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A process for placing the human at the centre of the constructive simulation.

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Human Factors, Combat ID, Situational Awareness, Modelling and Simulation, Synthetic Environments, Agent Based Models, Constructive Simulations, Data Farming.

Topic 3 – Modelling and Simulation

David Dean, Alasdair Vincent, Beejal Mistry – Dstl, UK
Mink Spaans, Peter Petiet – TNO, NL

D.F.Dean MSc CEng MIET
dfdean@dstl.gov.uk
DSTL Land Battlespace Systems Department
Room C27
West Court
Portsdown West
Portsdown Hill Rd
Fareham
PO17 6AD
Tel 44 (0)23 9221 7795
Fax 44 (0)23 9221 7900

Mink Spaans
Mink.Spaans@tno.nl
TNO Defence, Security and Safety
Oude Waalsdorperweg 63
P.O. Box 96864, 2509 JG The Hague, The Netherlands
Tel: +31 70 374 0211, Fax: +31 70 374 0642

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A process for placing the human at the centre of the constructive wargame.

Abstract:

This paper will describe different aspects of human behaviour and characteristics that can be represented by modelling techniques, based on ongoing work within the UK Defence Science and Technology Laboratory (Dstl), the Nederland's Organisation for Applied Scientific Research (TNO) and the US Naval Postgraduate School (NPS). It will then propose how these characteristics can be used within a range of different types of constructive simulation, in particular agent based models. Importantly, it will also consider an integrated process of experimentation and analysis to validate and maintain development of human factors representations within constructive simulations.

Background:

The authors have been studying the representation of Combat ID within combat models and analysis tools. One of the key observations that came from this work is the overriding impact of human factors, particularly those based around cognitive science, on the outcome of Combat ID processes. This led to the development of the Integrative Combat Identification Entity Relationship (INCIDER) model, a simple analysis tool that represents a Combat ID 'encounter'[1].

The logic and process that went into the development of INCIDER includes aspects which are applicable to a variety of decision making processes. Therefore it was understood early on that the extension of the model to represent human error mechanisms within other decision making processes could be extremely beneficial for the representation of naturalistic decision making.

A number of other modelling approaches, aimed at different types of decision making processes, were also identified as providing representations of complementary aspects of human behaviour and decision making. A way of assessing how they could fit into a comprehensive analysis approach was required.

This paper provides a process for addressing problem formulation, model exploitation, and Validation and Verification and set of architectural components that can be applied to the future development of constructive simulations and agent based models to enable the rapid generation of human factors representations within military simulations.

[1] INCIDER defines an encounter as being the process of a single decision maker detecting, recognising and identifying an unknown object or entity on the battlespace (Dean and Handley 2006).

1. Introduction

Four years ago, a customer in the UK Ministry of Defence asked a fairly straightforward question:

> "What is the optimum balance of investment between Target Identification Devices, Situational Awareness Tools, and Tactics, Techniques and Procedures to increase combat effectiveness without slowing operational tempo?"

Combat Identification improves combat effectiveness by reducing fratricide, reducing missed opportunities, and enabling decisions to be taken with more confidence. However, excessive time taken making decisions can reduce tempo. This question seems straightforward; however, it could not be easily answered for the following reasons:

- Combat identification is a complex socio-technical issue, only rudimentary representations of decision errors and fratricide existed in the wargames and simulations available.
- The measures of performance associated with the different solution categories are not directly comparable - the benefit of a new sensor system in this context extremely difficult to assess against improving an operators identification training.
- The human factors relationships that affect Combat ID were not supported by empirical data that could be used to build predictive models.

In order to address this problem, a prototype analysis tool was developed which could be used to predict the outcome of Combat Identification encounters (Dean and Handley 2006). The analysis tool was very useful for undertaking detailed analysis on a limited set of scenarios and the process that it represented had significant potential to be exploited within wargames and constructive simulations; however, the tool had not been validated.

An iterative development approach was instigated to simultaneously develop the model concepts, undertake validation and verification using Synthetic Environments and live exercises, and investigate exploitation routes using constructive simulations. Through this process a high level set of architectural components evolved which could be used to drive and monitor the development process.

The following two sections describe the architectural areas and process and developed, and provide guidance intended to assist in:

- answering analysis questions with novel human factors aspects;
- developing analysis tools to represent novel human factors representations;
- migrating novel human factors concepts into military simulations[2].

