will be integrated into the mission model intended to be developed by the research presented here.

3.1.2 Problem-Solving in HATs

Mission execution typically presents unexpected challenges and uncertainties due to unpredicted environmental conditions. Problem-solving skills are considered essential for adapting to changing circumstances and overcoming obstacles. Cognitive factors, such as those presented above as well as e.g. creativity, critical thinking, and the ability to formulate effective solutions, influence the ability of HAT members to address mission-related problems. Literature implies that effective problem-solving enhances the team's resilience and adaptability, contributing to mission success, described through research addressed by Barber et al. [16].

3.1.3 Individual Differences in Cognition

Individual differences in cognition encompass a wide range of factors, including cognitive styles, personality traits, and skill levels. These differences can potentially have a profound impact on HAT performance and coordination [17]. For instance, individuals with varying risk tolerances may approach decision-making differently, potentially leading to conflicts within the team. Moreover, differences in perceptual acuity or problem-solving abilities may result in uneven contributions to mission tasks.

3.2 Impact on Mission Success and Team Coordination

The collective influence of decision-making, perception, problem-solving, and individual differences in cognition on mission execution are as already suggested of significance for the overall mission of an HAT. When cognitive factors align optimally within HATs, mission success is more likely to be achieved. However, cognitive discordance or mismatches may impede team coordination, leading to inefficiencies and even mission failure.

3.2.1 Teaming

The issue at hand becomes that of *teaming*. What is a team and how do they operate internally? There are different team dynamics, and an HAT must quickly be able to adapt to current circumstances.

Some team members may operate with high interdependence, relying heavily on one another for critical information and decision-making. In contrast, others may function with lower interdependence, where their tasks are more self-contained and less reliant on constant interaction with the team. This varying degree of interdependence allows for flexibility and adaptability in mission planning and execution, ensuring that the strengths and capabilities of both human and autonomous team members are leveraged effectively. It fosters a cohesive and responsive defense team, capable of addressing multifaceted challenges and optimizing mission success through a balanced distribution of tasks and responsibilities. Figure 2 presents an adaptation of the work presented by Mach et al. [18] to describe degrees of interdependence of team-members, and seeks to illustrate the different internal dynamics of the various types of settings.

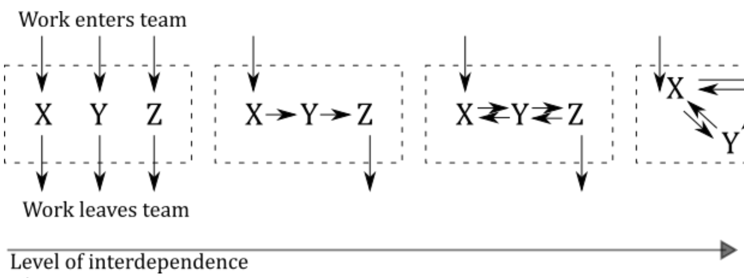

Figure 2 Level of interdependence in teamwork between individual, class-agnostic agents X, Y and Z.

3.3 Modelling HAT Missions

As already suggested, a fundamental assumption to this work is that autonomy-based agents can ultimately be treated as team-members equal to humans. However, as there are obvious differences in strengths and weaknesses between the two classes for the foreseeable future, they must be treated as such for an optimal use of their capabilities. For this purpose, this work seeks to delineate and discretise the fundamental elements to mission planning and execution. Table 1 is approaching a definition of the building blocks to a mission model for HATs and sets out to clarify their respective roles in a more elaborate framework.

Table 1 Crucial elements in HAT mission modelling

Resource Allocation and Capability Assessment	Identification of equipment, personnel, and time constraints. Approaching guarantees that resources are allocated efficiently to achieve mission objectives.
Roles and Responsibilities	Specification of roles, which include explicit definitions of task responsibilities and collaboration in military contexts. This includes identifying the primary decision-makers, operators, and support roles.
Task Allocation and Coordination	Description of task allocation among team members. Seeks to address coordination mechanisms, task dependencies, and how information is shared among team members.
Communication Protocols	Description of communication protocols and information-sharing mechanisms within the team. This includes specifying communication frequencies, formats, and procedures for both human-to-human and human-to-machine-to-human interactions.
Decision-Making Framework	Definition of the decision-making hierarchy and processes within the team. Specification under what circumstances humans or autonomy have the authority to make decisions and how conflicts are resolved.
Situational Awareness	Description of sensors, data sources, and information displays used by both humans and autonomous systems to understand the environment and mission status.
Risk Assessment and Mitigation	Risk assessment methods and procedures for identifying consequences, potential hazards or uncertainties in the mission. Mitigation management, including contingency plans.
Adaptation and Learning	Mechanisms for the team to adapt to changing circumstances and learn from experiences
Performance Metrics and Evaluation	Definition of metrics for evaluating the performance of the team and mission success. Seeks to establish criteria for assessing both quantitative and qualitative aspects of the mission.
Feedback and Reporting	Procedures for team members to provide feedback on the mission, autonomous system behavior, and overall team performance.
Scalability and Flexibility	Scalability and adaptability to accommodate variations in mission complexity and scope

