An Initial Investigation of Concepts of Command and Control Using an Agent Based Approach

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Abstract: This paper investigates the effect of different Command and Control Concepts (C2) on the outcome of military engagements. The C2 concepts from literature were found to be based on the OODA loop or derivatives thereof. Agent Based Modelling software is used to implement the C2 concepts in basic combat scenarios. In the scenarios opposing forces consist of agents with the aim of finding and destroying each other. The outcomes of the simulations showed that the implementation of basic C2 concepts and rules will improve the probability of success. The application of situation awareness information to direct agents and concentrate resources drastically improved engagement outcomes. Although being basic implementation of C2, this investigation forms the basis for future detailed research.

Keywords: Command and Control, OODA, Agent Based Modelling

1. Background

The complexity of modern conflict challenges industrial age Command and Control (C2) doctrine. Both sides of conflict have separate and often different C2 processes or cycles to direct resources in the process of achieving an objective. In traditional, or conventional, warfare both sides of a conflict had similar concepts of C2. However, in asymmetrical warfare there exist vastly different processes between the adversaries. This is caused by differences in culture, organisation, infrastructure and equipment asymmetric.

The different C2 processes will have different strengths and weaknesses. The speed with which decisions will be made and the quality thereof may differ vastly. It will be the objective of Command and Control Warfare (C2W) to attack or exploit the opponent's weak points to gain the advantage in the battle.

It is the aim of this paper to investigate the effect of different C2 (asymmetrical) processes applied in a conflict between forces. The OODA (Observe, Orientate, Decide and Act) Loop from Boyd 0 will be used as a basis to compare centralised and decentralised decision making. Decentralised decision making will utilise the situation awareness of one agent to try and concentrate friendly resources on an engagement. Centralised decision making will make use of the combined situation awareness of all the friendly agents to direct resources to engagements.

AnyLogic will be used to implement Agent Based Modelling (ABM) of combat between Red and Blue forces. AnyLogic has the capability to combine Enterprise Processes, System Dynamics as well as Agent Based Modelling. The model will be used to emulate asymmetrical warfare by utilising different C2 Models.

2. Command and Control

2.1 Definition

"Command and Control" seems to be an overused and often misused term. C2 is actually a common term for the management of military personnel and resources 0. Throughout history C2 was referred to only by "Command". The U.S. military defines "command" as "responsibility for effectively using available resources, planning the employment of, organising, directing, coordinating, and controlling military forces for the accomplishment of assigned missions" 0. This definition subsumes control as a part of command. The role of control is to ensure that command is achieved.

In modern combat, C2 ends up being a distribution of functions, and occurring integrated across different layers of the organisation. It encompasses the decisions a commander takes and execution thereof (distribution of the orders to the relevant elements). Alberts 0 provides a basic conceptual description of C2 as seen in Figure 1. The elements of the diagram will be discussed below. He lists the functions of C2 as:

a. Establishing intent, in other words the goal or objective that the mission must achieve.

b. Determining roles, responsibilities, and relationships of commanders at different section or levels of the organisation.

c. Establishing rules and constraints or the plan to achieve the goal or objective of the mission.

d. Monitoring and assessing the situation and progress and implement changes to the plans when required.

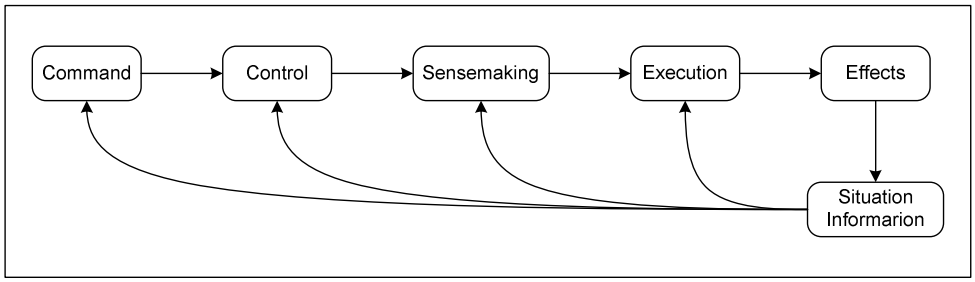

Figure 1: Modern C2 Description from Alberts 0

2.1.1. Command

The main roles of "Command" are determining and communicating the intent and initial set of conditions. This is measured against a continuous assessment of the progress of the mission. If required, this will induce a change of intent or objectives. The quality of information available will determine the effectiveness of command.