[2] Three types of simulation are used to represent warfighting: live exercises, where the people and equipment are both real; virtual environments, where the people (players) are real, but the equipment is

Section four gives an overview of work undertaken collaboratively by Dstl[3] and TNO[4] which has used the architecture and process to implement a representation of a Combat ID analysis tool within an agent based modelling environment.

2 The Architecture

This section describes a Systems Engineering Architecture which is intended to map solutions and concepts to exploitation routes, place research tasks in context, and provide a means of comparing alternative methods and tools which may complement an analysis task under consideration. The architecture can also be considered as a check list to ensure that the right set of characteristics is being investigated for the representation of interest, to identify other areas that the work could dovetail into, to assess whether a particular model or technique could contribute, and to identify potential exploitation routes.

A large body of research from both the human sciences and wargaming and simulation domains exists which can be used to support the process and development of representations described by the architecture. Pew and Mavor, 1998, describe a comprehensive set of issues and characteristics relating to the representation of human behaviour within military simulations. NATO SAS-026, 2002, provides guidance on analysis assessment and contains a comprehensive human factors taxonomy. There have also been significant developments in Complex Command and Control and decision making representations (Moffat, 2007) which represent operational and mission level processes.

Area 1 - Type of question

There may be no direct objective for a human factors representation. It may be being developed for purely theoretical purposes, to represent a theory or concept. However, there will ultimately be questions to which it can be applied – consideration of these early on in a piece of research can pay dividends downstream.

Being aware of the types of question that end users of these models wish to address, considering the impact that the type of question will have on the information requirements of subsequent analysis, and assessing the suitability of different approaches to provide an exploitation route is therefore an extremely useful application of the architecture.

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simulated; and constructive simulations and wargames, where both the people and equipment are simulated.

[3] Defence Science and Technology Laboratory (Dstl) – Part of the UK Ministry of Defence (MOD) responsible for providing advice on science and technology.

[4] **T**oegepast-**N**atuurwetenschappelijk **O**nderzoek TNO: the Netherlands Organisation for Applied Scientific Research.

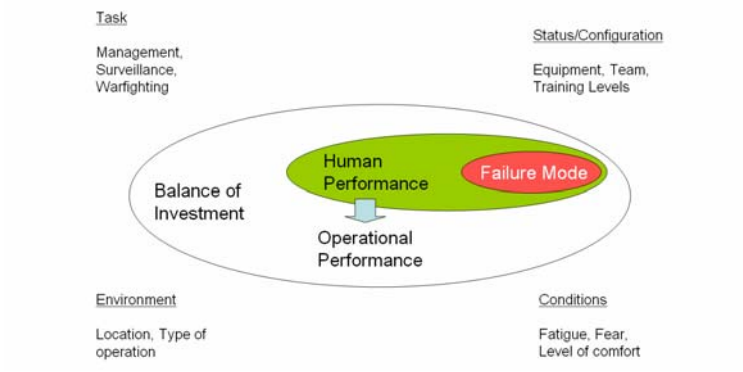

Figure 1 - Area 1: Type of Question

The list provided below (illustrated by Figure 1) highlights some of the important areas that human factors analysis can address:

Balance of Investment - How do investment options for equipment and training impact upon human performance within the operational context?

Human Performance - What will the performance of the human be within a particular operational context?

Operational Performance - How well will blue force perform within the operation, based on expected levels of human performance?

Failure Mode - When will the human in the system become too tired, or overloaded with information to undertake their role effectively?

These questions will be applied within a particular set of operational considerations, and from a particular domain viewpoint:

Operational Considerations

As well as the question of interest, it is also vitally important to know the context within which the question is being placed. Aspects such as military task, type of scenario and theatre of operation will have a marked impact upon the type and quality of the human representations required.

Modelling Domain

Which area is the question being applied to? The domain will place different considerations on the quality and required resolution of outputs. The domains used by the UK[5] are:

- Equipment Definition,

[5] UK Ministry of Defence Acquisition Management System (AMS) 2008

- Operational Analysis,
- Equipment Manufacture,
- Equipment Support,
- Operational Support,
- Cost,
- Timescale.

Area 2 - Types of human representation

Figure 2 - Area 2: Level of human representation

It is not possible to model everything! By its very nature, modelling is an attempt to simplify the real world. Decisions have to be taken about the level at which Human representation is appropriate. This area, along with area 3 of the architecture (level of human decision) forms the notion of 'Area of Coverage' of the human factors representation. To provide a link to an analogous architecture that is used by the UK MOD to describe different levels of abstraction in modelling and simulation, it is proposed that Area 2 of the architecture be formed of eight layers. The layers identified are:

- Sub Characteristic – Individual human behaviours such as confirmatory bias[6].

