DESCRIBING JOINT AIR DEFENCE WITHIN OPERATIONS OTHER THAN WAR CONTEXT AS A COMPLEX SYSTEM

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. This may even happen within the context of Operations Other Than War (OOTW). Like general warfare, OOTW is a complex environment where discrimination between friendly and hostile forces is difficult, resulting in tight timelines. To successfully achieve the objectives of JAD, resilient command and control systems with supporting doctrine are required. Field exercises provide an opportunity for the operator and environment to interact, capturing complex behaviour. Agent Based Modelling can be used to create scenarios by capturing emergent behaviour. This provides a "safe-fail" environment where successes, failures and lessons can be recorded to support doctrine development.

1 Background

The effectiveness of Joint Air Defence (JAD) is reliant on an effective Command and Control (C^2) system to integrate all its elements. This success depends on smooth integration of all the communication systems, effective decision support systems and underlying doctrine.

To evaluate a JAD system with its doctrine, representative scenarios and exercises are required. This can be achieved by understanding the phenomenon of complexity and the application thereof in warfare. Complex System Engineering can be used to model combat systems and their application in warfare.

This paper will firstly investigate the theory of complexity and identify the main characteristics. This will be applied to Systems Engineering and modelling techniques, to propose a method of implementation in the real world. The application of complexity in warfare is discussed to form a foundation for the discussion of JAD. Finally, the sources of complexity in JAD are identified and an approach to address these proposed.

2 Complex Systems

2.1 Definition of Complex Systems

The theory of complex systems has received increasing prominence over the last two decades as it attempts, according to Das [1], to explain the organisation principles of nature and society. Consider the following systems or phenomenon in nature or everyday life:

- The economic dynamics of global markets.
- The apparent goal driven behaviour of an ant colony.
- Chaotic dynamics of global weather patterns.
- Information flow on the internet.
- Asymmetrical or ideological based warfare.

These are but a few examples of complex systems. Stirling [2] holds that complex systems self organise globally as a result of many local interactions, as can be seen from the examples above. Complex systems also respond to information by changing and this adaption in itself leads to further complexity.

Complex systems theory provides us a general approach to understand the overall behaviour of systems composed of many nonlinear parts. The interaction between these parts gives rise to the system's behaviour as a whole. Ilachinski [3] states that this behaviour is described as an emergent self organised phenomenon, built on the aggregate behaviour of many nonlinearly interacting parts. Two common causes of complexity in systems are:

- Humans whose actions or decisions may influence the overall behaviour of the system.
- The environment can impact on the system, or vice versa, causing it to behave in an unpredicted or unstable way.

According to Das [1], our purpose in studying complex systems is to extract general principles in order to gain knowledge to assist in solving other complex problems.

2.2 Characteristics of a Complex System

Das [1], Stirling [2] and Ilachinski [3] agree that the fundamental properties of complex systems, which are of importance to our discussion, are:

- Complex systems can be organised hierarchically, with complex behaviour resulting from interaction between elements at different levels.
- The overall behaviour is self-organised under a decentralised control.
- Complex systems can move between order and disorder without becoming fixed in either.
- Complex systems can persist in spite of changes in the diverse individual components as the interactions of all the components are responsible for persistence.
- Organisations occur without any central organising structure or entity.
- Formation or operation and the timescale involved.

Systems engineering as a discipline has also benefitted from the foundation of complex systems.

3 Engineering of Complex Systems

3.1 Traditional Systems Engineering

We firstly need to discuss the ability of traditional System Engineering practices to address complex systems.

According to the INCOSE System Engineering handbook [4] a system is defined as a combination of interacting elements to achieve one or more stated purposes. A System of Systems applies to a system of interest whose systems elements are themselves systems.

Norman [5] explains that the shortcomings of traditional Systems Engineering begins with specification of requirements that are assumed to be complete, closed and precise. They rely on making predictions and attempt to fulfilling them in a linear fashion. Systems are then implemented to satisfy these exactly according to standard development and life cycle processes. One of the main problems is that integration takes place at the end of the project and relies on linear systems theory.