2.1.2 Control

The "Control" element makes adjustments, under the guidance of "Command", when current or planned actions are not in line with the intent of the commander. The "Control" mirrors the "Command" element except for the function of intent.

2.1.3 Sensemaking

The "Sensemaking" element is the perception of available information and culminates in the taking of actions. The aim is to create a situation awareness to be used in assessing the current situation. This awareness is used in predicting the future and to compare it to the commander's intent and plans.

2.1.4 Execution

The aim of C2 is to utilise all possible resources in achieving the objectives of a mission. This is where the success of a mission will be measured. The execution may be the product of a collection of decisions derived from the situation awareness.

2.1.5 Effects

The execution of actions will have an effect on the environment. This may include, amongst others, own forces, opposing forces, neutral forces, infrastructure, natural environment and many more. These effects will have an influence on the possibility of success of current plans to achieve the current objective. This will necessitate the changing of plans, objectives or intent, hence the importance of Situation Information.

2.1.6 Situation Information

Situation Information includes the sensing and gathering of information on the environment as well as the effect of actions.

2.2 C2 Models

A number of models, old and new, for C2 exist in literature. One of the most widely used Industrial Age C2 models is the OODA loop as defined by Boyd 0. He noted that it is the objective to operate inside to enemy's OODA loop into forcing him to react to your actions, instead of the other way round. To be faster than the enemy and attack him where he does not expect it. However, the OODA loop is flawed in the sense that it is reactive, and does not incorporate the commander's intent or exit criteria. Furthermore, the OODA loop does not address the inherent delays in the C2 and execution system. On its own the OODA loop is a model for winning and losing, not specifically for implementing C2. Most criticism comes from the proponents of Cybernetic C2 model. Despite this, a basic OODA loop or variations thereof have long since been accepted as a robust model to be adapted for specific C2 applications. It has the ability to absorb the latest buzzwords such as Situation Awareness and Sensemaking. Many authors have adapted the basic OODA loop with different words in the four stages to be better suited for C2, as seen in Figure 2.

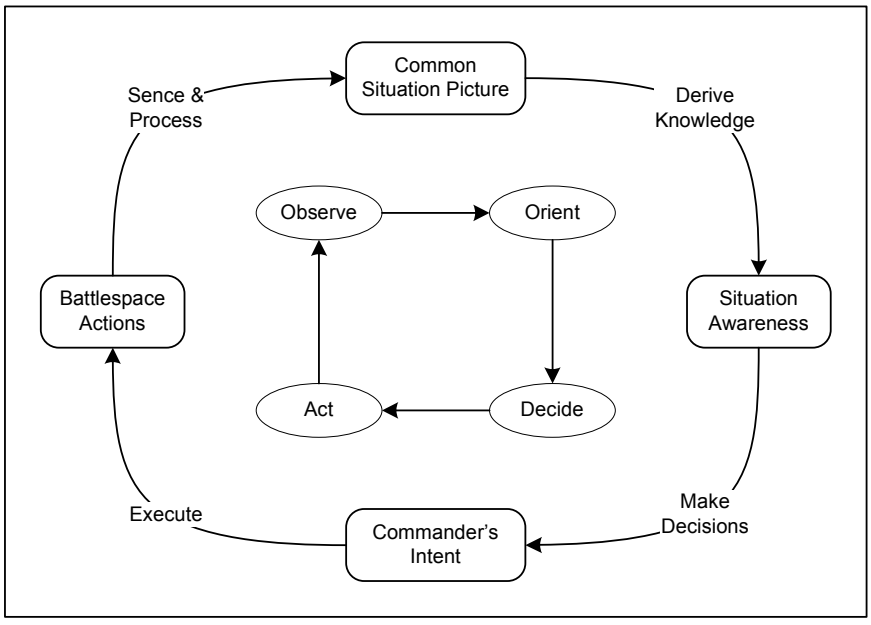

Figure 2: Adapted OODA Loop 0

However Grant [7] listed a number of shortcomings of the OODA loop. Those relevant to this study are:

- The scope of the four processes was not defined. It requires decomposition and formalisation before implementing an OODA based C2 system.
- The planning process is not present.
- Psychological elements, such as memory, attention and knowledge, are not present. This limits it to rule based reasoning. It should be extended to support learning and deliberative planning.

