THREAT AIRCRAFT INTENT ESTIMATION IN JOINT AIR DEFENCE WITHIN OPERATIONS

By

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Abstract

The objective of Joint Air Defence (JAD) is to defend own assets against all types of hostile aerial attack. Due to modern trends this will often occur within the context of Operations Other Than War (OOTW). OOTW is a complex environment where discrimination between friendly and hostile becomes extremely difficult.

The modern airspace is much busier than a few decades ago. This has also become a rich environment for attempting terror attacks against military and civilian targets. A capability is required to determine the intent of an aircraft to assist in classification of airborne threats/targets. Throughout all military operations Intent is used to plan and execute operations. Knowledge of the enemy's Intent will be useful to predict his actions. The estimation of Intent can be modelled through a Command and Control (C2) simulation system employing Agent Base Modelling (ABM) to capture human cognitive and social interactions. This can be implemented as a Sense-Making tool in the form of modelling and simulation of the enemy C2 process to be used in estimating a set of planned actions.

1 Background

To reduce the risk of fratricide and collateral damage, the accurate knowledge of identity and classification of an aircraft is crucial. This is ever increasing in importance due to the occurrence of civilian and neutral aircraft within the environment of OOTW "battlespace". Even if the identity of the aircraft is totally legitimate, there is still no certainty on the intent of the flight crew. The aircraft may be hijacked or stolen to commit an act of terror or crime.

Within the South African context the new focus is on border control and protection. Small aircraft is a convenient way of smuggling contraband, stolen goods and weapons over borders to small and obscure airfields. During border protection operations the identification of criminal or smuggling aircraft and verification of their destinations are required. Often these aircraft may utilise false flight-plans and disable their transponders.

Despite having identified an aircraft, it is still impossible to determine what is happening in the cockpit and even in the minds of the crew. The pilot who took off may not even be in control of the aircraft anymore. No Identification Friend or Foe (IFF) or related identification system can provide that type of information. There is no way to derive what their planning entails and what the actions are going to be. This compounds the uncertainty when performing Air Defence Control (AD Control) to engage an aircraft.

Therefore, knowledge of the Intent of the aircrew in an aircraft to augment identification and classification is a crucial factor in successful Joint Air Defence Operation (JAD). This paper proposes a mechanism for determining and tracking the intent of an aircraft within a JAD. Using general C2 principles with the focus on Sense-Making and Decision-Support, a tool can be designed and implemented to support Intent Estimation and/or Intent Tracking. However, the complexity challenges associated with determination of intent while harnessing the cognitive and social advantages found within a Network Centric Warfare (NCW) system must be addressed.

2 JAD as a Complex System

Many difficulties are associated with the safe and successful execution of JAD as it operates within a complex environment. This is especially true for OOTW or Border Control operations. According to the author's previous work [1], JAD has a hierarchical structure with many interfaces to entities inside and outside the SANDF. These interactions occur at different levels of the hierarchy. The amount, type and criticality of the data exchanged causes complex interactions between these entities. Coordination is required with different organisations inside and outside the SANDF. Sources of intelligence, such as flight plans, may originate from international organisations.

The external environment to the JAD systems may be explained by self organised behaviour. The environment consists of own forces, civilians, the enemy or belligerents and criminal elements. In the case of OOTW, civilians with their social interfaces, culture and motives will cause a diverse range of actions and reactions. Rossouw [2] explains it as a set of complex multidimensional conflict management activities with a diplomatic and political focus, in which the

military is but one of the many role players involved. All these characteristics lead to unpredictability within the operational scenario. This will serve as an input to the possible decisions the JAD C2 system will be confronted with.

One of the most significant sources of complexity in a JAD system is the timescales involved. The system is required to be operational for extended periods of time as attacks can happen at any time of day. Operations can be as short as a few hours up to a number of months. During this period the systems are required to perform surveillance, building the situation picture and make decisions while the environment is continuously changing.

