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Representing Human Decision Making in Constructive Simulations for Analysis

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Representing a Combat ID Analysis Tool within an Agent Based Constructive Simulation

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Abstract

This paper describes an approach for the development of a model of a complex set of human factors relationships relating to Combat Identification (Combat ID). These factors are incorporated within an experimental Agent Based Model (ABM), using an integrated approach to analysis and experimentation. The paper is based on ongoing work within the UK Defence Science and Technology Laboratory (Dstl), the Netherlands Organisation for Applied Scientific Research (TNO) and the US Naval Postgraduate School (NPS).

Background

The authors have been studying the representation of Combat Identification (Combat ID)[1] 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 the Combat ID process.

This led to the development of the Integrative Combat Identification Entity Relationship (INCIDER) model, an analysis tool that represents a Combat ID 'encounter'[2]. The logic and processes that are included in INCIDER include aspects which are generally applicable to decision-making. Therefore the extension of the model to represent human error mechanisms within other decision-making processes represents a logical next step.

This paper includes a case study describing the implementation of a specific Combat ID analysis tool within two constructive simulations, illustrating a process used to bring all of these strands together as part of an iterative, multi-layered approach to model development.

Introduction

There have been many attempts to introduce human factors into constructive simulations. In the past these have been based upon simple stochastic parameters, intended to represent imperfections in

1. UK military doctrine defines Combat Identification as "The process of combining situational awareness, target identification, specific tactics, training and procedures to increase operational effectiveness of weapon systems and reduce the incidence of casualties caused by friendly fire." (Ministry of Defence 2006).
2. INCIDER defines an encounter as being the process of a single decision-maker detecting and identifying an unknown object or entity on the battlespace as described in Dean and Handley (2006).

the combat and decision-making processes. These tended to represent quality parameters and trigger points at which behaviour would change. Examples include:

- *Training* and *experience* factors which increase—or decrease—detection and engagement ranges, and *engagement effectiveness* (essentially improving the single shot kill probability).

- *Morale* and *fear* factors which, when combined with a *unit quality* attribute, lead to either *panic* and *retreat* or *exuberance* and a degree of *loss of control*.

Although such approaches are valid in their attempts to represent aspects of human behaviour and are perfectly acceptable ways of generating certain representations of human performance, they are limited in their fidelity and cannot be used to represent more complex cognitive processes.

The INCIDER model, which is the basis of the case study described in this paper, was developed as a means of predicting the outcomes of Combat ID encounters. It is a complex and unique tool which predicts the outcome of an identification process undertaken by a single decision-maker observing a single unknown entity. This work has required extensive consideration of the nature of human factors and possible methods for modelling these factors. The INCIDER model has been validated by a number of Synthetic Environment (SE) based experiments, which have provided an empirical link between its representations of cognitive behaviour and behaviour recorded from virtual world observations.

A limitation of INCIDER is its inability to deal with many-on-many encounters. This severely limits the fidelity of its representations of Situational Awareness (SA). The logical next step is to incorporate the core behaviour of INCIDER within an Agent Based Model. This paper will describe work undertaken collaboratively by

Dstl[3] and TNO[4] to implement a representation of the INCIDER model within the NetLogo[5] agent based modelling tool (Wilensky 1999). This work has required the development of a number of novel human factors representations, and has followed an integrated approach to analysis and experimentation.

A Process to Develop Human Factors Relationships

The complexity and uniqueness of the INCIDER decision model led to the development of an integrated analysis and experimentation process. This facilitated progression from a defined problem to the generation of a human factors representation, embedded within a constructive simulation. This process is summarised in Figure 1. The 5 coloured boxes represent the core activities undertaken during INCIDER development; these were supported by the tasks shown in grey boxes linking into them.

The process nominally starts[6] with problem definition. This can be supported by historical analysis, and will certainly involve the input of stakeholders; generally military customers and end-users. 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 defini-

3. Defence Science and Technology Laboratory (Dstl) – Part of the UK Ministry of Defence (MOD) responsible for providing advice on Science and Technology.
4. Toegepast-Natuurwetenschappelijk Onderzoek TNO. An English translation is: the Netherlands Organisation for Applied Scientific Research.
5. NetLogo is a freeware modelling tool, developed by Northwestern University.
6. Due to the iterative nature of the process, it is possible to start elsewhere and work around the cycle to the problem definition task—this could be the case for pure human factors research which has been commissioned with no defined customer question.

tions, metrics and interrelationships. The problem will be fed from human factors research (and body of knowledge) in particular targeted experiments, often using SEs.

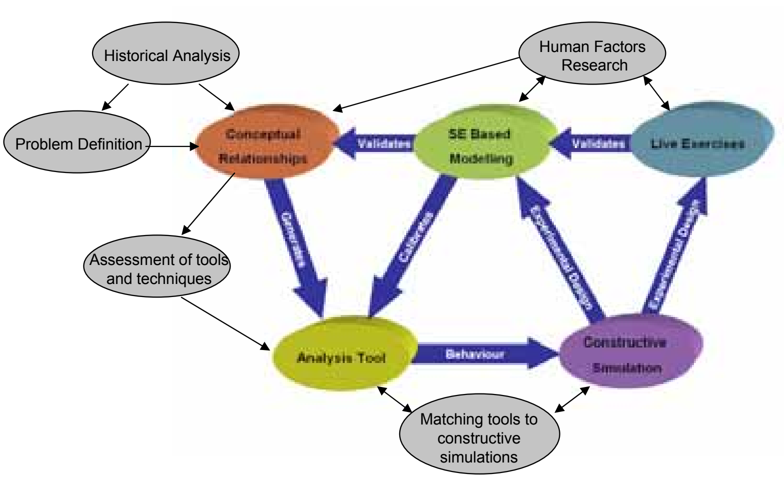

Figure 1. Process components for Human Factors model development.