- Characteristic – Major human activities such as decision making.

- Individual – Aspects relating specifically to the cognitive and physiological abilities of an individual such as personality type, and IQ.

- Pair/Small Group – Aspects relating to the behaviours exhibited by tightly coupled groups of individuals undertaking a common activity. A small platform such as a tank is a good example.

- Larger Team – Teams can be of a wide variety of different types. Aspects will relate to teams and groups of individuals undertaking a common function.

[6] This is a particularly important characteristic of Combat ID, see Eysenk and Keane, 1999

- Command Function – This is a specific example of a team undertaking management processes. Again the team could be of a wide range of sizes.

- Organisation – This is aimed at larger military formations, within which members of the organisation are unlikely to have a detailed knowledge of the entire organisation.

- Larger population – This is aimed at larger groups. This type of group is particularly important when looking at the behaviour of national and ethnic populations, for example in peace keeping scenarios.

Area 3 - Levels of human decision representation

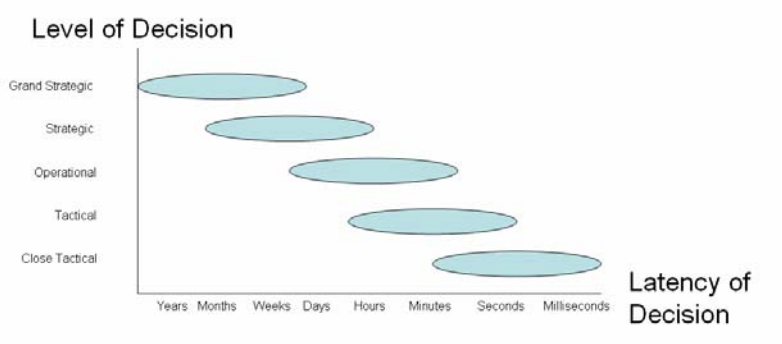

Figure 3 - Area 3: Level of decision

An important consideration, particularly when looking at the representation of human cognitive processes is the level at which a decision is being made. For each level, there is also an associated timeframe for the decision.

- Grand Strategic – Political level and overall objectives

- Strategic – How objectives can be met

- Operational – Campaign level scenarios

- Tactical – Mission level operations

- Close Tactical – Engagements and military tasks.

These levels of decision represent the freedom and authority associated with the decision maker possesses, and as such relate very closely to the types of human representation in Area 2[7]. Areas 2 and 3 taken together form the notion of 'Area of Coverage' of human factors representation. Another useful way of looking at these levels comes from James Reason's study of safety critical systems, in particular the Swiss cheese model (Reason, 1997).

[7] As such they are also aligned with UK Ministry of Defence AMS, 2008

Area 4 - Types of implementation

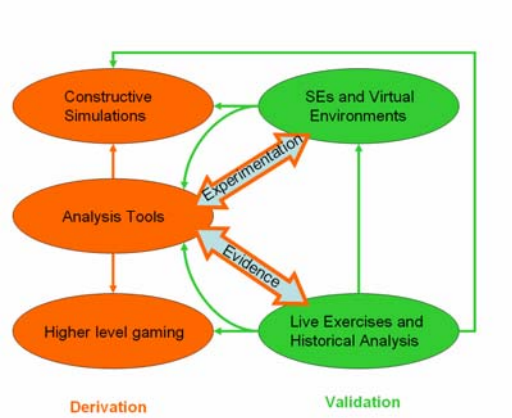

Figure 4 - Area 4: Type of implementation

There are five main types of implementation within which human factors representations can be synthesised. It should also be noted that the different types of implementation can also be used as tools and methods to enable validation and verification. For this reason, live exercises and historical analysis have been included. The five types proposed under the architecture are:

- Analysis Tools. These tools can be used to look at specific aspects of socio-technical behaviour. The main problem with such tools is undertaking sufficient verification and validation to ensure that the relationships that they contain are correctly represented.

- Synthetic Environments (SEs) and Virtual Environments provide an excellent tool for monitoring an individual or team's behaviour by creating a computerized reality for real operators to interact within. From a human factors perspective, SEs are particularly useful for experimentation.