Despite long operational time, compressed timelines exist when engagements occur and decisions are to be made. Once a target requires action, the operators are required to analyse information based on situation awareness, make decisions on the action required, issue orders and monitor the engagement. This will necessitate the support of an automated Decision Support system to support human action.

During Border control operations the smuggling aircraft may vary from business jets to micro-light aircraft. For a successful interception, the criminals must be pounced upon during this small window of opportunity. The authorities require up to date information on where suspicious aircraft may be landing.

3 Command and Control in Warfare

In order to understand the role of Intent, the general field of military C2 should be considered. As JAD is a special case in general military C2, this will form the basis of the discussion. The total generic process of C2 within a military context, as derived from the work of Alberts [3][4] and Mason [5], is presented in Figure 1.

For any operation, military or civilian, some form of Intent or objective is required. This is the basis for all planning and decision making to follow. The value of knowing the actual and true Intent of the opposing forces is invaluable. Knowledge of the enemy's Intent will insure that own Intent is correctly formulated and the planning optimised.

The initial Intent is the result of first-order Sense-Making of the environment, supported by an existing Awareness, mainly formed by the available intelligence and perception of the enemy's past and current actions. The Intent should be the high level solution to that overall "problem". The available capability package should govern the extent of the total Intent.

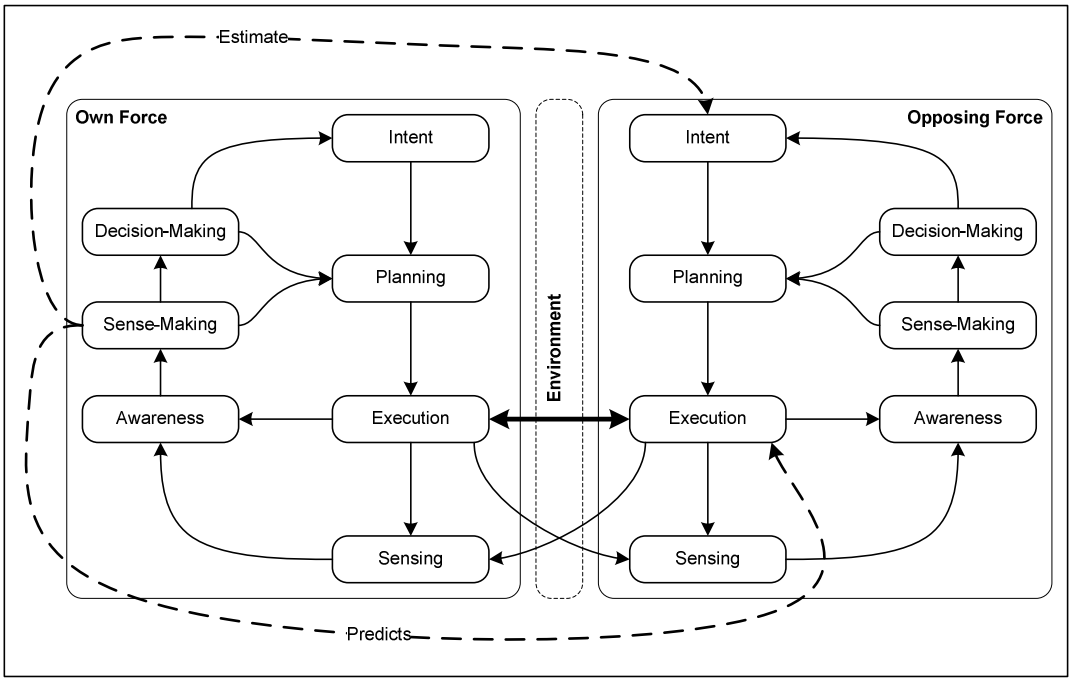

Figure 1: Using Intent in Command and Control

The Intent is the starting point for planning an operation and guides the development of a plan for the operation through selection of options and alternatives. Intent is linked to the enemy's objectives. The optimum is if the enemy's actual Intent is known. Planning is often performed on perceived enemy Intent.