The conceptual relationships can be used as a source from which to derive a number of analysis tools, each representing different facets of human behaviour. In the case of INCIDER, a model was developed that represented the process undergone by a single decision-maker during a single encounter. In order to assess the 'fitness-for-purpose' of the analysis tool, a number of iterative experiments were undertaken which in turn led to a number of different tools and techniques being assessed for applicability.

Both the analysis tool and conceptual relationships will need to be validated, and it is almost unavoidable that the validation process will result in a revision of both the model and the analysis tool. An effective method adopted by the Combat ID research was to undertake initial validation of INCIDER using SEs, including adaptations of commercial computer games (so-called 'serious games'). It is important to note that any SE to be utilised must be validated against the real world before any inferences about real world behaviour can be made; typically, this can be done through live exercises or historical evidence.

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

Such limitations must be identified early since it is possible that they will be severe enough to render the representation useless. In any case, the representation within the constructive simulation must be assessed against the validation experiment or other empirical data as soon as is practical in order to identify implementation problems early on.

An alternative approach is to opt for a new, bespoke development. This, however, involves a high level of risk. The Dstl INCIDER team, in association with colleagues from TNO, opted for a phased approach to implementation:

- Phase one – an experimental agent based model was developed in NetLogo, to test theories and identify new areas of development and requirements. The model developed, although crude, could be applied to analysis applications.

- Phase two – integrate INCIDER concepts into a modified conceptual model, the Close Action Environment (CAEn). Phase one is currently being used to de-risk future development of CAEn, and it is intended to use lessons learned within NetLogo to improve the future development of CAEn.

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

A Supporting Architecture

In order to support the process of developing Human Factors relationships, it is useful to consider how each stage can be used to develop elements of a supporting architecture. Architecture is a rather grand title, but in this context it simply means a framework within which to categorise and contextualise different types and levels of Human Factors (HF) representation, model, tool or analysis task. Gathering these components together allows some of the important relationships between these areas to be explored. The architecture is illustrated in Figure 2 and described in more detail in Dean et al. (2008).

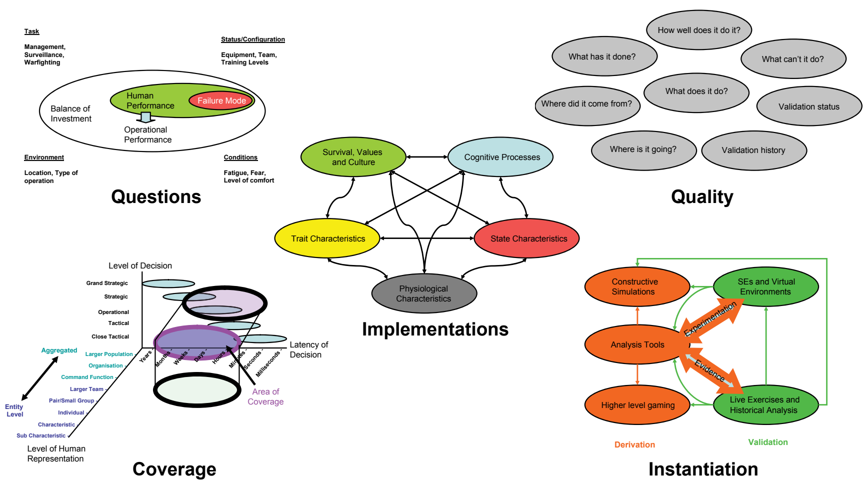

Figure 2. An architecture for instantiating human factors in combat models.

The architecture is composed of six areas[7] which describe the problem space; aspects of human behaviour and performance to be represented; context; and solution space. The areas are summarised in the list below:

1. *Types of question* – What questions do the models and representations need to address? These can include investment decisions, assessment of operational effectiveness, computation of reaction times etc. It is important to understand what questions are to be addressed in order to assess the suitability of an analysis approach, and the fidelity required.

2. *Types of human representation* – Is the model representing individuals, teams, or other types of abstracted behaviour? The answer may be all three, but each type will give rise to different assumptions and demonstrate human characteristics in different ways.

3. *Levels of human decision representation* – There are four main areas of representation that constructive simulations need to address; Strategic, Operational, Tactical and Close Tactical. Associated with these are different decision times, and different types of interaction with encompassing and interfacing systems.

4. *Types of implementation* – What type of analysis tool or constructive simulation is the human representation to reside within? In particular, what constraints does it impose upon the human representation?

5. *Types of characteristic to be represented* – Which human aspects are to be represented? This could represent anything from cognitive processes to physiological performance.

7. Note that 'Level of Decision,' and 'Level of Human Representation' have been combined under the 'Coverage' category in the figure above.

6. *Quality* – What is the status of the representation? Has it been validated? What degree of confidence can be attributed to its use?