- Constructive simulations use representations of humans and systems to model scenarios without the presence of a human commander. Wargames enable users to direct representative forces. These are extremely useful tools particularly for making predictions about operational performance.

- Higher level gaming. This includes strategic games where users operate by implementing policies, and monitoring the effect on outcomes – red teaming and paper based scenario walkthroughs are typical examples.

- Live exercises, training and historical analysis. As mentioned before, these are sources of information rather than implementations of human factors but they can be very useful for obtaining experimental evidence for analysis purposes and validation.

Area 5 - Types of human factors characteristic to be represented

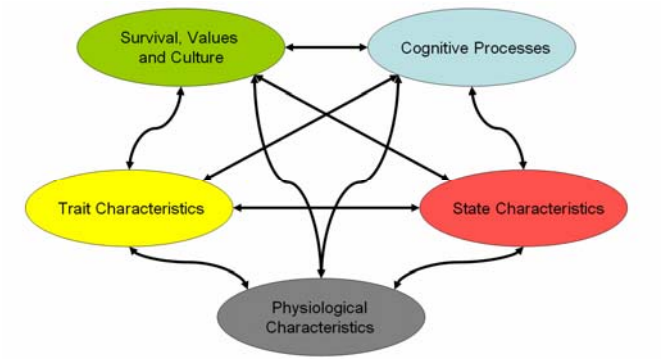

Figure 5 - Area 5: Types of human factors characteristics

A number of well developed architectures already exist which provide modelling frameworks for representing human factors within simulations, including ACT-R (Active Control of Thought – Rational, Anderson, Bothell, Byrne et al, 2004), and Soar (Laird, Newell and Rosenbloom, 1987) which provide a rich source of reference and implementation information.

The INCIDER conceptual model identified over 50 individual characteristics relating to human factors associated with Combat ID. A number of other similar hierarchies have been identified (Schwarz 2007, Alt 2007) as well as comprehensive coverage within the NATO Code of Best Practice for C2 Assessment (NATO SAS-026, 2002). Five essential elements that need to be considered, and are illustrated in figure 5, are:

- Survival, Values and Culture – This group of characteristics represents objectives and rules that the individual or team will strive to achieve.

- State Characteristics – This represents dynamic properties of the individual or team which change in response to the environment. Typically these will include factors such as stress fatigue and fear.

- Trait Characteristics – This represents properties of the individual set prior to the activity (mission or operation) being represented. Examples include personality type, level of experience, and level of training.

- Physiological Characteristics – human physical abilities in terms of strength, speed, fatigue etc.

- Cognitive Processes – This group of characteristics represents the tasks and higher order functions that the individual undertakes. Extremely important among these is the decision making process (Endsley, 1988 contains a useful representation of this). Importantly for Combat ID modelling, this area also includes confirmation bias (Eysenk and Keane, 1999).

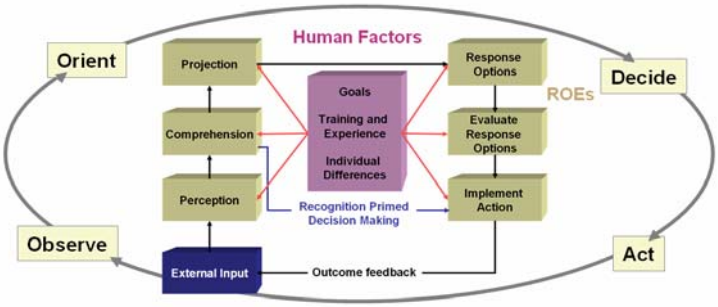

Figure 6 - Representations of human cognitive processes

Figure 6 combines a number of different concepts relating to human cognition within command and control which fit within the cognitive process group.

Area 6 – Quality

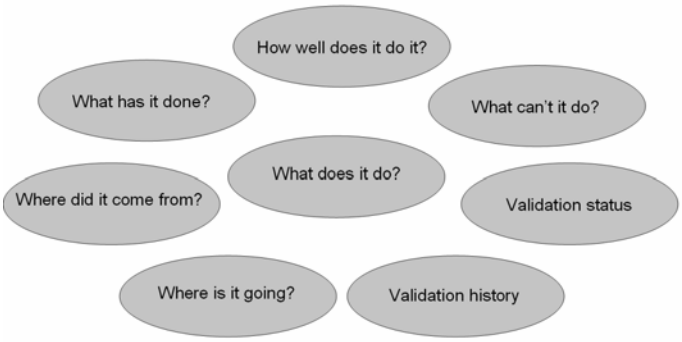

Figure 7 - Area 6: Quality

The main purpose of this area of the architecture is to provide a statement which will enable users of the human factors representation to assess its utility with respect to a particular task. To a certain extent it fulfils the function of a modelling and validation logbook, but applied to a wider set of analysis activities. The key questions and records required are illustrated by figure 7.