The plan guides the execution of the operation. Actions of own forces during the execution of the plan have an effect on the opposing forces, the environment as well as on the own forces itself. This may cause changes in both the enemy's and own Intent, resulting in different plans for future actions.

The execution and progress of the planned actions are continuously monitored for success as well as changes in the environment and opposing force actions/reactions. This is compiled into an Awareness of the current situation. Sense-Making can then be used "predict" what the next actions of the opposing forces or the changes in the environment will be. This constitutes the "Control" aspect of C2. Contradictions between past Sense-Making and current Awareness point towards an invalid assumption on the enemy Intent and planning.

Knowledge of the enemy Intent and the changes thereof are extremely useful in guiding the planning own course of action. Using the Intent of the enemy will ensure that the tradeoffs between options will be more effective during Decision-Making. Sense-Making support tools may use the Intent and the observed current status of enemy assets to predict future actions. Furthermore, knowledge of the possible effect of own actions on the enemy's future actions may be used to optimise plans.

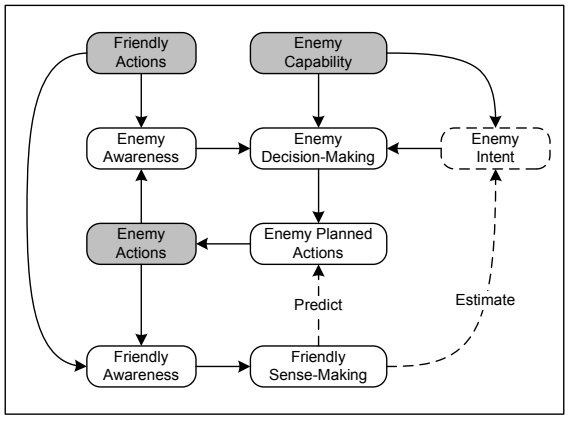

Figure 2: Enemy Action Prediction

A Sense-Making tool in the form of modelling and simulation of the enemy C2 process can be used to estimate a set of planned actions. The perceived Intent will be the main input. Planned own forces action will be simulated in combination with these. As the progress of actions is detected and Situation Awareness updated, it can be compared against the predicted results. The differences can be used to augment the initial estimations on Intent and planning. Alternative choices of own plans are continuously tested against these for the best possible outcome.

Figure 2 summarizes the prediction of enemy actions and estimation of enemy Intent. The shaded blocks indicate to information known to some extent. The only variables are the Intent and enemy actions. Over a period a trend can be formed of the enemy actions, leaving only the Intent as an unknown variable. This process will assist in Sense-Making to support Decision-Making.

4 Sense-Making and Decision Support

4.1 Command and Control in JAD

A C2 network is the integrative element that will ensure effective JAD implementation. The value of knowledge of the overall Intent of the opposing force remains valuable in planning of the defence of vulnerable points. During the Execution and Sense-Making phases on a tactical level the knowledge of the Intent of individual aircraft should improve AD Control.

The ability of the operator to make a "good" decision or select the appropriate action will influence the effectiveness of the complete JAD system. Within an OOTW scenario, two of the main political considerations are fratricide and collateral damage. The operators within the JAD system must decide if, where and when to engage a perceived airborne threat. The following aspects are determined by effective decision-making:

- Threat Hostility Classification or Target Classification.
- Track Management.
- AD Control.
- Threat Evaluation and Weapon Assignment (TEWA).

The cycle relates to all levels of warfare, i.e. strategic, operational and tactical. The plan for one level equates to the intent of the next lower level. The knowledge of intent at any level is of importance for the planning and execution cycle.

At a strategic level knowledge of enemy intention is very important as it will determine to initial objective of any operation. With decentralised (mission) control the lower tactical level is interested in the intent at a tactical level.

4.2 Intent Tracking in JAD

JAD presents a continuous stream of information over a long period. Sources are radars, Intelligence, flight plans, Electronic Warfare and tracking of own force elements. When harnessing this richness in information, the Sense-Making and Decision-Making can be greatly improved. A Sense-Making and Decision-Making support tool based on Agent Based Modelling (ABM) may be useful in utilising the available information.