3.3.1 Towards an Ontology for HATs

This work proposes an ontology to describe HATs, as presented by Figure 3. This ontology aims at providing a formal description of the interrelated elements of an HAT executing defined tasks and predefined roles, that can be assumed by any agent provided their unique capabilities. Note that the impact of the aforementioned mediators (as illustrated in Figure 1) is here handled as disruptors in the operational environment, which in turn will have a direct impact on the consequences of any action.

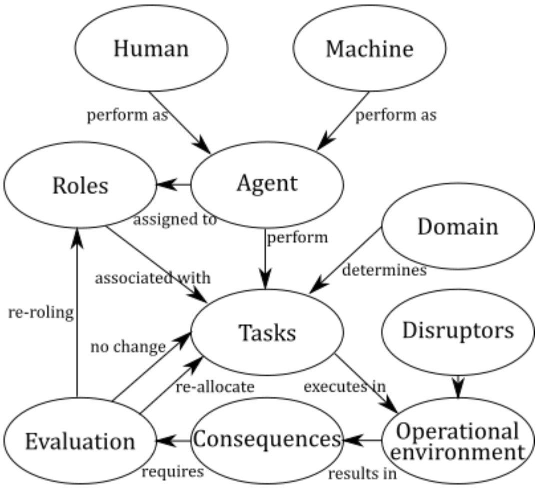

Figure 3 A proposed ontology for HATs.

3.3.2 Mission Model for HATs

The components provided above lay the foundation for the mission model proposed by this work, as presented by Figure 4. The model assumes commander's intent as starting point and associates this with the overall purpose of the mission. This information is fed to an interpreter that "understands" the true objective from the cognitive capabilities of each class of agent included in the current HAT. Cognitive capability is therefore modelled in this box later. The interpreter enables task formulation based on the unique capabilities of included agents and tracks the mission purpose through expected consequences of the actions that are associated with the tasks. The subsequent effect is then measured and mapped to the initial intent. Incremental effect is approximated from the collective experience of the agents that are included in the framework.

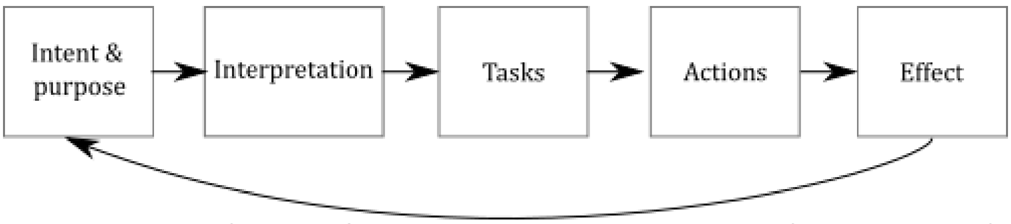

Figure 4 A mission model for HATs. Commander's intent and the purpose of the mission are fed to an interpreter that in turn enables task formulation. The tasks are translated into actions that cause effect. Any achieved effect is mapped to commander's intent in order to evaluate effectiveness.

3.4 Humans Modelled as Sensors

This research is inspired by work presented by Marathe et al. [19] and proposes an extension to a proposed sensor framework for modelling human variability. This concept involves treating human team members as dynamic sensory components as part of a holistic network. By incorporating humans as sensing capabilities into mission models, HATs can take advantage of the cognitive and perceptual abilities that humans possess in the early stages of design and planning. As suggested above, defense-domain mission planning is a process of absolute essence that demands meticulous consideration of various factors, including the physical and cognitive capabilities of human operators. The integration models on human factors into mission planning holds the potential to account for the aforementioned variability, enhancing mission success in complex and dynamic operational environments. Such models are intended to offer a means to represent and simulate the individual processes of agents, providing insights into how they perceive, reason, make decisions, and adapt to changing circumstances, as suggested above. Hence, the following subsections describe some of the content of the boxes outlined in the proposed mission model illustrated in Figure 4, to include human factors that significantly differ from their machine-based counterparts in HATs.

3.4.1 Physical Modeling in Mission Planning

The integration of physical modeling into mission planning sets out to optimize mission success. There is yet vast exploration of techniques to be done on the subject, such as biomechanical modeling and physical simulation as they potentially provide the means to comprehensively account for the physical variability encountered in dynamic operational environments. Detailed biomechanical modeling and physical simulation enable simulation and assessment of how human and machine agents interact with their physical surroundings. They potentially offer insights into issues such as mobility, ergonomics, and equipment compatibility of human agents and may highlight the importance of real-time data and adaptive mission models, as physical conditions can change rapidly in the field. In addition to that, the operational environment outside of the human, including e.g. terrain, climate, and equipment performance, can significantly impact mission execution. Sources indicate that effective mission planning requires the ability to adapt to these physical variations in real-time. However, such physical models require an intricate level of detail, which is challenging to include on the system level that is intended here - a level that also needs to include other considerations: cognition and emotions.