Norman [5] continues to state that requirements do change over time as well as the environment where the system is to be deployed. Traditional Systems Engineering assumes the environment to be sufficiently bounded and all elements to be linear in order to derive an optimised solution to the problem.

It is clear that traditional System Engineering practices do not address complex systems sufficiently. Traditional techniques tend to overlook the roles and effects of humans on the larger system. They tend to ignore the fact that a human is part of the system and plays a major role in the system of systems. Therefore, different techniques are required to model and analyse complex systems or problems.

3.2 Complex System Engineering

Ryan [7] points out that Complex System Engineering, when taken literally, is a contradiction in terms, as is clear from the discussion above.

However, Ilachinski [6] simplifies the field by stating that when applying Complex Systems Engineering we tend to surround and conquer the problem rather than divide and conquer as with traditional Systems Engineering. We must abandon the notion of complete understanding and control of the system we are designing or managing. We must acknowledge the limitations of certainty, predictability as well as test and evaluation.

White [8] adds that System Engineering methods must now include techniques that influence rather than control, not only the system under consideration, but also the environment where the system is deployed. Complex Systems Engineering embraces the presence and actions of autonomous agents and the environment as important elements of a Complex Systems. It may be eliminated when applying traditional Systems Engineering.

We must understand all the elements that may have an influence on the system as well as their integration. This does not imply a new or renewed attention to detail, but focussing on the overall coherence in a system. Norman [5] agrees that Complex System Engineering addresses overall coherence without a direct and immediate attention to detail. Furthermore, it must be remembered that complex systems are alive and constantly changing. They respond to- and interact with each other and the environment.

The role humans play within systems, with their cognitive and non-deterministic behaviour requires consideration. Cognitive processes used to interpret information and derive decisions are complex. Unlike simple systems, humans tend to learn and remember positive and negative experiences. These cognitive influences must be captured to fully describe a complex system.

3.3 Modelling of Complex Systems

Most of the approaches used for the study of simple systems, as Das [1] points out, can be applied to the study of complex systems. The extra dimensions required to capture the complexity of a system must be included.

According to Ho [9], 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. Agent Based Modelling and associated simulations can then be performed to capture the emergent complex behaviour of the complete system.

Deloach [10] proposes two phases to perform Complex System Engineering, as provided in Figure 1. Analysis, the first phase, consists of capturing goals, applying Use Cases and refinement of agent roles. The second phase, Design, consists of creating agent classes, constructing conversations, assembling agent classes and system design. The aim of this process is to capture the dynamics of a complex system in order to predict the effect of design choices. Agent Based Modelling techniques can be applied on the designed system.

The output of modelling Complex Systems should be a system that provides an excellent solution to the problem or requirement. In reality it will be impossible to find the best or optimum solution because of all the possibilities available. The success of the solution will be determined by the robustness of the system to persist within a complex environment. It must continue to fulfil its role, even under adverse environmental conditions. The influencing factors include politics, economic climate, social structures and cognitive decision making processes.