Brehmer 0 improved the OODA loop with Cybernetic C2 model inputs and manoeuvre warfare concepts to form the Dynamic OODA (DOODA) loop, as provided in Figure 3. It includes the elements of the mission and command concept or intent. There also exists an exit condition when the mission objectives have been achieved.

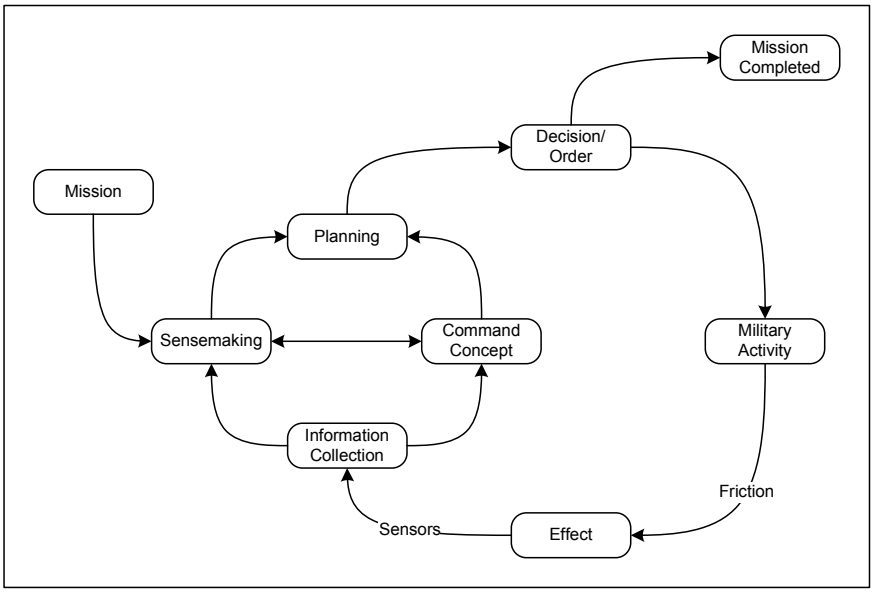

Figure 3: DOODA Loop 0

2.3 Problem Statement

C2 is occurring in both the friendly and opposing forces, each with their own unique concepts and processes. The success is not only dependant on own C2 models or processes, but rather the complex interaction with the enemy's C2. The accuracy and speed of the enemy's process may counter or promote friendly actions. As mentioned before, the following aspects of C2 interactions require investigation:

a. The level in the organisation where C2 is taking place (centralised or decentralised).

b. The quality and quantity of information required to make decisions.

c. Cooperation between operational elements.

3. Experiment Design

3.1 Agent Based Modelling

Agent Based Modelling (ABM) is used to achieve an understanding of the complexities involved in the C2 interactions. This is achieved reducing the complexity to simplistic rule sets which can be followed by the agents. The different C2 concepts are implemented with Anylogic using its ABM and Enterprise simulation capabilities. It is used to investigate emergent properties when agents interact with each other and/or the environment.

The agents will interact according to simplified engagement rules. The focus is to compare the effect of different C2 concepts on the success of the mission. The aim of ABM is not to predict the outcome

of a scenario, but to understand how interacting agents co-evolve. The effect of different C2 combinations will be compared using population graphs and the emergent behaviour will be investigated.

3.2 Basic Experiment Design

The experiment setup will consist of 100 Blue and 100 Red agents on a flat earth of dimensions 200*200 units. The agents will interact according to simple set of rules. The behaviour of each agent is modelled as an OODA loop as seen in Figure 4. The rules are the following:

- Sight Range: 20 range units.
- Shoot Range: 10 range units.
- Health: 10 units, agents with zero or less than units are considered dead and are removed from population.
- Damage Rate: 1 life unit per time unit per shooter.
- Movement: All agents move randomly on the environment. An agent identifies a random destination then move towards it in a straight line. Once the unit reaches the destination it randomly reselects a location to walk to. If an agent engages an enemy it stops movement until engagement resolved.
- Start Point: All Blue and Red agents start at opposite ends of the environment.
- Detection: Once an enemy agent is detected the agent react in accordance to the different C2 concepts.
- Engagement: Once the agent is within the Shoot Range it commences shooting. The other agent (target) also returns fire at the same instant and rate.
- Communication: The agent can communicate the position of an enemy agent, according to the defined C2 concept, to other agents or the HQ. These agents may assist in the engagement and help to kill the enemy with concentrated firepower.

