A Reference Architecture for Human Behaviour Representations

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ABSTRACT

Currently it is not possible to easily represent the breadth of human, organizational and social behaviours observed in real life across the breadth of military simulation systems and Computer Generated Forces. Whether the need is for synthetic teammates, instructors or adversaries for individual training or the effect of cultural behaviours in more abstract strategic level simulations, improved representations and methods of integration are required This manifests itself as a trade-off between the number of entities that can be computed on a single platform and the realism of the observed behaviours.

In 2009 NATO HFM-128 stated: "..the human aspect is still often represented in a mechanistic way, bearing little resemblance to observations, as if all humans always act the same way in a situation much as a machine would. In reality, human behaviour is not deterministic. Without proper representation of behaviour, and the reasons behind the behaviour, the validity of the model may be seriously flawed, making its performance and predictions questionable."

Previous research has highlighted the challenges faced in modelling human behaviour, highlighting the need for Human Behaviour simulation standards. A NATO Modelling and Simulation Group (NMSG) activity has recently developed the idea of a baseline Reference Architecture (RA) and interoperability standards for human behaviour modelling to facilitate the creation and integration of human behaviour representations into simulation.

This paper presents the findings of that group and its initial human behaviour reference architecture model, and recommendations on how it can be applied to represent a more complete human behaviour model in a specific use case.

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BACKGROUND

Human behaviour modelling (HBM) includes the quantitative representation of performance, decision making and behaviour of individuals and small groups. It is an emerging technology with both a wide range of applications and the commensurate challenges to put these models reliably into practice as indicated in North Atlantic Treaty Organisation (NATO) Symposia (e.g. HFM-202) and Specialist Team meetings (e.g. MSG-107).

A particular area of interest is the seamless interaction of Live players with realistically simulated human characters. This capability has broad applications, ranging from training for urban operations, to red force representation in tactical Air-to- Air training. The required level of fidelity in such models may vary considerably across uses. However, they are all intended to represent important characteristics of human cognition and performance.

There is a need for standards for operational model architectures wherein humans and virtual humans can work together. These virtual humans should adequately model behaviour based on general human aspects (e.g., cognition, emotion, physiology) as well as on cultural background and role in society. The behaviour should be validated and fit-for-purpose to meet the requirements for military training. There is also a need for support of more natural interaction between human trainees and simulated characters (e.g., gestures and speech rather than keyboard and mouse).

NATO RTO, NATO armaments groups and the NATO military modelling, analysis and simulation communities would be well served by a consensus Reference Architecture for HBM. This would provide a common framework for developing HBMs for training, facilitating model reuse and information exchange, and ultimately savings in time and resources for development of particular training applications.

The challenge is the integration of science-based models that describe (only) part of human behaviour- into complex military training settings. The scope and limitations of currently developed models and architectures need to be investigated and the best approach for a consolidated Reference Architecture must be decided. Exploration of the state-of-the-art in human behaviour modelling, architectures and implementations requires a cross-disciplinary approach that should involve NATO experts from HFM (Human view), MSG (architectures and standards), academia and industry.

In 2009 NATO HFM-128 was tasked to look how Human Factors (HF) are represented in military models. The group stated:

"..the human aspect is still often represented in a mechanistic way, bearing little resemblance to observations, as if all humans always act the same way in a situation much as a machine would. In reality, human behaviour is not deterministic. Without proper representation of behaviour, and the reasons behind the behaviour, the validity of the model may be seriously flawed, making its performance and predictions questionable."

This weakness in modelling human behaviours is becoming more apparent as organizations attempt to model robotic and autonomous systems. Currently, there is little in the representations that can clearly differentiate human system performance from robotic system performance, principally due to the long-standing failure to model humans as humans (Blais 2016).

THE HUMAN CONTEXT

The abstract to Numrich and Tolk's paper "Challenges for Human, Social, Cultural, and Behavioral Modeling" (Numrich and Tolk 2012) summarizes the problem well:

"Today's military focus has moved away from the force-on-force battlefield of the past century and into the domain of irregular warfare and its companion security, stability, transition and reconstruction missions. With that change in focus has come a need to examine the operational environment from a far wider perspective, one that includes the whole range of human experiences and circumstances. As the set of factors and list of players expands, the need for reliable modeling and simulation increases, if for no other reason than to help the human decision maker make sense of this expanded decision space."

However, to do this, the models and simulations must take into account not just the individual but the "whole of government," "whole of society," and all those with an interest in the region in question – allies, trade partners, adversaries, individuals, and networks of influence. That is, these must be accounted for at least to the extent that this expanded set of actors and influences affects the intended use of the model or simulation. Numrich and Tolk suggest the ideal solution is to inject models from the human sciences into our kinetic simulations and declare success, but this is not possible.