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 previously. Two models are being used:

- CAEn. This is an existing combat model used within Dstl. Ongoing research had already made some progress in the investigation of different methods of representing Combat ID, making it a suitable fit for the incorporation of INCIDER parameters.

- NetLogo. This is an off the shelf agent based modelling environment. The representations that are achievable within it are relatively crude; however it is an extremely useful test-bed for identifying and exploring functionality that can be used both to de-risk CAEn development, whilst at the same time leading to the production of a simple simulation tool.

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, and Tactics, Techniques and Procedures (TTPs; e.g. doctrine and training). The INCIDER model was developed based on an initial investigation including historical analysis[8], military judgement and psychological literature review[9], and has two main components:

- The INCIDER conceptual model is a repository containing more than 70 parameters relating to the Combat ID decision-making process, grouped under physical, human and operational categories. The conceptual model represents area 5 of the architecture, the characteristics to be represented.

- The INCIDER encounter model is an analysis tool which represents the process undertaken by a single decision-maker identifying a single unknown entity. In particular it represents the following:

    - The distance between the entities at initial detection;

    - The real identity of the unknown entity;

    - The sensor systems and information sources available to the decision-maker;

    - Human characteristics of the decision-maker (Personality, Experience, Stress, Fatigue);

    - The level of confidence that the decision-maker needs in order to make a decision;

    - The decision-maker's preconceptions (what they are expecting to see).

8. For example Regan (1995); Sa'adah (1992); and Bickers (1994)
9. For example Newell (1990); Nofi (2000); Eysenck and Keane (1999); Reason (2000); and Klein (1989)

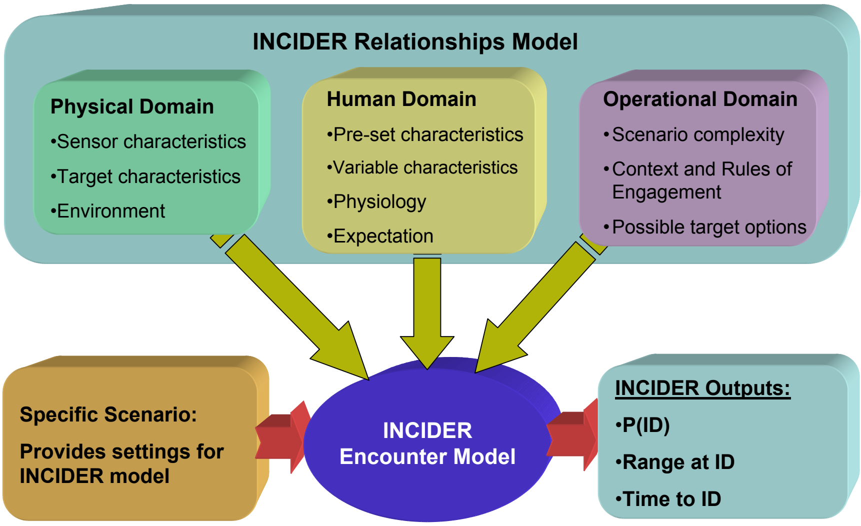

Figure 3. The INCIDER model.

The INCIDER model is summarised in Figure 3. The encounter model process compares new information about the unknown entity (from sensors and information sources) with a representation of preconception (based on a mixture of pre-mission briefing and gut feel). It then iteratively obtains more information by using the different sources available and by moving closer to the unknown entity. This process continues until either a decision is reached, or until a timeout condition is reached, 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 (i.e. the separation between the decision-maker and the unknown entity).

Representation of INCIDER within CAEn

A review was undertaken to identify existing models that would allow, and benefit from, an improved representation of Combat ID. The model highlighted by this process as having the closest match to INCIDER requirements is CAEn.

CAEn is a stochastic, multi-sided, close combat interactive war game and simulation, representing the all-arms battle at up to the company group level. When used as a simulation, the players give orders before the model is run and these are executed at the appropriate moment during the game. In wargame mode the players interact with the simulation directly, giving orders to the entities under their control[10].

The model enables 15 players and up to 15 sides to participate at once. This allows some scope for representing the confusion caused by the many factions involved in Peace Support Operations. It can be played at two resolutions; a 10m resolution and a 1m resolution (used primarily for urban scenarios). The model can operate the true 3D environment, as experienced by any individual entity (Figure 4); however it is usually operated via the 2D display shown in Figure 5.

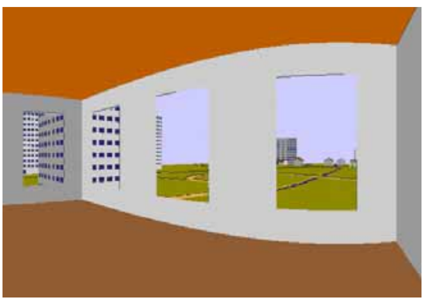

Figure 4. CAEn sensor view.

Figure 5. CAEn 2D display.

10. An entity in this context can be an individual soldier, a civilian, a vehicle or a remote system.

Implementing INCIDER Behaviours within CAEn

CAEn used a procedure similar to the one shown in Figure 6 in order to identify unknown entities on the battlespace[11]. This process did not permit the agents within the model to incorrectly identify an unknown entity.