Every track, air or ground, must be handled as an agent. All possible information available on that track must be tagged and monitored to guide its behaviour. The crew, operators and passengers of aircraft may be implemented as sub-models within the agents.

The current actions of an aircraft, tracked through one or more sensors, must be continuously monitored and measured against the original or "presumed Intent". Deviations should be automatically picked up and highlighted for the operators. All past information recorded and implemented in the agent models will form a history to be compared with the information available on the Intent.

Although humans have a unique cognitive capability, it is impossible to monitor a large number of aircraft for minor deviations in their behaviour. Computerised systems will do the bulk of the monitoring and only highlight those aircraft that deviate more than a set threshold.

4.3 Parameters of Intent

4.3.1 Flight Plan

The origin of aircraft's "presumed Intent" is the flight plan, if available. It will indicate the point of origin, destination, planned times, aircraft type, purpose and payload. These present a useful basis to compare the actions and aircraft track against.

The flight plan should be available from all friendly and neutral aircraft, either military or civilian. Friendly or neutral aircraft without a flight plan should immediately receive special attention. The flight plan of military enemy aircraft in a conventional setting will not be available, but their intent should be predictable.

4.3.2 Rules of Engagement

The Rules of Engagement (ROE) set the guiding "rules" of an operation. They provide the guidelines for execution and measuring of agent behaviours.

4.3.3 Track Information

The trajectories of the airborne agents will be populated and form the basis for behaviour assessment. This will be in the form of radar plots and augmented through Secondary Surveillance Radar (SSR) in association with IFF. It will form a history to be used for short term predictions. Other attributes can be derived from the trajectories, such as aircraft type, to be confirmed against the flight plan.

4.3.4 Airspace Control Measures

Airspace Control Measures (ASCM) defines the rules of the JAD environment. How well an aircraft adheres to these, might be used to identify intent and confirm the validity of flight plans. Transgression of ASCMs is normally one of the first indicators of change of an original declared intent.

4.3.5 Physical Environment

The environment frames the agents that participate in a mission. The environment also provides queues to understanding the behaviour of agents, such as geography and contours. The contours may indicate attempts to evade radar detection. The location, vulnerability, structure and importance of ground targets may assist in identifying specific attack profiles. The environment also changes as a mission progresses and the location of own forces and possible targets change. In the application of Border Control the location and classification of different airfields will be required.

5 Framework for Intent Tracking Tool

5.1 Modelling of Complex Systems

As seen from the discussion above, JAD as well as its C2 system presents a complex system. Even more so if one attempts the support of Sense-Making and Decision-Making through the modelling of agents participating in the operational environment. Cognitive processes used to interpret information and derive decisions are also complex. Unlike simple systems, humans tend to learn and remember positive and negative experiences. These cognitive influences must be captured to fully describe and predict behaviours of a complex system through pattern mapping.

According to Ho [6], Complex Systems Engineering tends to follow a bottom-up approach in order to model behaviour as opposed to a top-down approach from traditional Systems Engineering. With the lower level elements of the system identified, a set of simple rules can then be defined to approximate the behaviour of the system. ABM and associated simulations can then be performed to capture the emergent complex behaviour of the complete system.

The emergent behaviour may form the basis for understanding the effect of different actions on the future actions of the opposing forces. Even if the output of the simulation and estimation of intent can not predict exactly what will happen, but can be used to identify and highlight certain aircraft that requires special attention.

5.2 Agent Based Modelling

Ho [6] and Bar Yam [7] suggest that ABM is a useful tool for analysis of Complex Systems, such as to perform military and combat simulation. Ilachinski [8] [9] and Ho [6] list the advantages of ABM applied to warfare are:

- It addresses the deficiencies of traditional modelling by representing individuals rather than aggregating entities into monolithic representation.
- It tends not towards a single solution, but to a variety of possibilities, which is more in line with real combat situations.
- It can be used to expose underlying irregularities in tactics and/or doctrine.