Dekker (Dekker 2013) talks about how social effects are critical when simulation of human behaviour within a society is necessary to assess a Course of Action (COA). He talks about the problems that occurred when simulations of social behaviour used to assess COA in Iraq and Afghanistan used western constructs that are not appropriate, in general, to that region.

For example, some simulations of social behaviour in Iraq and Afghanistan have used the "Hierarchy of Needs" developed by Abraham Maslow. This theoretical construct suggests that human beings seek to satisfy five different kinds of needs in priority order: physiological, safety, love and belonging, esteem, and self-actualization. However, Dekker suggests that Maslow's hierarchy, being inherently individualistic and "Western" in nature, is "non-deployable" to countries like Iraq, where the needs of the family, clan, or tribe often outweigh personal needs (Dekker 2013).

Numrich and Tolk go on to identify three main management issues:

1. **A lack of common vocabulary among physical scientists, social scientists, and user communities**. The presence of so many different academic disciplines in Figure 1 is testimony to the fact that cultural (and lexical) divisions separate the groups engaged in the study of the human domain.

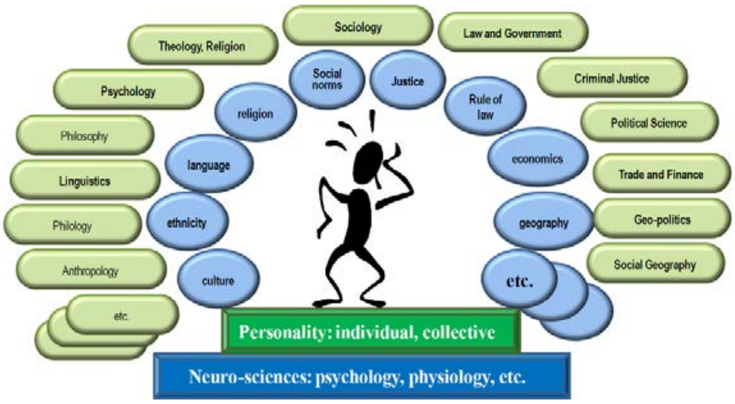


Figure 1: Factors Involved in Human Decision Making and their formal academic disciplines(Numrich and Tolk 2012)

2. **The management structure in military simulation**, including the groups that fund the development of new models, is dominated by physical scientists – those very people who get headaches whenever they are confronted with the issues and methods of the human sciences.

3. **Nobody wants to be responsible for the data**.

Dekker summarized that HBM is "an emerging science of modelling and simulation that systematically addresses these concerns." We are now over 15 years past the call by Pew and Mavour (1998) for such a science to provide:

- formalisation of an appropriate body of knowledge, using a consistent vocabulary;
- interdisciplinary research, including collaboration between military and non-military (economic, sociological, agricultural, medical, etc.) simulation communities;
- improvements and extensions to successful models of individual humans and small groups (including successful models of emotion) in order to represent larger groups and complete societies;
- appropriate data collection; and
- a foundation for research and development, including epistemology (what we know), ontology (what exists), teleology (what our goals are), and methodology (what we do).

THE DEFENCE CONTEXT

The UK MOD Future Operating Environment (FOE) 2035 (MOD 2014) forms part of the Development, Concepts and Doctrine Centre's (DCDC) Strategic Trends Programme and aims to "describe the characteristics of the 2035 operating environment to provide evidence-based insights that can inform future Defence capability development".

The document identifies characteristics of the FOE. Figure 2 shows the likely areas of friction. The document states that operating successfully in future environments requires a detailed understanding of their likely characteristics. Identifying influential trends early will help decision-makers plan more effectively for the future.