3. A process for developing complex human representations

Figure 8 illustrates an integrated analysis and experimentation process to enable evolution from a defined problem to the generation of a human factors representation within a constructive simulation. The central coloured 5 box area represents the core activities undertaken during INCIDER development. These were supported by the grey tasks linking into them.

The process is iterative, and each activity, particularly the central section, should be revisited several times. This ensures that holistic decisions are taken during the development processes, and the consequences of implementation decisions on exploitation routes will be better understood.

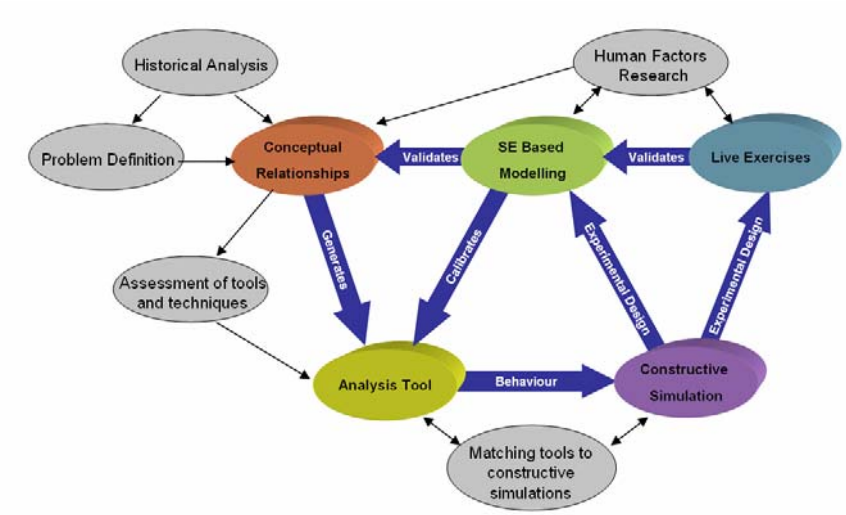

Figure 8 - Process components for Human Factors model development

The process nominally starts[8] with problem definition, this can be supported by historical analysis, and will certainly involve the input of stakeholders – generally military customers. Once the problem has been defined, a set of conceptual relationships to support the human factors representations will emerge. These will essentially consist of a set of human factors along with their definitions, metrics and interrelationships. This will be fed from human factors research (and body of knowledge) and potentially targeted experiments – typically using SEs.

The conceptual relationships can be used as a source from which to derive an number of analysis tools, each representing different facets of human behaviour. Generation of the analysis tool is generally accompanied by a certain amount of iterative experimental development during which time different tools and techniques are assessed for applicability.

The conceptual relationships will need to be validated. The use of synthetic environments, particularly if used to leverage the results from live exercises can be an effective way of achieving a desired level of validation, though this process is likely to need some iteration. Similar experiments can also be used to calibrate and validate the analysis tools.

The next step is to investigate exploitation routes, particularly by looking at potential application within constructive simulations. This requires matching between the simulation and analysis tool which will require both tool and simulation to be assessed for fit. If an existing tool is to be utilised, it must be acknowledged that there may be limitations on the ability of the model to represent the desired parameters.

[8] Due to the iterative nature of the process, it is possible to start elsewhere and work around the cycle to problem definition task – this could be the case for a piece of pure human factors research which has been commissioned with no defined customer question.

The partial (or full) development of a constructive simulation representation will lead to new requirements for validation, verification and research. As a result it will feed back into the initial stages and continue the iterative cycle.

4. A Case Study – Implementing INCIDER within an Agent based Simulation

This section will describe ongoing research to develop a working version of a complex human factors representation within an agent based model. The work is being undertaken following the process outlined in section 3, in particular the INCIDER model described represents a specific example of an analysis tool linked to a set of conceptual relationships which have been partially validated by a series of SE experiments. The behaviour captured has been transferred to a number of constructive simulations including the Close Action Environment (CAEn) and Net Logo.