3.4.2 Models of Cognition and Emotional States

Emotional and cognitive modelling in mission planning represent an emerging frontier in enhancing mission success. Factors including stress, frustration, or fatigue, are essential to human behavior, which implies that one of the main advantages of HATs in contrast to fully human teams, is the possibility to use autonomous functions that are more predictable in their performance to reduce the cognitive load and mitigate the risk of errors.

The use of cognitive models would allow for a more comprehensive assessment of the impact of cognitive variability on mission outcomes. Individual differences in expertise, experience, fatigue, stress, and emotional states are factors that significantly affect the performance of even highly trained military personnel. However, available cognitive models, such as those mentioned above, have drawbacks for evaluating decision-making and task execution on system level as they describe individuals. The multifaceted nature of cognitive variability, combined with the dynamic and unpredictable nature of military operations, causes emergent behavior on global level and imply states that are challenging (or even impossible) to predict. As the integration of real-time cognitive assessments into mission planning requires robust data collection and processing capabilities that are not always available, this work proposes to treat human variability as fluctuating sensory input.

3.4.3 Modelling Humans as Sensory Input in Mission Models

This work proposes the treat humans as a special class of sensors when including their decision-making capabilities in mission models for HATs, as illustrated by Figure 5. This approach suggests that these specialized sensors provide critical input data based on each agent’s cognitive capabilities and perceptual processes. The inputs include not only sensory modalities such as visual, auditory, and haptic perception but also higher-level cognitive processes, decision-making, and problem-solving abilities. In essence, humans become integral components of the mission model, continuously feeding valuable information into the decision-making processes of the HAT. The model ought to be considered as an expansion of the applicable elements of the model presented in Figure 4 as to deal with the interpretation of commander’s intent, formulating tasks and evaluating the effect of actions and their mapping to the initial intent, all the while keeping track of the mission purpose such as to enable adaptation to changes in the operational environment.

The model assumes the capability to merge human and autonomy decisions as a weighted sum depending on the assessment of the objective in terms of a common objective function where the sensory data has been evaluated for correctness through common situation awareness. Each agent is assumed to have an individual knowledge base, which is being build up by sensory input and internal world models. Machine-based agents are assumed to build their cognition synthetically through an OODA-loop (observe, orient, decide and act) like feedback system of sensor inputs and actuator outputs.

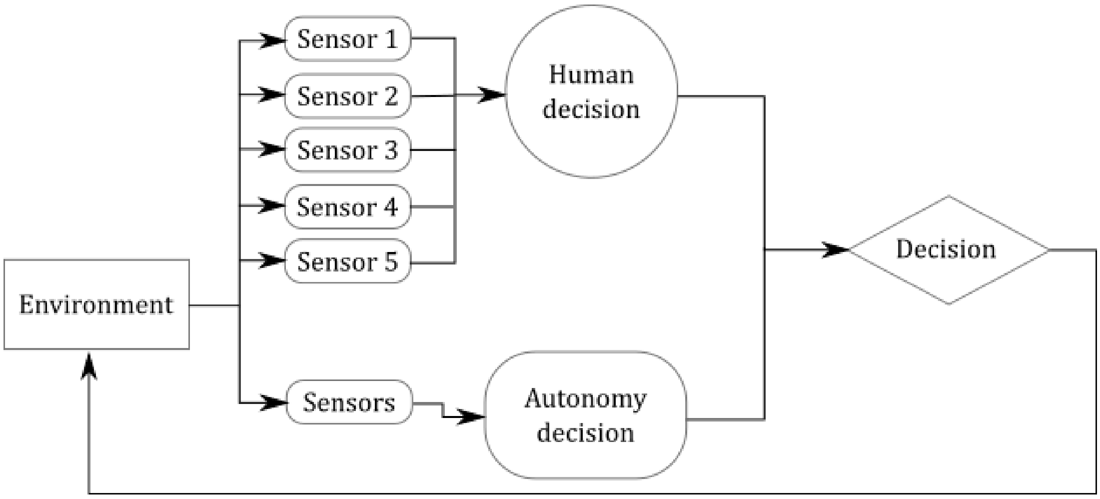

Figure 5 An instance of the proposed framework where humans are modelled as a special class of sensors.

The proposed framework discretizes human traits and abilities into a set of separately defined sensors. They account for measurements of the temporal variability that appears from internal and external states in the human agent. This framework is thereby expected to provide an approach to considering variability in human performance without modelling human behavior as such. Experiments and simulation of the proposed framework are yet to be made within a controlled environment.