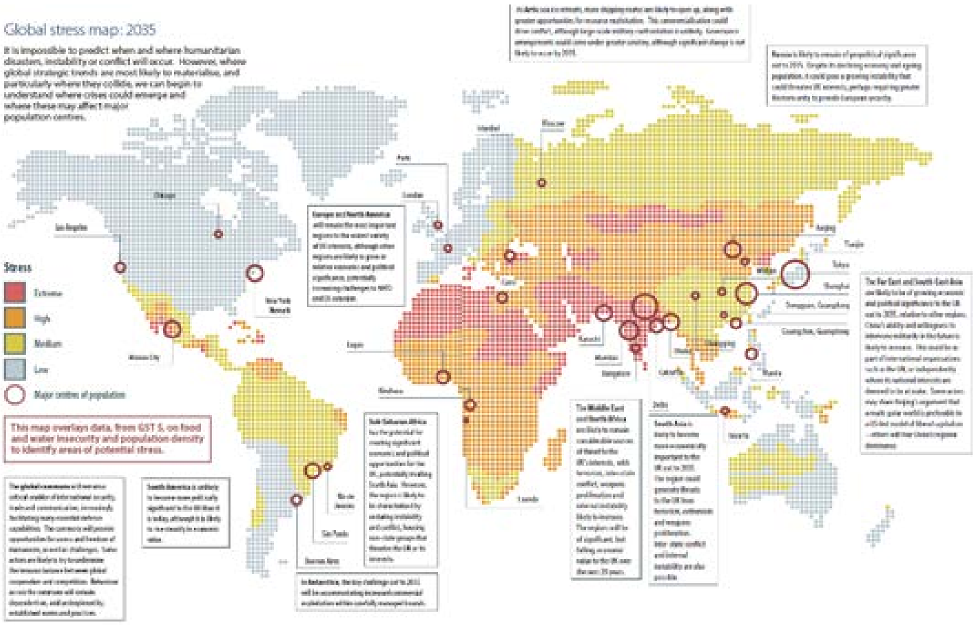


Figure 2: FOE 2035 Heat Map © Crown Copyright

Important characteristics of these future environments include:

- Traditional state-on-state conflict cannot be ruled out over the next 20 years, but state-sponsored terror attacks, use of proxies and cyber attacks are more likely.
- Three-way engagement between militaries, non-governmental organisations and multinational corporations will become increasingly important out to 2035. For urban operations, engagement with city authorities will be particularly relevant.
- Extremist non-state actors increasingly will be able to exploit a wider array of military capabilities, using innovative tactics that exploit our inherent vulnerabilities, including any institutional inertia. These actors are likely to develop ever-higher levels of lethality to counter our protection systems and may even have access to weapons of mass effect. (MOD 2014)

In addition, both, NATO nations and partners face challenges regarding training and exercises: current and future operations are multi-national in nature; also, the missions and the systems are becoming more complex (urban operations) and require more detailed preparation and rapid adaptation to changing circumstances. At the same time, opportunities for (live) training and exercises are reduced due to available resources and limited time spans between political decision making and deployment. Training and exercising using simulation is now critical to NATO nations' and partners' mission readiness.

NATO MSG-127 TASK GROUP

The NATO Modelling and Simulation Master Plan (NMSMP) defines the following vision regarding M&S:

NMSMP Vision
"Exploit M&S to its full potential across NATO and the partner nations to enhance both operational and cost effectiveness."

The NMSMP identified several gaps and defined five main objectives:

1. Establish a Common Technical Framework;
2. Provide Coordination & Common Services;
3. Develop Models & Simulations;
4. Employ Simulations;
5. Incorporate Technological Advances.

The NATO Modelling & Simulation Group (NMSG) MSG-127 Task Group seeks to address in particular the common technical framework objective while supporting the incorporation of technological advances. HBM is considered an important issue regarding the use of M&S in support of military training. The NATO M&S Gap Analysis Report and the findings of the NATO M&S Standards Profile (NMSSP) document (AMSP-01 2012) underpin the need for improved human behaviour models and more standardisation to enable re-use.

MSG-127 set out to develop a Reference Architecture (RA) for human behaviour modelling of individual players intended for use in military training applications. It aimed to cover:

- Analysis of relevant training applications
- Conceptual modelling of individuals
  - Social and cultural influences on behaviour
  - Cognition, including decision making, error and planning, and emotions
- Investigation of (sub)model architectures and hierarchies
- Development of a Reference Architecture capturing model integration and model interface standards
- Training provision validation and implementation
- Guidelines for tailoring the Reference Architecture to specific applications and implementations

HUMAN BEHAVIOUR

FOE 2035 suggests Defence organizations need to become better learning organisations that can quickly adapt at the strategic level. At the operational level, Defence must rapidly and flexibly meet novel threats with suitably structured, trained and ready forces. The ability to adapt at the tactical level will require highly trained, educated and motivated Service personnel with a range of equipment and technology optimised for the varied missions that will be required:

> **"Doctrine** is a **guide** to anyone who wants to learn about war from books: it will light their way, ease their progress, train their judgement and help them to avoid pitfalls. **Doctrine is meant to educate the minds of future commanders**.....not to accompany them to the battlefields" (7).

Add to this the complexity and breadth of defence simulation. Consider, for example, the situation depicted in Figure 3**Error! Reference source not found.** reproduced from a 2009 U.S Naval Research Laboratory (NRL) Diplomatic, Information, Military, and Economic (DIME) / Political, Military, Economic, Social, Information, and Infrastructure (PMESII) Requirements project. The diagram illustrates the challenges in this area, given the wide potential areas of conflict identified.