4.1 The INCIDER model overview

The INCIDER model was developed to answer BOI questions for the UK Ministry of Defence - specifically to look at the balance of investment between Situational Awareness (SA), Target Identification (TID) systems (IFF systems) and Tactics, Techniques and Procedures (TTPs - doctrine and training). After an initial investigation including historical analysis, military judgement, and psychological literature review, the INCIDER model was developed. A number of SE based validation experiments have been held using military participants to validate and calibrate the model and its parameters. The INCIDER model has two main components:

- The INCIDER conceptual model which has captured over 70 parameters grouped under Physical, Human and Operational categories and forms a repository describing area 5 of the architecture – the characteristics to be represented.

- The INCIDER encounter model which is an analysis tool (area 4 of the architecture) representing the process undertaken by a single decision maker identifying a single unknown entity at the close tactical level (from area 3 of the architecture).

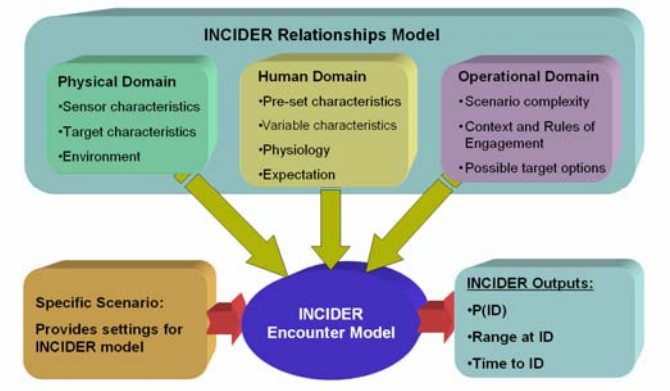

Figure 9 - The INCIDER model

The INCIDER encounter model is summarised in Figure 9. The encounter model process compares new information about an unknown entity (from sensors and information sources) with a representation of preconception. It iteratively obtains more information by using different sources of information, and moving closer to the entity. This process continues until either a decision is reached, or until a timeout condition, indicating that the decision maker was unable to declare an identification decision.

Running INCIDER multiple times enables statistics to be gathered on probability of correct identification, probability of incorrect identification, probability of no decision, time taken to identify, and the range at which identification takes place.

4.2 Implementation within the Net Logo tool

A tool was required which could rapidly be used to develop simple representations of behaviour, and investigate the effect of a large number of different variations in SA, TID, HF, and TTP within different operational contexts on mission level combat effectiveness and fratricide. An analysis of available tools highlighted Net Logo (Wilensky 1999) as being a suitable development environment.

In order to examine effects of a large range of different variations in SA, the use of Data Farming[9] (Brandstein and Horne, 1998) was adopted. Data Farming allows for the investigation of huge numbers of scenarios by the use of efficient experimental designs; a key part of the process is discovering outlying results to identify areas of exception and anomalous behaviours. This also makes it very useful for error trapping during prototype development. The Data Farming practices were engineered in cooperation with the Simulation Experiments and Efficient Designs (SEED) Centre (The SEED centre for data farming, 2008).

The Net Logo model represents a single agent that moves through the environment, encountering and identifying surrounding objects. The allegiance of objects can either be part of the enemy forces (red), neutral (green), or friendly (blue), and can be of type ‘person’, ‘car’, or ‘tank’.

The model initialises by automatically generating a ground truth and perception of red, green, and blue objects. Currently, this is performed by defining centre points on the X-axis (one for red, green and blue). Triangular probability distributions are then initialized with random Y values to set the ground truth and to generate a normalised red, blue and green distribution.

Figure 10 shows a colour coded example of an agents’ belief distribution and a combination of the belief distribution and ground truth. By design, the ground truth and

[9] Data Farming is a method to address decision-maker's questions that applies high performance computing to modeling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options. Potentially millions of data points are explored and captured. It could be considered akin to Data Mining combined with feedback which allows for the more intelligent collection of more data points.

the agents' initial SA are unlikely to match. This enables a wide range of different conditions to be automatically generated within a farmable data set. This study examines the effects of all such combinations on the number of correct identifications, misidentifications and fratricide incidents.