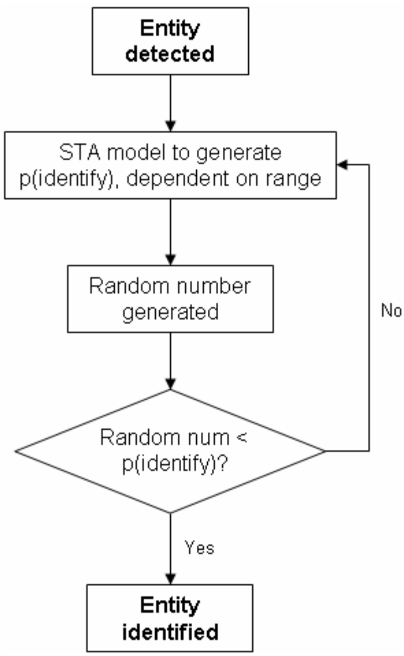

Figure 6. Basic CAEn ID process.

It was decided that a simplified version of the INCIDER process would first be implemented. The areas developed during this initial implementation are outlined below and illustrated in Figure 7.

11. The term "STA model" in Figure 6 and Figure 7 refers to the probabilistic Surveillance and Target Acquisition (STA) processes already used within CAEn. The term "p(identify)" refers to the probability that the unknown entity is identified; this is generated by the STA model.

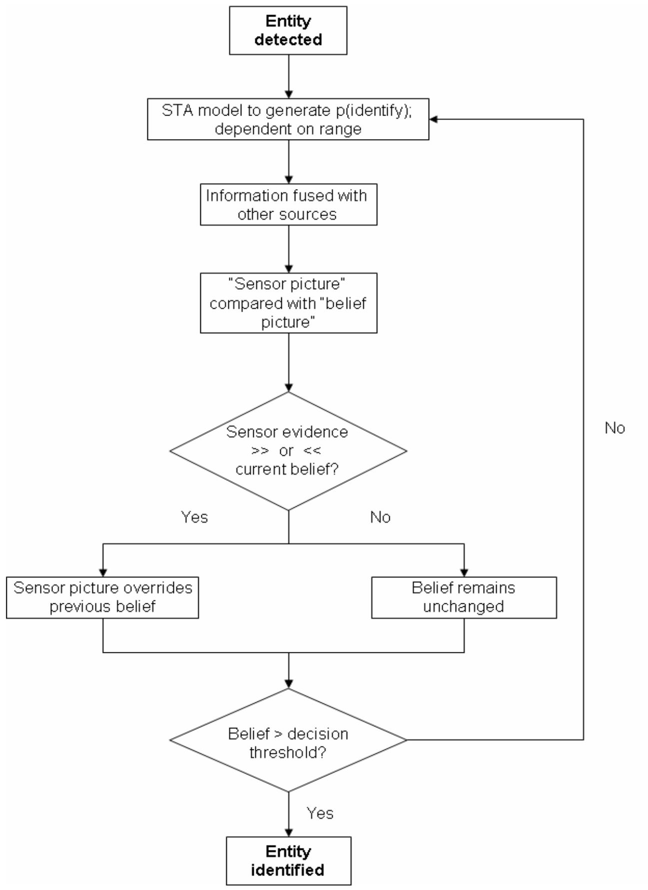

Figure 7. Flow diagram showing new CAEn ID process.

- *Preconceptions, derived from the pre-mission briefing.* This refers to the effect that preconceptions have on the decision-maker[12]. Preconceptions are represented by allocating each entity type (Blue, Red, White[13], Other) a score on the range [0,1]; the higher the score, the greater the expectation of meeting an entity of that type.

12. In CAEn, the term 'decision-maker' refers to the individual agents that represent entities within the model.
13. For various technical reasons CAEn refers to neutral entities as white, whereas NetLogo refers to them as green.

- *Cognitive sensor fusion.* The INCIDER model allows the decision-maker to take feeds from a variety of information sources, including sensors, situational awareness aids, radio updates etc.

- *The INCIDER decision engine.* Once the information from the various information sources has been fused, it is compared to the current level of "belief"[14] using a decision engine. If an appropriate level of evidence has been provided from information sources, the current level of belief will be overridden; otherwise the decision-maker will ignore the information from his information sources.

- *Decision threshold.* The decision threshold represents the level of evidence required for a positive ID to be made. This is currently a range-dependent function; as the separation between the decision-maker and the unknown entity closes (as a result of the agent moving closer to the entity), the threshold falls to reflect the need to maintain battle tempo and the increased potential threat posed by the unknown entity.

Further Extensions

In addition to these behavioural alterations, a number of other changes have been made to CAEn.

- *Fatigue (sleep deprivation).* Within INCIDER, the effects of sleep deprivation are represented by a decrease in the ability of the decision-maker to draw information from his sensors and other information tools.

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14. The concept of "belief" is taken from Dempster-Shafer Evidential Reasoning; see Dempster (1967); Shafer (1976, 1990); Koks and Challa (2003).

- *Expanded sensor fusion algorithm.* CAEn is required to represent a large number of entities simultaneously, with each entity containing a decision-making process. In order to minimise the effects of these extra computations, the sensor fusion algorithm used in INCIDER was reviewed and refined, potentially allowing an infinite number of sensors and entities to be represented simultaneously.