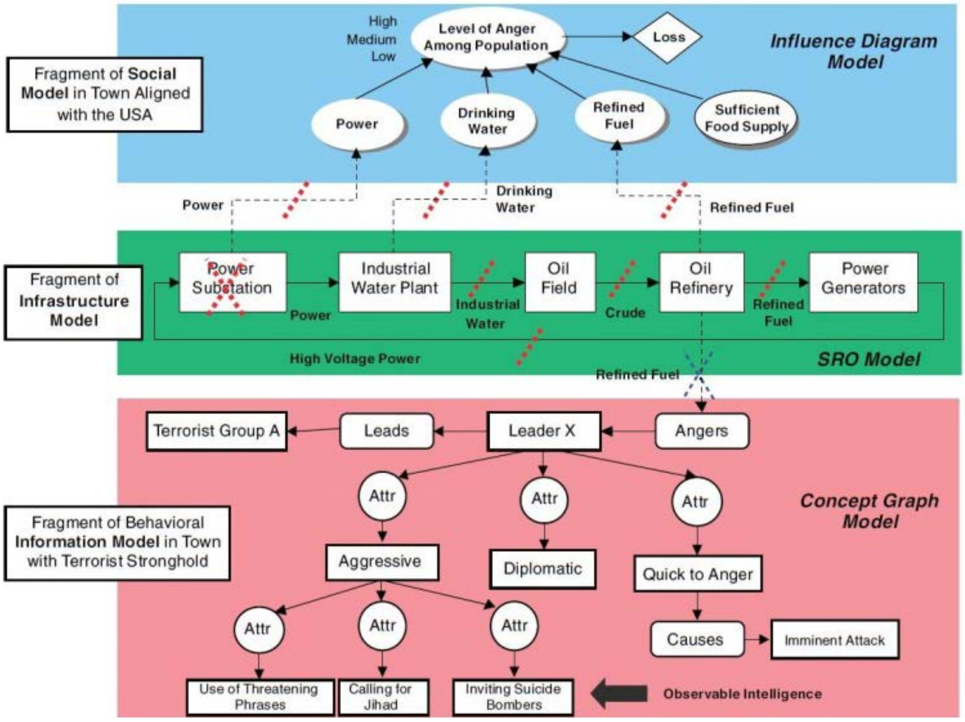


Figure 3: Interoperability of three different PMESII models (Langton and Das (2007)).

The NRL report concluded there is a "lack of model integration scheme" to guide integration of the multiple models needed to represent the complexity and interdependencies of the DIME / PMESII problem space, and an "absence of models that cover the full range of military activities" (from high level abstract strategic simulations down to individual entity level tactical simulations). The report highlighted that modelling conflict is fine but the modelling of specific operations including the effectiveness of training host nation security forces or military operations to provide infrastructure security is lacking.

Figure 3 demonstrates the need for special consideration when aggregated units are used as entities in a constructive simulation, as observed by HFM-128. Teams and larger units have additional HBM factors, differing representation requirements and properties that do not exist at the individual level. It is recommended that simulations be scaled by aggregating elements where necessary and incorporating the associated HBM appropriate to the level of aggregation.

ARCHITECTURES AND STANDARDS

NATO recognizes the International Organization for Standardization / International Electrotechnical Commission (ISO/IEC) concept of a standard as follows: "A standard is a document, established by consensus and approved by a recognized Body that provides, for common and repeated use, rules, guidelines or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context". It is noted that "a standard should be based on the consolidated results of science, technology, experience and lessons learned" (ISO/IEC).

The main qualities which make a good standard are the following (AMSP-01 2013; Huiskamp et al 2014):

- *Relevant*: a standard should be relevant to the targeted user/developer community;
- *Substantive in content*: a standard should provide meaningful information and/or results;
- *Enabling timely production*: a standard should provide timely production in an efficient manner, to ensure that the product is useful to the community;
- *Reviewed*: a standard should be reviewed by the technical community to which the product applies and have large acceptance;
- *General*: a standard should be as general as possible, while still maintaining usefulness, to support the broadest community of current and future users;
- *Stable*: a standard should be established and changed only as necessary. It should be prototyped and tested before being proposed for adoption to demonstrate its maturity;
- *Supportable*: a standard should maintain the integrity of the existing product suite and the needs of the user.

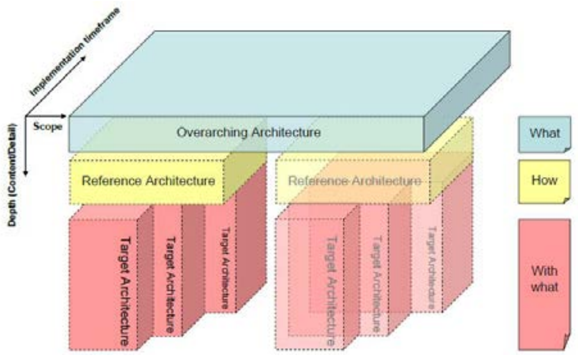
Standards must mature to meet changing requirements. When new requirements emerge or technical innovations become possible, new standards will likely be needed.