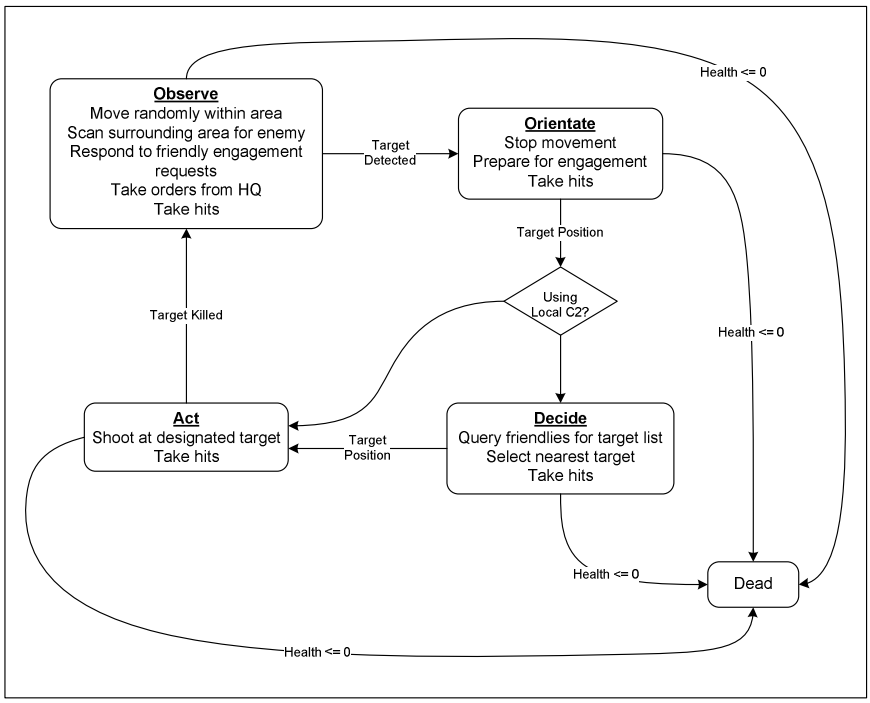

Figure 4: State Chart for Agents

The DOODA Loop (Figure 3) will be implemented as the C2 model in three different concepts. The variations between the three concepts are discussed in the following paragraphs.

3.2.1 C2 Concept One

This is a decentralised C2 concept where each agent operates independently, without C2 or coordination, as seen in Figure 5. Agents operate without guidance and higher level control as well as independently from friendly agents. They move around independently: if an enemy is detected the agent moves towards it and start shooting. The enemy will return fire instantaneously. If the agent is still alive after the engaged enemy was killed, it will again move randomly to find the next. If another agent "stumbles" onto an engagement between red and blue agents, he joins the shooting. The enemy is then killed at twice the speed.
It is interesting to note that according to the Figure 4 the "Decide" function is ignored in this concept. No decision is taking place, the agents move random and shoot on sight.