- *Visualisation.* A single player in CAEn will control a number of entities, some/all of which will be attempting to identify an unknown object. This may, for example, lead to some entities identifying the object as friendly, while others within the same group may identify it as an adversary. Such a discrepancy must be communicated to the player. The mechanism used by the CAEn team to represent this is to enclose each entity in coloured brackets, representing the believed allegiance of the unknown object.

- *Preconception grid.* Unlike the INCIDER model, which considers the identification of only one unknown entity in one area of the battlespace, CAEn needs to represent the different levels of decision-maker preconception across a wide area of the battlespace. Currently CAEn are considering implementing this by introducing a grid covering the battlespace, with different squares within the grid having different levels of preconception based on the briefing given to the players. This is the key feature which was investigated by the NetLogo tool. The results of this will be fed back into CAEn during the next extension, currently planned to be completed by mid 2008.

Implementation within the NetLogo 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 suitable tools highlighted NetLogo as being a suitable development environment (Wilensky 1999).

In order to examine the effects of a large range of different variations in SA, the use of Data Farming[15] (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 SEED Centre[16].

The NetLogo 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.’

Initialisation

The model initialises by automatically generating a ground truth of red, green, and blue objects (this uses a random distribution and is therefore data farmable). Currently, this is done by defining three random centre points on the X-axis (one for red, green and blue). A triangular probability distribution is then initialized around this point with random Y values.

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15. Data Farming is a method that applies high performance computing to modelling in order to examine and understand the landscape of potential simulated outcomes, enhance intuition, find surprises and outliers, and identify potential options.
16. The SEED Center for Data Farming http://harvest.nps.edu/

Figure 8 shows an example object distribution. In this Figure, green objects are fairly central within the environment. For each run, the centres of each side will differ, enabling random amounts of overlap between sides, and hence enables the automatic generation of a large number of random scenarios.

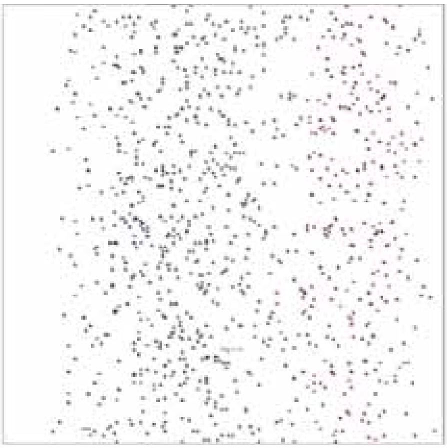

Figure 8. Ground truth distribution.

The model now generates an overlay of preconception. This represents what the agent thinks is in the ground truth[17] (this can also be considered as its belief, or SA). The agent's belief of a certain spot in the environment is defined as a normalised triplet (for each point on the grid, the belief in the identity at that location of each of the allegiance types is set to a particular normalized value). For example, the triplet is [0.8 0.2 0.0] states that Blue expectation is 80%, Red expectation is 20%, Green expectation is 0%. The mechanism for defining centre points is also used for the distribution of beliefs. This distribution of beliefs is parameterized, and thus data farmable.

17. This essentially represents a decision-maker's prior belief, typically as a result of information gained from a pre-mission briefing.

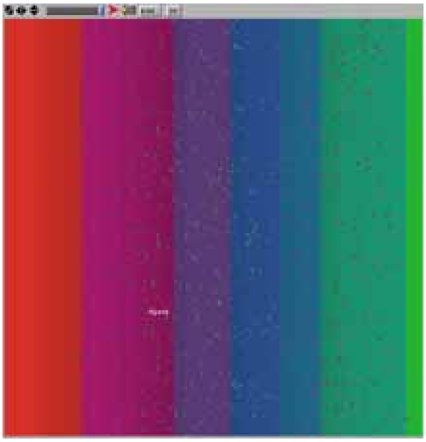

Figure 9. Initial belief distribution, or situation awareness (left) with ground truth superimposed (right).

Figure 9 shows a colour coded example[18] of an agent's belief distribution and a combination of both layers combined. By design, the ground truth and the agent's initial SA are unlikely to match. This enables a wide range of different conditions to be automatically generated within a farmable data set.

Agent Behaviour

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[19]. The agent can detect, classify,

18. In these figures, the colours have been mixed to represent the relative percentages of red, blue and green (purple is a mix of blue and red etc).
19. Fully random movement could bring the agent into an undesirable loop, not exploring the whole ground truth.

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).

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 current level of belief.

Representation of SA

An interesting addition to INCIDER behaviour implemented by the NetLogo model was to introduce the notion of Global SA and Local SA. This creates a distinction between (Global) SA about the entire environment and (Local) SA about the direct surroundings of the agent[20].

The size of the local SA and the granularity of the global SA are parameterized (and thus data farmable). The local SA is updated each time new sensor information is accepted or as a result of moving. When the agent moves, the local SA grid moves with it, keeping the agent centred. As a result of the move, some cells will be removed from the local SA and new cells are added, taking the belief distribution of the global SA cell as its initial belief (see Figure 10).