For HBM to keep pace and influence M&S for training and to play the role required it is crucial M&S HBM architectures adopt and remain current with M&S practice. Therefore, MSG-127 is looking at an RA that supports current practice and could be employed in a Modelling & Simulation as a Service (MSaaS) paradigm (van den Berg 2016).

According to Schmidt and Schneider (2004), reference models are development guidelines providing standardized solutions for certain modelling problems of a (homogeneous) class of real systems. They are usually characterized by the two main attributes: universality and recommendation character (Thomas 2006).

- *Universality* refers to the idea that a reference model should be applicable not only in one special case, but across problems of a certain class.
- *Recommendation character* refers to the idea that a reference model should serve as a blueprint, or even as a default solution, for certain problems.

Figure 5(?) shows the NATO Architecture Framework where the overarching architecture is supported by one or more reference architectures (*source*). **add more discussion of what is conveyed in the diagram**



- **Reference Architecture (RA)**: an abstract form of architecture. A reference architecture generally provides a template solution for a concrete *solution architecture*
- **Architecture Element**: an element in the description of the reference architecture, such as *layer*, *architecture building block*, *architectural pattern*; each of these elements has *attributes*
- **Target Architecture (TA)**: the architecture of a specific solution, derived from the reference architecture
- **Target Element**: the realization of an architecture building block and an element of the solution

Figure 4: NATO Architecure Framework (Noble Prog Ltd 2014)

An architecture can be described at different levels of abstraction and the term reference architecture is typically used for a more abstract form of architecture. The purpose of the RA is to provide a template for the development of of one or more concrete target or solution architectures. The RA provides guidelines, options, and constraints for making design decisions with regard to a target architecture (TA) and implementation.

The MSaaS RA referred to above has been defined with certain principles in mind, similar to the Open Group Service-Oriented Architecture (SOA) RA principles. These principles apply to the proposed HBM RA as well and are summarized below:

- The RA should be a generic solution that is vendor-neutral.
- The RA should be based on a model of standards compliance.
- The RA should be extendable, allowing the addition of more specific capabilities, building blocks, and other attributes, allowing it to be used as a base for more specialized reference architectures.
- The RA must be compliant with NATO policies, standards (such as AMSP-01) and architectures.
- The RA must facilitate integration with existing M&S systems.
- The RA should be capable of being instantiated to produce:
- Intermediary architectures
- Solution architectures
- The RA should address multiple stakeholder perspectives.
- The way the RA is instantiated should be determined by the user.

The enabling technology provides the means for realization of an architecture element. Example technologies for implementing the interoperability needed between architecture elements of the HBM RA could be High Level Architecture (HLA) object models and middleware (RTI), web services, or other options.

DEVELOPING A HBM REFERENCE ARCHITECTURE

In a 2014 Industry/Intraservice Simulation and Education (I/ITSEC) paper (Gunzelmann, 2014), the MSG-127 members proposed an initial RA for HBM as shown in Figure 5. It is not intended to embody a detailed theory of the human information processing system. Rather, it is a structural description of the cognitive system at a relatively high level of abstraction. The structures are intended to reflect components of cognition for which there is relatively broad consensus within the scientific community.

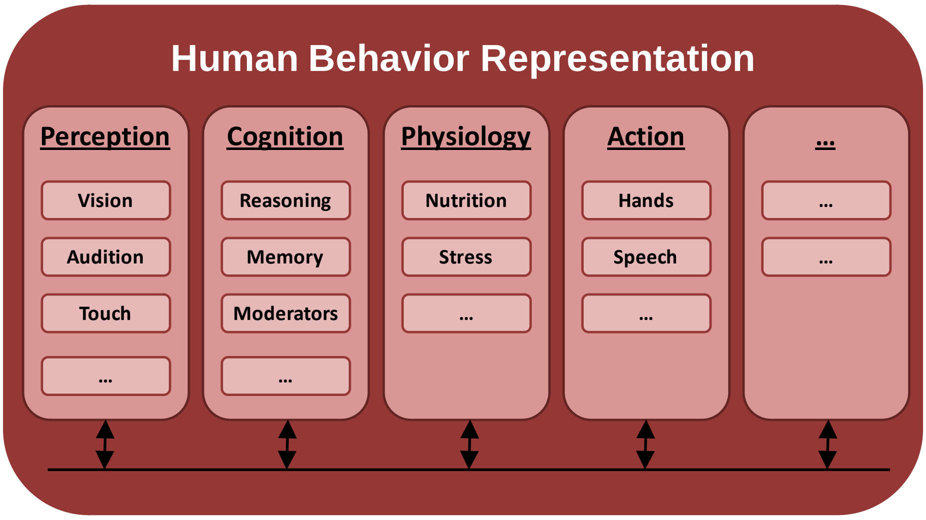


Figure 5: Initial overarching architecture for human behaviour models (Gunzelmann et al 2014)