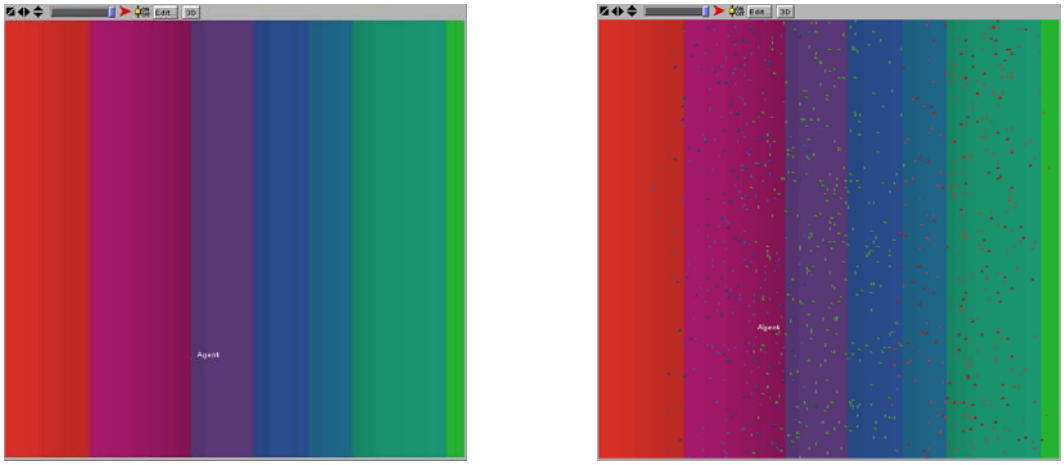

Figure 10 - Initial belief distribution, or situation awareness (left) with ground truth superimposed (right).

After initialization, the simulation begins, with the agent exploring the ground truth, identifying objects, and updating its SA. Exploring the ground truth, is currently implemented as a pseudo-random movement through the environment[10]. The agent can detect, classify, and identify (DCI) objects depending upon range. The DCI values are set as range dependent probabilities, and vary depending upon the ground truth (the values of each are data farmable).

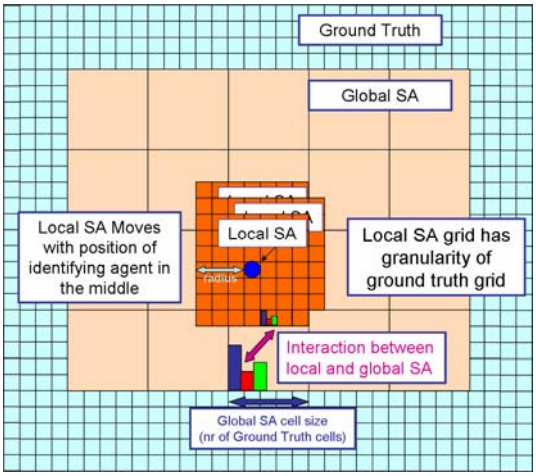

Figure 11 - Local SA and Global SA

[10] Fully random movement could bring the agent into an undesirable loop, not exploring the whole ground truth.

On initial detection, the agent will enter into a representation of the INCIDER decision making process, and can either decide on identity, or move closer. Identification is based on a comparison of the preconception grid, and identification probability. Identification decisions take place once the decision threshold (another data farmable variable) is exceeded by the belief in either preconception or ground truth.

An interesting addition to INCIDER behaviour implemented by the Net Logo model was to introduce the notion of Global SA and Local SA (see figure 11). This creates a distinction between (Global) SA about the entire environment and (Local) SA about the direct surroundings of the agent[11].

Using the data farming approach, the effects of these variations in SA were examined. The number of correct identifications, the number of misidentifications, and the number of fratricide incidents were system outputs. At least 17 parameters were used as farmable variables in each version of the model, and to ensure efficiency of computing, the "Nearly Orthogonal Latin Hypercube" (NOLH) was adopted. This was based on a design, supplied by the SEED Centre (Brandstein and Horne 1998).

5. Summary

The representation of Human Factors within models and analysis is an extremely complex and demanding endeavour. The architecture described by this paper provides a set of checkpoints to characterise and contextualise such representations. This has the potential to reduce the risks, time and costs of model development as part of a Systems Engineering approach to model development. The proposed process described in section 3 is a way of methodically developing representations that fit into the architecture, and has proved to be extremely useful during the development, validation and instantiation of the INCIDER model.

The agent based modelling work has developed a number of unique representations of SA within the context of Combat ID, and has proved to be an extremely powerful and flexible technique for the rapid development of human factors representations. It has the potential to drive the requirements of future simulation development, and may also be able to address a range of focussed analysis questions.

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