20. Global SA may be viewed as a part of history, or Long Term Memory (LTM), and Local SA as Working Memory (WM).

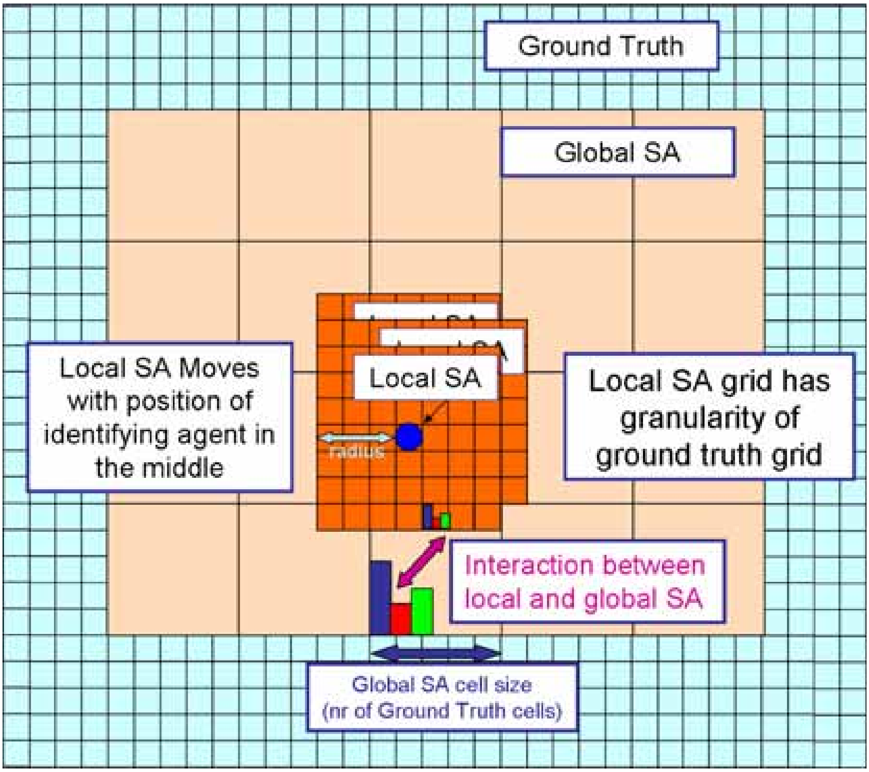

Figure 10. Global SA and Local SA.

The effects of having different granularities in Global SA are illustrated in Figure 11. After encountering an object, an agent who has a detailed Global SA updates its belief over a small area, whereas an agent with a less detailed Global SA updates its belief over a larger area. The same holds, to some extent, in real world (battle space) environments. In case of open warfare one could roughly localize the enemy. However, within urban warfare behind each wall, door, or window there might be an ally, a citizen, or an enemy. A number of implementations of SA were investigated, in particular how global SA can be updated from local SA and observed ground truth. These are discussed in the section entitled *Experimental Variations*.

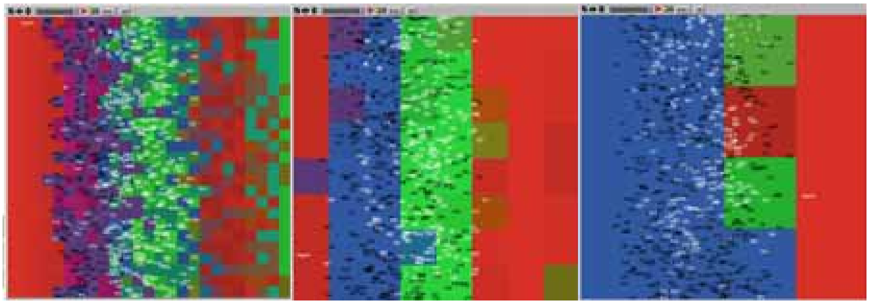

Figure 11. Different granularities of global SA.

Representation of Preconception

The INCIDER study identified human factors confirmatory bias concepts[21] as among the most important influences on Combat ID. In order to model these concepts, Information Acceptance Curves are used to represent the agent's willingness to accept/reject sensor input.

Figure 12 shows an example of the curves used to represent confirmatory bias. They act as a band reject filter, with sensor inputs that fall between the reject bands being ignored in favour of the preconception. The usage of the curves is described below.

- The appropriate upper and lower bounds are calculated from the current level of belief in a particular entity type; e.g. in Figure 12 the current Blue belief score of 0.4 translates to a lower bound of ~0.29, and an upper bound of ~0.72.

21. Confirmatory bias is the tendency of individuals to reject new information because it does not agree with their prior beliefs (see Eysenck and Keane (1999)).