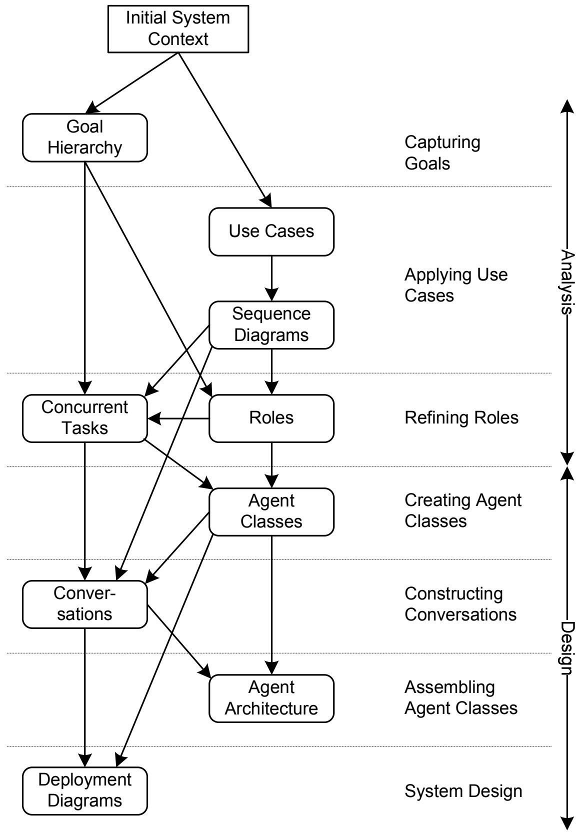

Figure 1: Multi Agent System Engineering Phases

4 Complex Systems in Warfare

4.1 The Complex Nature of Warfare

Worldwide there is a move to apply complex systems theory to warfare and other forms of combat. This is in contrast to the Lanchester Equations used since 1914 for conventional warfare simulations that focuses on attrition rates. Ilachinski [6] explains that these equations are intuitive and easy to apply by only addressing simple issues such as firing rate and attrition rate, which are assumed to be constant over time. They homogenise entire populations and ignore the spatial component. They do not incorporate the human element into combat, such as psychological and decision making capabilities.

Ho [9] states that lately, due to the advent of asymmetrical warfare, the importance of the effect of attrition influence on military outcome has diminished as opposed to political, economic and social outcomes. Conflicts have also moved from open battlefields to dense urban environments where additional considerations regarding collateral damage become more significant.

Furthermore, Bar-Yam [11] added that complexity increases in military conflict where the application of effective force must be more carefully selected or more accurately targeted. This is especially true for targets inside densely populated areas where fallout of errors and collateral damage are more severe.

Ilachinsky [6] captures the essence of complexity in warfare by identifying that certain aspects of combat can be viewed as emergent phenomena. This is a result from the collective, nonlinear decentralised interactions amongst combatants. When considering the characteristics of complex systems as discussed in the previous sections, the following similar characteristics can be extracted from modern warfare:

- A battle consists of a large number of nonlinear interacting agents in a command and control hierarchy. This may result in emergence.
- Local action which is apparently disordered induces long range order, giving rise to the notion that combat is self-organised.
- Forces must adapt to their environment, as well as the actions of the enemy to survive continuously.
- Today, the common principle is to have centralised command and decentralised control.

Ilachinsky [3] also listed the problems of Land Warfare that give rise to complexity. They are combat attrition, command and control, coordination, intelligence, tactics, strategy training etc. The most important actors in warfare are the combatants, which at this stage are still mostly human. They have emotions, fears, paradigms motivations and cognitive decision making capabilities. These agents have to execute orders in order to achieve objectives and are very much part of the systems.

Du Toit [12] concluded that especially in asymmetrical warfare the softer issues are critical and the effect of military actions on attitudes of people must be considered for desired effect. With this in mind we can agree with Bar-Yam [11] that warfare is a complex encounter between complex systems in a complex environment.

4.2 Operations Other Than War

Operations Other Than War (OOTW) introduce another level of complexity. This is even further away from typical conventional war on open battlefields than what asymmetrical warfare is. Rossouw [13] 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. The complexity added by OOTW includes:

- The military is under civilian control. Civilians (diplomats) normally do not have the knowledge and experience of military command and control.
- Belligerents will attempt to use any incident as propaganda for their cause.
- Belligerents will attempt to utilise the Rules of Engagement to their advantage in offensive actions.