Much discussion between the panel members has taken place, with differences in thoughts and ideology coming between and within the physical scientists and the Human Factors and Behavioural Scientists involved. Taking a architecture framework approach and building the HBM RA according to NATO Architecture Framework Principles (NAF) (NAFDOCS.org), the proposed overarching architecture (OA) for HBM is shown in Figure 6. From a Ministry of Defence Architecture Framework (MODAF) or U.S. Department of Defense Architecture Framework (DODAF) perspective, this could be considered as the System View (SV-1) for the architecture.

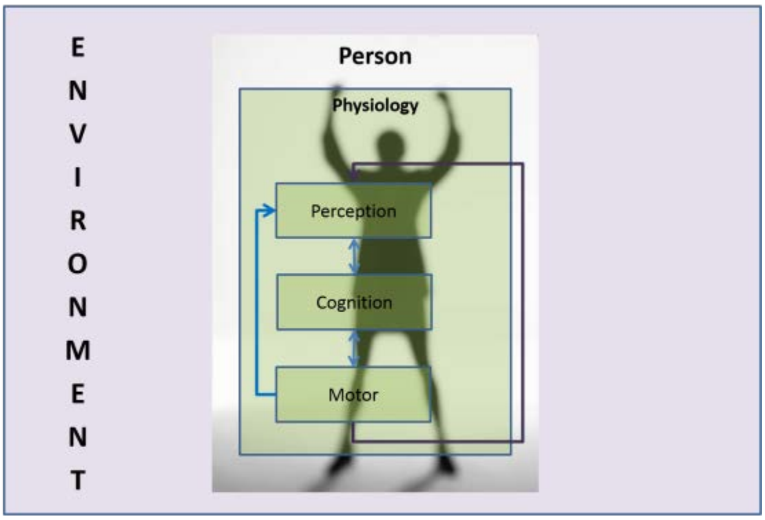


Figure 6: OA for HBM v1.0

In order to make an RA that supports a vision for more open and accessible simulations, it is proposed that the MSG-127 RA be developed in line with the complementary work of MSG-131 and MSG-136 on Modeling and Simulation as a Service (MSaaS) and the NATO C3 Taxonomy, respectively. Figure 8, adapted from Hannay (2016), shows how the RA has been described to support those efforts.

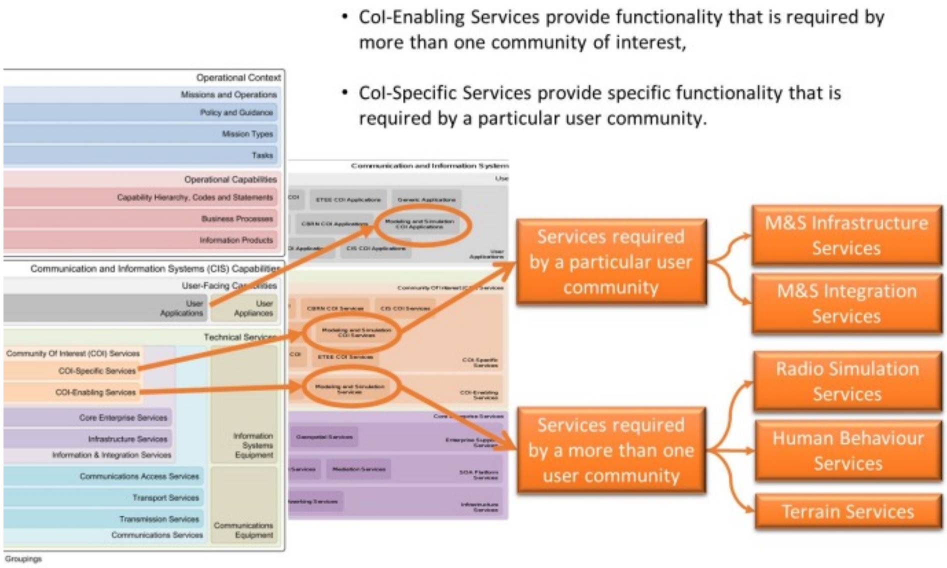


Figure 7: NATO HBM RA v1.0 (Adapted from Hannay 2016)

APPLYING THE REFERENCE ARCHITECTURE

In developing the RA we have used the example given in Gunzelmann et al. (2014) where the application of human behaviour representation is used to generate the behaviour of virtual humans (agents) in support of Helicopter Directing Officers (HDO) training (van den Bosch and Boonekamp 2013). Using the MSG-127 RA to develop a specific TA for this use case would be implemented at a high level as shown in Figure 8.