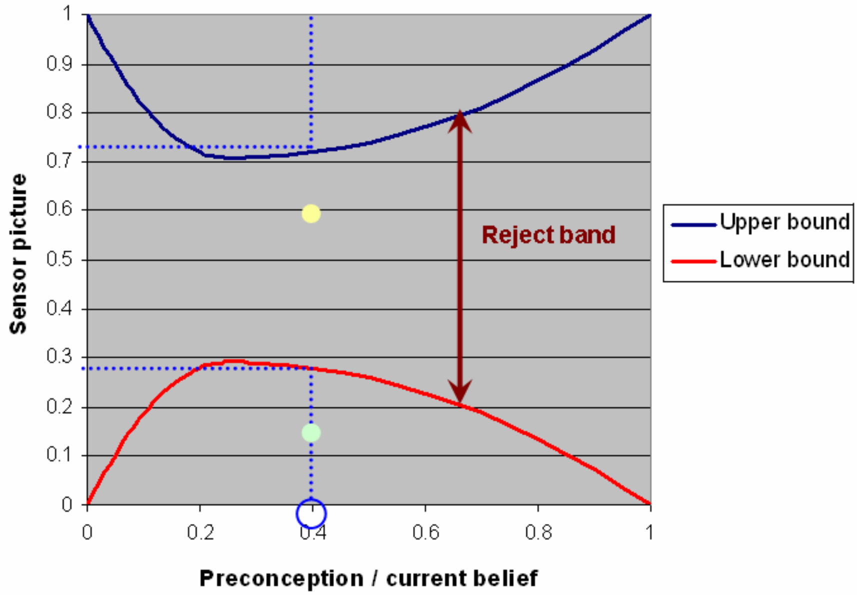

Figure 12. Information acceptance curves.

- If the information received from sensors and other information sources suggests that the likelihood that the entity is Blue is below the lower bound or above the upper bound, the current belief is replaced by the sensor picture for that entity type; e.g. the green dot in Figure 12.

- However, if the information received from the sensors falls between the upper and lower bound then insufficient evidence has been seen to override the current belief, and the decision-maker ignores his sensors (during that iteration); this situation is shown by the yellow dot in the diagram.

- This process is repeated for the belief scores of each of the four entity types.

As the agent becomes more receptive to new information (or more open minded) the reject band between the two sets of curves decreases. As the agent becomes less willing to accept new information (or close-minded) the opposite is true, and the agent's preconception determines the outcome of the identification process leading to a higher potential for misidentification.

The level of information acceptance or openness is parameterised (and thus data farmable). For the initial versions of these curves, the top of the Information Acceptance Curves was (always) 1, and the Y-axis intercept is 0. This indicated a preconception or belief level that was so strong, whatever evidence the sensors presented was ignored (though the likelihood of achieving such a state was very remote).

Currently, the Information Acceptance Curve remains fixed during a single run.

Experimental Variations

A number of variations, based on changes to the implementation of the Global SA, Local SA, and Information Acceptance Curves were implemented. In particular, experimental runs were made with several variations of Global SA and its method of update:

- In the first version, a count is kept of the allegiance of objects identified within each global cell. After each new identification, the preconception values within the global SA cell containing the identified object are updated to reflect an average of the entities identified so far.

- In the second version, a parameter "Belief Increase Steps" (BIS) was incorporated to update the Global SA grid in steps towards a probability of 1 (100% preconception). The global SA preconception in a particular allegiance is increased by 1/BIS after each positive identification.

- In the third version, a parameter "Surprise Level" was implemented[22]. A surprise function was defined to represent bigger changes of global SA if an unexpected result was obtained, and smaller changes if an expected result was obtained[23] (see Figure 13).

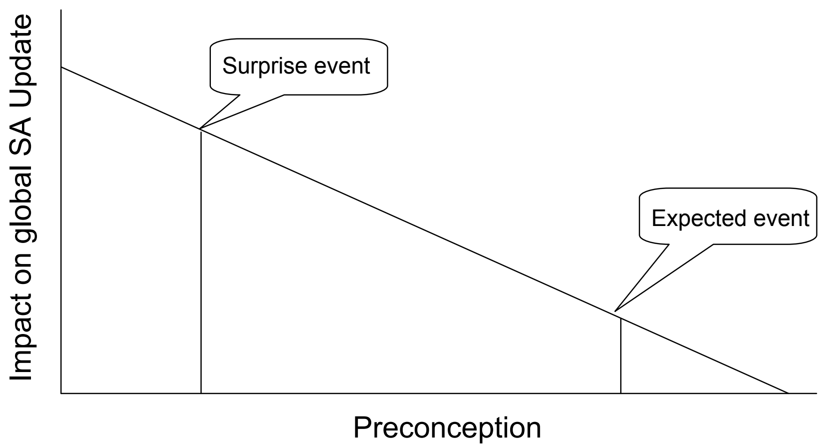

Figure 13. "Surprise Level" function.

- In the fourth version, version 3 was extended to include variable ranges of the lower and upper bounds of the Information Acceptance Curves, including a change to allow the curves to

22. This mechanism tries to represent the premise that a "surprising" result has a greater impact on the decision-maker than an expected result.
23. An example of a surprise event is a friend being identified within an area associated with enemy forces.

cross the y-axis at points other than 0 and 100. This enables better control of information acceptance behaviour and in particular solved some problems with the previous curves[24].

Using the data farming approach pioneered by the NPS, 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 Centre16.

Future Development

Progress to develop a partial representation of the INCIDER model has been highly successful, and the behaviour of the agent based model continues to grow. The approach has proven to be an extremely valuable learning experience which will contribute to the definition of future constructive simulations. In particular it has spawned some unique representations of SA. The prototype is now at a stage where the decision elements can be moved to more complex implementations and will be used to drive future development of CAEn. Some of the options for future development of the NetLogo model are described below.