The output of the ABM and simulation process may be used to enhance Sense-Making and Decision-Making. Real time ABM and simulation may indicate trends to the operators for tracking of intent and prediction of the possible actions.

5.3 Agent Based Models for Intent Tracking

A tool is required to follow and analyse observed enemy actions on a continuous basis. The tool must operate at different levels of the organisation, from force to platform level, to capture critical prompts. Its aim should be to link observed actions to a perceived Intent. This knowledge will be useful for Sense-Making and Decision-Making within a JAD scenario while deriving the enemy's intent. A typical architecture is proposed in Figure 3.

The ABM simulation, of all elements in the operational environment, will continuously absorb new information as it becomes available. This will be used to validate assumptions and estimations from earlier in the operation. The simulation tool can then highlight areas of contention to the operators for special consideration.

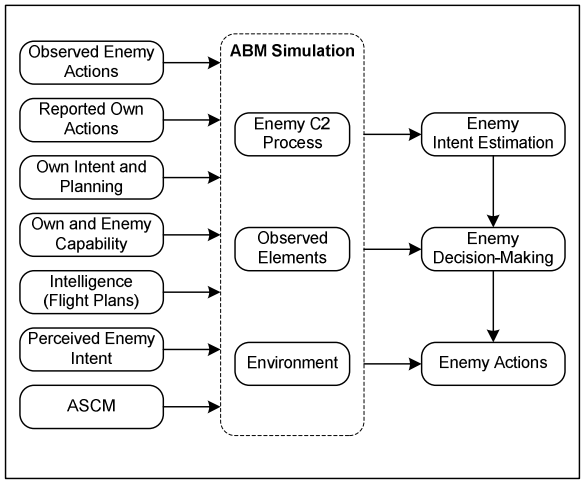

Figure 3: ABM Architecture

The most difficult part is to model and simulate the opposing force C2 process. Friendly C2 is known an also imported. In order to predict the enemy's actions, Intent must first be confirmed and/or derived. This can be achieved by modelling the estimated enemy's decision making in relation to friendly force actions. Furthermore, a similar architecture is required at different levels of the organisation to capture critical prompts.

A generic C2 simulation based on Brehmer's [10] update of Boyd's [11] Observe-Orientate-Decide-Act (OODA) cycle is presented in Figure 4. The C2 model must use information from the simulated environment for Sense-Making and Decision-Making. The Crux of the C2 simulation is the "Reasoner". The Commander Module Decide if action is required by comparing the current state with the desire end-state. The "Reasoner" has to decide if the current situation is in line with the Intent and planning in order to achieve the objectives. This decision making capability may on a Belief-Desire-Intention (BDI) approach, as suggested by Mason [5]. It must have the ability to perform complex reasoning, in order to make decisions, plan, perform spatial and temporal reasoning, etc. The planning function consists of the sequencing of tasks. The "Reasoner" will have to select the most appropriate task for the current situation. The "Reasoner" requires the following additional attributes:

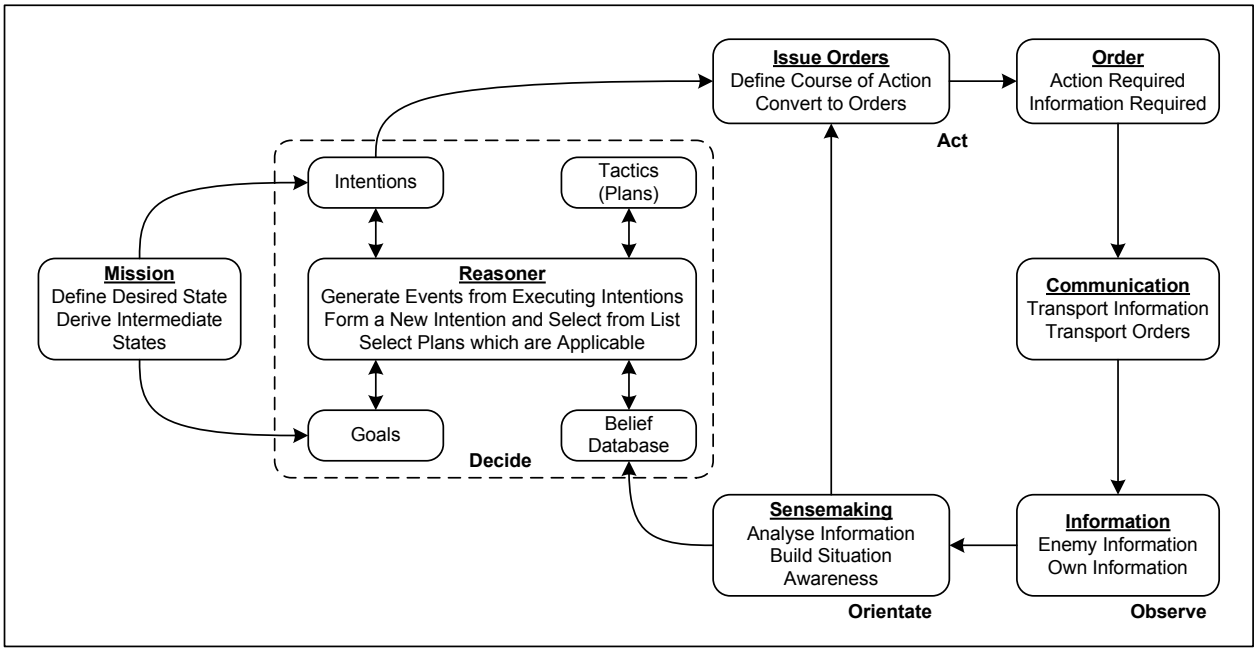

Figure 4: C2 Model with Reasoner

- Simultaneous Goals. The ability to hold multiple goals and interleave their achievement.
- Proactive and Reactive. The ability to react to the changing world and to interleave pursuing goals and reacting to the world. Humans exhibit behaviours that are not always rational or easily explained.
- Emotions. The ability to represent and manipulate emotions and model the way these emotions affect other processes.
- Social Awareness. The ability to interact with other humans being modelled and to represent and manipulate social structures.
- Innovation. The ability to adopt innovative and novel responses when faced with unfamiliar scenarios. The above requirements relate to the fidelity of the simulation.
- Real-Time Performance. The ability to perform activities in a time scale comparable to human activity.

Different possible models must exist and optimised for civilian, hijacker, terrorist and soldier to be in command of the aircraft. The behaviour predicted that best fits their actions and reactions will indicate the possible original or current Intent. The model will help to extrapolate the current actions into the near and far future. Indicate the possible changes in the enemy intent and try to derive what the current intent actually is. This can be achieved by capturing the emergence of certain phenomena.

6 Conclusion

One of the most neglected aspects of C2 is Sense-Making and Decision-Making, resulting in a lack of quality support systems. For Sense-Making of the current situation with regard to opposing force planning and actions, their Intent must be known. This is not always possible due to intelligence constraints. Intent might even change during the course of a mission as a result of own force and opposing force interaction and changes in the environment. Therefore the requirement exists for a tool tracking the intent to support Sense-Making and Decision-Making. Another spin-off may be the ability to understand the effect of own force actions on the opposing force future intent.

The concept of Intent Tracking will be useful for JAD during OOTW and Border Security operations. Even though aircraft file flight plans, they may not present the actual Intent. Since there may be numerous aircraft within the scenario, it is difficult for controllers and operators to carefully

monitor each track. This paper proposes the development of a tool to assist human operators to identify tracks not behaving in accordance to flight plans or other available intelligence.

The Intent Tracking tool must employ the latest methodologies to function in a NWC environment and utilise the available cognitive and social capabilities. Using the advantages of ABM, this tool will go a long way to ensure a successful system dealing with complex situations within the real world.

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