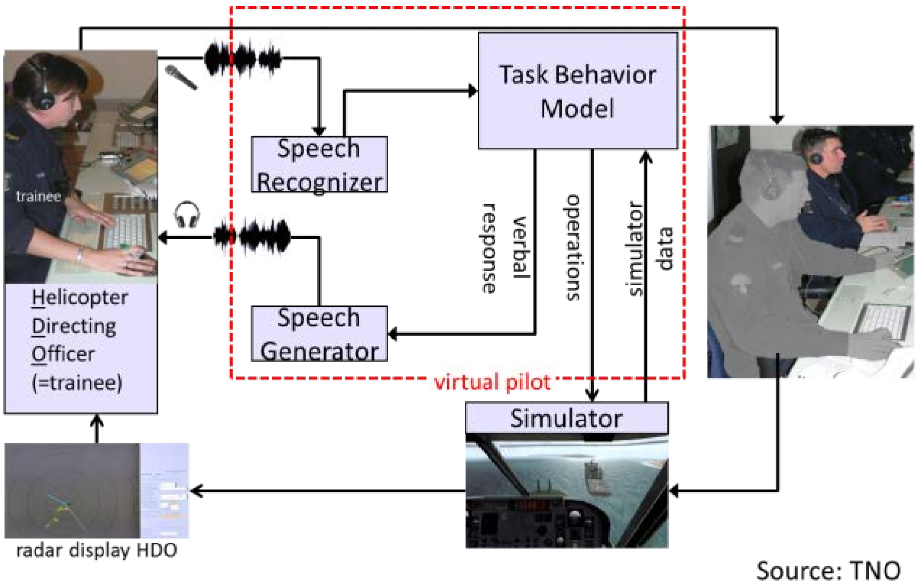


Figure 8: Virtual Pilot Use Case. Adapted from van den Bosch and Boonekamp (2013).

DISCUSSION

Even with a developed RA and specific TA's, a significant amount of research, development and testing still needs to be done to develop all the elements needed to support HBM. The U.S. Army Research Laboratory (ARL) Human Research and Engineering Directorate (HRED) Simulation & Training Technology Center (STTC) initiated the Distributed Soldier Representation (DSR) research project to "investigate those factors that affect Soldier effectiveness, identify where there are gaps in modelling those factors in current Soldier representations, and offer a service-oriented distributed M&S environment able to assist in filling those gaps" (Fefferman et al. 2015, p vii).

The intended outcome was "to provide a capability to represent those human aspects that affect Soldier performance with greater fidelity and an increased realism in the representation of the Soldier within simulations" (*ibid*.). In 2015, the report identified eleven areas of deficiency in modelling human behaviour; as identified in Table 1.

Table 1: Summary of HBM Deficiencies. Adapted from Ferrerman et al. (2015).

Deficiency		Comments
1	Cognition	Thought processes comprised Judgement, rational analysis and intuition
2	Decision Science (Making)	Methods and tools to gain understanding
3	Human Physiology	Biology that deals with the mechanical, physical, bioelectrical, and biochemical functions of humans
4	Human Psychology	The scientific study of mental functions and behaviours
5	Leadership	The ability to influence the actions of others
6	Morale	The capacity of people to maintain belief in an institution or a goal, or even in oneself and others
7	***[Human]/***Soldier as a Family Member	Examining military family issues associated with readiness
8	***[Human]/***Soldier Resilience	The ability to adaptively respond to challenges and adverse events
9	Stress	The complex and constantly changing result of processes inside a Soldier while performing a combat-related mission
10	***[Military / Civilian]*** Unit, ***[organisations & cultures]*** as complex system	The self-organizing properties of a unit emerging from the complex interactions within the unit and with external influences
11	***[Military / Civilian]*** Unit ***[organisations & cultures]*** Cohesion	Described as interpersonal bonds among members (social cohesion) or a shared commitment to the mission (task cohesion).

Although only looking at the deficiencies in modelling those aspects relevant to the soldier (significant in itself), if we broaden the perspective to include all individual human traits, cultural and organizational differences across the spectrum of future conflict areas shown in Figure 2, the scope of the problem becomes larger than any one country or NATO member state is likely to solve on its own.

Figure 10 summarizes where those behaviours are also needed across the whole spectrum of defence Computer Generated Forces (CGF) use from requirement setting through to Command and Staff training. Demonstrating the breadth of the requirements, the work needs to range from individual real-time human and doctrinally-accurate behaviour, through to aggregate faster-than-real-time socio-cultural behavioural modelling.