4.0 CONCLUSIONS

The paper presents a work-in-progress that investigates mission models for Human Autonomy Teams (HATs) that take into consideration the complex dynamics of human cognitive, emotional and physical variability. These aspects ought to be included without describing their dynamics in detail as that approach may be prohibitive. Instead, the aim to provide a system level perspective on the issue at hand to enable design and validation at an early stage of system development. The premise of this work is that to fully harness the potential of HATs, it is imperative to account for the inherent variability in human capabilities within mission planning and execution. The study addresses the intricacies of capturing variability in human capability and emphasizes the importance of recognizing and accommodating cognitive, emotional, and physical variability among human team members. Such recognition not only optimizes human-machine collaboration but also enhances mission performance, safety, and adaptability. The work highlights the potential and predicted significance of modelling humans as sensory inputs within a proposed mission framework. This approach acknowledges the unique cognitive and perceptual abilities of humans and integrates them into the decision-making processes of HATs. By doing so, it unlocks the potential for improved mission success by leveraging human expertise and adaptability, all while accommodating the variability inherent in human performance and mitigating risks related to underperformance during stress and cognitive overload.

5.0 REFERENCES

[1] Pentland, Alex, and Andrew Liu. "Modeling and prediction of human behavior." *Neural computation* 11.1 (1999): 229-242.

[2] Tossell, Chad C., et al. "Appropriately representing military tasks for human-machine teaming research." *HCI International 2020–Late Breaking Papers: Virtual and Augmented Reality: 22nd HCI International Conference, HCII 2020, Copenhagen, Denmark, July 19–24, 2020, Proceedings 22*. Springer International Publishing, 2020.

[3] https://defenseinnovationmarketplace.dtic.mil/technology-interchange-meetings/autonomy-tim/human-machine-teaming/ as per 2023-09-20

[4] O'Neill, Thomas, et al. "Human–autonomy teaming: A review and analysis of the empirical literature." *Human factors* 64.5 (2022): 904-938.

[5] Rich, Charles, and Candace L. Sidner. "COLLAGEN: When agents collaborate with people." *Proceedings of the first international conference on Autonomous Agents*. 1997.

[6] Epp, Clayton, Michael Lippold, and Regan L. Mandryk. "Identifying emotional states using keystroke dynamics." *Proceedings of the sigchi conference on human factors in computing systems*. 2011.

[7] Quimby, A. R., and G. R. Watts. *Human factors and driving performance*. No. LR 1004 Monograph. 1981.

[8] Stranks, Jeremy. *Human factors and behavioural safety*. Routledge, 2007.

[9] Salas, Eduardo, Nancy J. Cooke, and Michael A. Rosen. "On teams, teamwork, and team performance: Discoveries and developments." *Human factors* 50.3 (2008): 540-547.

[10] Shouhed, Daniel, et al. "Integrating human factors research and surgery: a review." *Archives of Surgery* 147.12 (2012): 1141-1146.

[11] Krausman, Andrea, et al. "Trust measurement in human-autonomy teams: Development of a conceptual toolkit." *ACM Transactions on Human-Robot Interaction (THRI)* 11.3 (2022): 1-58.

[12] O'Neill, Thomas A., et al. "Human-autonomy Teaming: Need for a guiding team-based framework?." *Computers in Human Behavior* 146 (2023): 107762.

[13] Uzonwanne, Francis C. "Rational model of decision making." *Global encyclopedia of public administration, public policy, and governance. Springer International. https:/doi. org/10.1007/978-3-319-31816-5_2474-1* (2016).

[14] Klein, Gary A. "A recognition-primed decision (RPD) model of rapid decision making." *Decision making in action: Models and methods* 5.4 (1993): 138-147.

[15] Gspandl, Stephan, et al. "A dependable perception-decision-execution cycle for autonomous robots." *2012 IEEE International Conference on Robotics and Automation*. IEEE, 2012.

[16] Suzanne Barber, K., Anuj Goel, and Cheryl E. Martin. "Dynamic adaptive autonomy in multi-agent systems." *Journal of Experimental & Theoretical Artificial Intelligence* 12.2 (2000): 129-147.

[17] Neubauer, Catherine, et al. "Multimodal Physiological and Behavioral Measures to Estimate Human States and Decisions for Improved Human Autonomy Teaming." *CCDC Army Research Laboratory Aberdeen Proving Ground United States* (2020).

[18] Mach, Mercè, A. C. Abrantes, and Ceferí Soler. "Teamwork in healthcare management." *Teamwork in healthcare* 23 (2021).

[19] Marathe, Amar R., et al. "The privileged sensing framework: A principled approach to improved human-autonomy integration." *Theoretical Issues in Ergonomics Science* 19.3 (2018): 283-320.