4.3 Agent Based Modelling and Warfare

Ho [9] and Bar Yam [11] explain that the analysis of Complex Systems, as in warfare, uses Agent Based Modelling (ABM) to perform military simulation. The motivation is to address key elements of modern warfare concerns. This is because warfare can be better executed by those who understand its complexity, than those who focus on the simple linear issues. Ilachinski [3][6] and Ho [9] lists 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.

Illachinsli [6] summarises that in these simulations the outcome of the battle is not as important as how the two forces co-evolved during combat. The macroscopic behaviour of combat results from collective interactions of individual agents as well as the effect of feedback on the rules governing the individual agent's behaviour. Characteristics that can be assigned and to combat are doctrine, mission, Situation Awareness and adaptability.

Whenever they are present within a scenario, such as OOTW, civilians and other agents can also be modelled. However, the characteristics and motivations may differ completely from combatants. In ABM the environment interacts with the agents and visa versa, making it possible induce more influences. Such a complex environment and role of civilians make it an attractive method to study the effects of Asymmetric Warfare and OOTW.

5 Joint Air Defence

5.1 Description of Joint Air Defence

The South African National Defence Force (SANDF) Joint Warfare Publication (JWP) 105 Part 7 [14], currently under review, defines Joint Air Defence (JAD) as "*all measures jointly designed to nullify or reduce the effectiveness of hostile air action*". This statement implies the application of all available resources, from the various arms of service within the specific area of operations, including the sharing of intelligence, air pictures and other situation awareness resources.

De Jager [15] explains that within the African Battlespace, JAD will most likely be deployed in support of ground forces/operations against insurgents. Insurgents will most probably not have an air capability, unless they are supported by a neighbouring country. African countries have only limited air capabilities, resulting in sporadic attacks on key positions or infrastructure at a critical time during a campaign. As a result, opportunities to gain experience within the African context will be limited. In order to be prepared for when a JAD capability is required, alternative methods must be used to train operators and refine doctrine.

For the purpose of this paper only the Command and Control (C^2) aspect will be discussed due to time and space constraints. A command and control network is the integrative element that will ensure effective JAD implementation. The main functions of the C^2 network are:

- Distribution of Situation Awareness information (air pictures from all sensors available).
- Distribution of Air Defence Control information and orders to all the entities responsible for commanding and directing JAD effectors.
- Integrating Tactical Command and Control information to enhance the situation awareness.

Many of the critical, decision and human cognitive interactions, aspects of the JAD systems are reliant on the C^2 functions listed above. The ability of the operator to make a "good" decision or select the appropriate action will influence the effectiveness of the complete JAD system. The following aspects are determined by effective decision-making:

- Threat Hostility Classification or Target Classification.
- Track Management or Fusion.
- Air Defence Control.
- Threat Evaluation and Weapon Assignment.

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. Contributing factors to the complexity of these decisions are the difficulty to detect a threat and to correctly identify it. These decisions are often compounded by a compressed engagement timeline.

For this reason it is important to utilise all possible sources of information, including air pictures from civilian aviation authorities, to reduce the risk of fatal errors.

5.2 JAD as a Complex System

As discussed before, warfare in general can be described as a complex system. Now it stands to prove that JAD, as a subset of warfare, also qualifies as a complex system. The properties of a complex system, as provided by Das [1], Stirling [2] and Ilachinski [3] in 2.2, are now used to prove JAD as a complex system.

5.2.1 Hierarchical Structure with Interfaces

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.

An additional contribution to complexity includes the application of a layered air defence system with the supporting decision making. This adds the implementation of a Beyond Visual Range capability which requires positive control and a robust classification/identification system.

The role-players within a JAD System normally consist of Army, Air Force and Navy with their cultures and own battle languages. This aspect can create chaos as communications can be misinterpreted. Sometimes communications are not even possible due to incompatible protocols or data models.

5.2.2 Self Organised Behaviour

The external environment to the JAD systems may be described with self organised behaviour. The environment consist of own forces, civilians, the enemy or belligerents. In the case of OOTW civilians with their attitudes, culture and motives will cause a diverse range of actions and reactions. All these characteristics lead to unpredictability within the operational scenario. This will serve as in input to the possible decisions the JAD C^2 system will be confronted with.