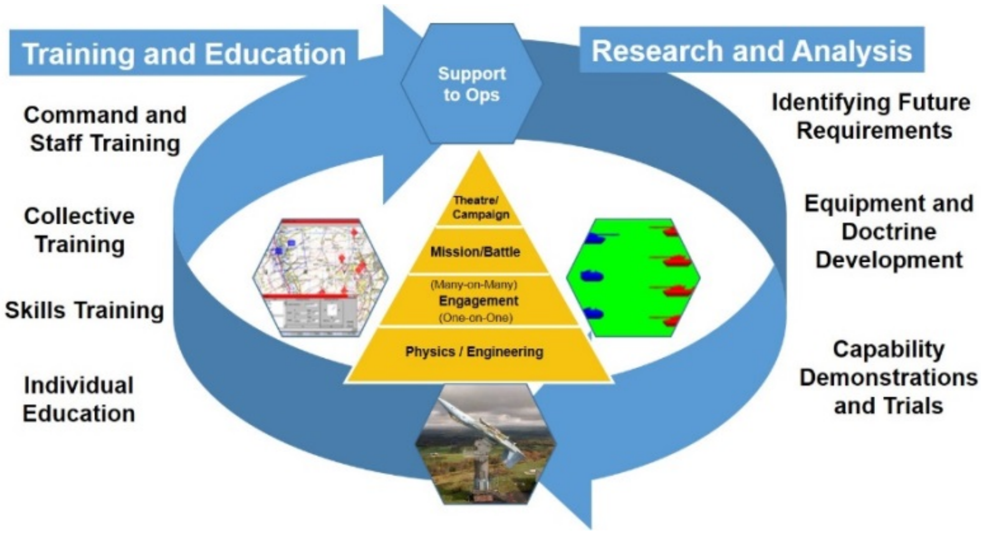


Figure 9: The Role of CGF's and Behaviours in Defence Simulation © Crown Copyright

Human behaviour therefore manifests itself in many forms depending on the application, (training /experimentation) the level of mission execution (tactical, operational or strategic). It is also required to adequately represent BLUEFOR and OPFOR (formal and asymmetric threats), but also civilians (with differing cultures and ideals), the level of interaction and the level of aggregation.

At the lowest level of training the CGF behaviour may well be a virtual instructor or an AI-controlled player that the trainee is interacting with. At the mission or battle level, it may be doctrinally-accurate manoeuvres of a force, but also an appropriate Pattern of Life for the civilian population. Finally, at the campaign level it might be the effect of a single Remotely Piloted Aircraft System (RPAS) operation or newspaper article on the stability of a region within the Area of Operations. Table 2 summaries the different types of HBM required.

Table 2: Relating types of simulation capability to the HBM requirements (Lewis et al. 2016)

Requirement	Simulation capability
Humans operating in isolation	Independent characters
Humans operating in groups	Crowd Flow Group behaviour
Humans operating platforms	Land domain simulation e.g. traffic Air domain simulation Maritime domain simulation
Human background clutter	Background Pattern of Life
Complex and simple behaviours	Artificial Intelligence based behaviour models Hierarchical behaviour execution

Therefore, given the range of potential outcomes from even the simplest interaction with a single human computer controller player, not only is there a challenge to adequately model the many aspects of the problem, but the subsequent variability of outputs needs to be considered to see if there is an impact on the way training is delivered. The complexity of the problem demands a highly flexible, highly evolvable, highly composable solution that a community-established reference architecture can provide

CONCLUSION

In the 2010-2012 timeframe, following the initial years of the Human Social Culture Behavior (HSCB) modelling initiative in the United States Department of Defense, a Simulation Interoperability Standards Organization (SISO) study group investigated the need for M&S standards in human behaviour modelling. The group published a final report (SISO 2012), but could not obtain agreement on a way forward nor sufficient participation to begin a standards product development (or even development of guidance, reference, or best practices products). One area proposed for initial standards work was data standardization but, echoing the conclusion of Numrich and Tolk (2012) that “nobody wants to be responsible for the data”, the community did not decide to initiate that activity. It is not clear if the international community is more eager today or if it may be even less motivated to pursue such standardization activities. It is hoped the present MSG-127 efforts wlli stimulate renewed interest in this area. Even though some may feel the problem is just “too big to tackle”, the modelling challenge is only becoming more complex, not less, over time. For M&S community activities to ever catch up with operational requirements, it must start now at some level of concerted effort. The current framework described in this paper is worthy of further study and specification. It may be time for an international standards organization like SISO to take a new look at this area.

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