24. The data farming approach was extremely useful for identifying problem behaviour during prototype development.

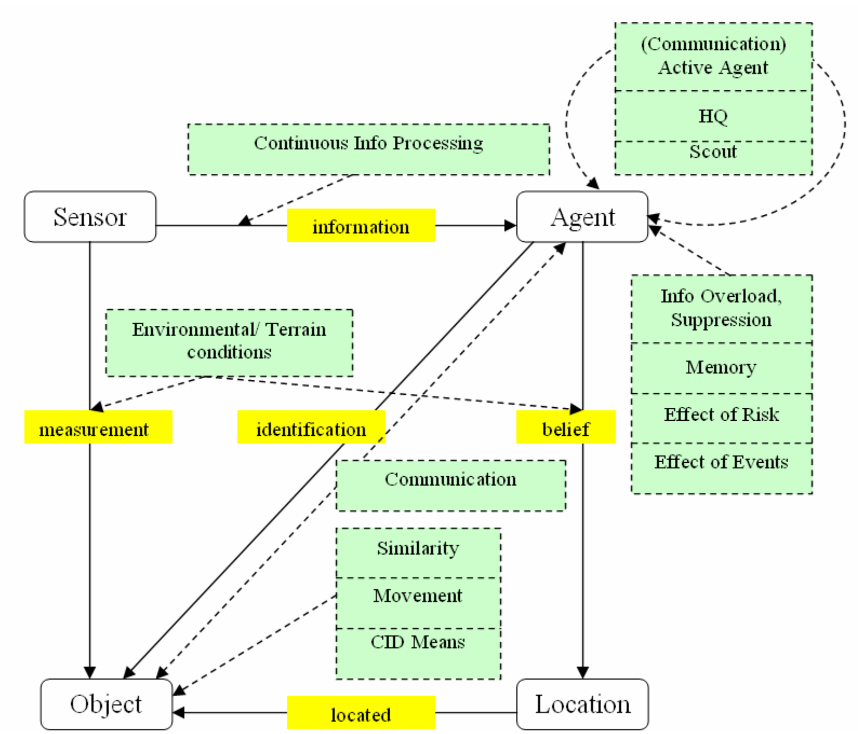

Figure 14. Agent conceptual model.

The NetLogo agent behaviour is summarised by Figure 14. The figure shows all of the key aspects of agent and environment that need to be represented within the Combat ID model. There are two main areas that are currently being considered for future development:

- The first is the modification to the way the decision-making agent processes sensor-input, represented by the link between "sensor" and "agent" in the figure. In the current version, the sensor provides two options for probabilities to represent close and distant objects. To improve this representation it is intended to use a higher resolution, continuous information set based on the ACQUIRE model (U.S. Army 1995).

- The second is a representation of terrain, weather conditions and object similarities to be taken into account. These play an important role in identification, and can lead to 'a belief disturbance.' In specific cases, this can lead to a belief in the wrong hypotheses, and as a result an enhanced representation of weather and terrain has the potential to create more fratricide opportunities. The representation of weather and terrain may be regarded as distortions between the sensor and the object, and can also be applied between the agent and the location, as shown in Figure 14. One could also view these conditions as properties of the location, in the same way that similarity is a property of the objects.

Development in these areas will allow for more disruptive factors to be incorporated into the model. Currently, new information is processed in a rather simple way. New sensor information is combined with old belief according to the information acceptance curve, and a decision is made when the belief is above the decision threshold. It is assumed that the new sensor information is always correct, although the agent may not be willing to accept it.

However, information may not always be perfect or complete, as shown in Table 1 (evolved from Nofi (2000)). This table shows how the user's confidence and the actual quality of SA can be mismatched. The worst case situation (in red, top right) represents a decision-maker incorrectly assuming they have correct information, when it is actually incomplete, inaccurate or inconsistent—this situation is potentially the most serious from the point of view of fratricide. The green top left and bottom right boxes represent correct assumptions about information quality, and the bottom left box amber represents a potential for lost opportunity, where the decision-maker is likely not to believe information which will slow down the decision-making process.

Table 1. Subjective and Objective Assessment of (Sensor) Information

	Quality of information: High	Quality of information: Low
Confidence in information: High	• all relevant info present & correct • subject is confident in information	• some info missing • subject is confident in info
Confidence in information: Low	• all relevant info present & correct • operator is uncertain	• some info missing • operator is uncertain

Summary

This paper has described an architecture and an associated process for the representation of human factors within constructive simulations, which has proved to be extremely useful during the development, validation and instantiation of the INCIDER model. The migration of the INCIDER model to constructive simulations has developed a number of unique representations of human decision-making and SA within the context of Combat ID.

The use of the NetLogo experimental prototype has proved to be an extremely powerful and flexible technique for the rapid development of human factors representations and has been used to de-risk future development of the CAEn model. It is anticipated that the human representations within the CAEn model will soon evolve to a level where it can provide a flexible representation of combat ID. This will allow for its application to a variety of analysis tasks.

The NetLogo tool remains as an adaptable developmental testbed, and has the potential to continue to drive the requirements of future simulation development. However it too could have applications as an analysis tool to address a range of focussed analysis questions.

Conclusions

The representation of Human Factors within models and analysis is an extremely complex and demanding endeavour. The architecture 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 agent based model representation described by the case study has made huge progress in an extremely short space of time. The prototypes are still being refined and expanded, and it is planned to have much more complex behaviour represented within the models. The data farming approach has proved to be an excellent way to de-risk model development. A number of novel representations of SA have also been developed which can potentially be applied to a variety of different applications.

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