5.2.3 Persistence

Persistence is per se a characteristic of a JAD system, but rather a requirement. JAD must be agile and flexible to deal with the uncertainty of complex emergencies as well as fog of war of conventional force on force conflicts. Complexity is increased during expeditionary coalition peace support operations.

Fallback modes must exist to cater for failures in the C^2 system. The lowest level of fallback is Procedural Control, which can be employed with little or no C^2 capability available. JAD capabilities should be available, although limited, despite various systems being unavailable.

5.2.4 Temporal Behaviour

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, for the duration of the operation. Operations can be as short as a few hours up to a number of months. During this period the systems is required to perform surveillance, building the situation picture and make decisions. During this period the operation environment and its influences may evolve continuously.

Despite long operational time, compressed timelines exist when engagements occur and decisions are 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.

5.3 JAD in OOTW

During OOTW the properties discussed above are still relevant. The major factor to increase complexity is the role of other entities, such as civilians, authorities, politicians, United Nations officials. They add even more diverse cultures and political agendas to the environment. The JAD system has to integrate over various communication systems and language barriers when operating in a joint, interdepartmental or multinational environment.

During operations, the air space is shared between enemy, own forces, friendlies and neutrals. It is totally unacceptable to engage any other than a belligerent or enemy airborne agent, especially during peace keeping missions.

Also, due to the fact that during OOTW the Defended Asset will probably be within populated areas, the consideration of collateral damage comes into play. As a target is engaged over densely populated areas, debris and projectiles can cause injuries to non-military inhabitants. This adds even more demands on the decision making process.

5.4 Applying Complex Systems Theory in Optimisation of Joint Air Defence

From all the discussions above it is reasoned that JAD is a complex system; even more so in OOTW. The discussion on the importance of C^2 to the overall success highlighted the role humans with their cognitive abilities play in the eventual success. To ensure the JAD system is effective in all possible scenarios, the C^2 system and supporting doctrine must be tested and exercised. Simulation is used to create a “safe-fail” environment to learn from successes and failures. These exercises can help the system to evolve into a robust system able to absorb the effect or criticality of chaos experienced within the deployed scenario.

5.4.1 Laboratory and Field Exercises

The system can be exercised during laboratory tests or field exercises. The critical aspect, of simulations and exercises, is to include the human interaction within the C^2 systems. The operator’s interactions with the system, on real hardware or simulated interfaces, will capture valuable lessons to improve JAD doctrine and system requirements.

Field exercises have the advantage that the operators are deployed to a representative (operational) environment where they can act according to their instincts. This exercises his cognitive and decision making abilities with real world information and real aircraft flying with actual engagement time lines. Unfortunately, it’s still not the perfect situation as the operator knows he is being watched and may act different in a real combat scenario.

The advantages of a well constructed field exercise were experienced during the Exercise JOINT participation of the annual EW Camp in August 2009 at the Roodewal Bombing Range. Shortcomings to doctrine and equipment were identified, which would have been very difficult to achieve in a laboratory environment.

5.4.2 Agent Based Modelling

When analysing JAD as a complex system, ABM can be utilised to simulate complex scenarios. ABM generates unexpected situations caused by emergence, created from interactions between agents as well as between agents and the environment. The output is used to facilitate doctrine development, training, refining information requirements and addressing timeline constraints within a JAD system.

ABM can be used to generate training scenarios to compensate for the lack of combat experience. These scenarios are representative of scenarios that can occur on the battlefield.

6 Conclusion

The JAD system must function within the real world with real world problems. This is even more difficult when participating in OOTW.

Complex Systems Theory and ABM is a solution to generating scenarios for testing systems and developing supporting doctrine. These scenarios must be tested under representative conditions to capture the human element within a C^2 system.

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