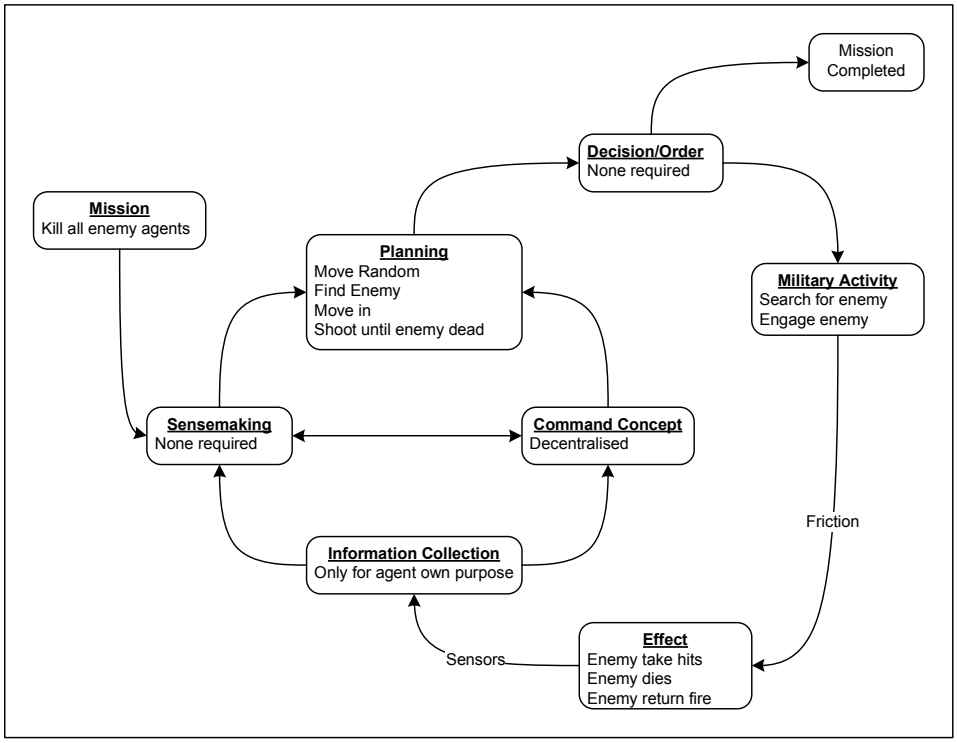

Figure 5: C2 Concept One

3.2.2 C2 Concept Two

This is a decentralised C2 concept where agents tend to operate in teams, as seen in Figure 6. They move around independent and random. If an opposing force agent is detected, its position is report to the closest 10 friendly units not engaged already. On receiving the message, the agents requested for assistance wait for a finite period of time to gather better situation awareness before choosing a destination with the highest probability of success. They then move closer to the engagement and start shooting when within range. This occurs without guidance and higher level centralised control. The enemy will return fire at the same instance. If the agent is still alive after the engaged enemy was killed, it will again start to search randomly. If another agent "stumbles" onto an engagement between red and blue agents, he joins the shooting as in the previous concept.

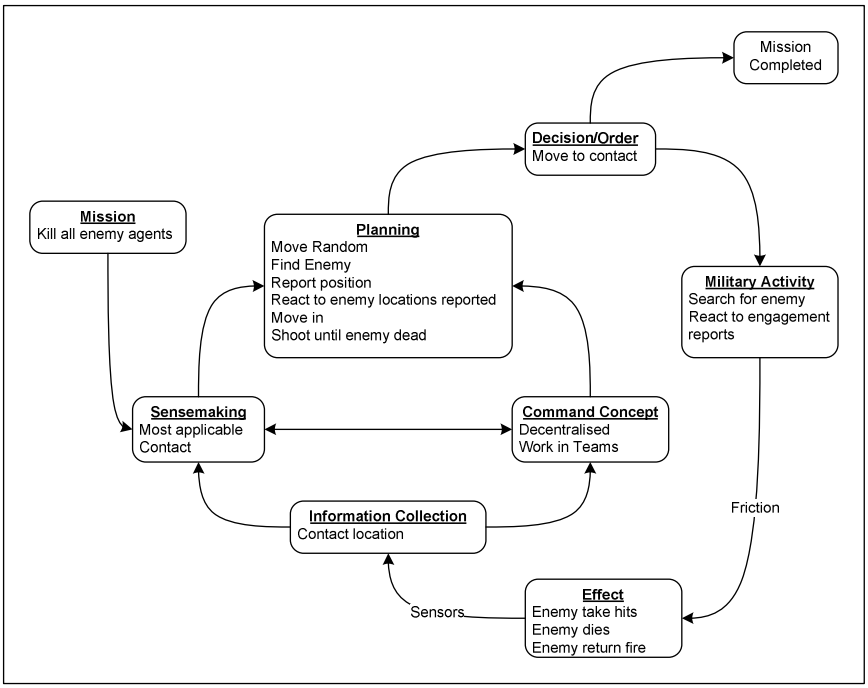

Figure 6: C2 Concept Two

3.2.3 C2 Concept Three

This is a Centralised C2 concept where agents tend to operate in teams as directed from higher authority or Headquarters (HQ), as seen in Figure 7. The HQ will determine the concentration of own forces in relation to enemy forces. The agents move around independently and report all enemy agents they detect to HQ. The HQ builds situation awareness, detects concentrations of enemy agents and direct local (closest 20 not engaged already) friendly agents towards it. Time delays have been incorporated to present a more realistic situation. Figure 8 provides the implementation of the HQ in Anylogic. The rest of the engagement is the same as before.

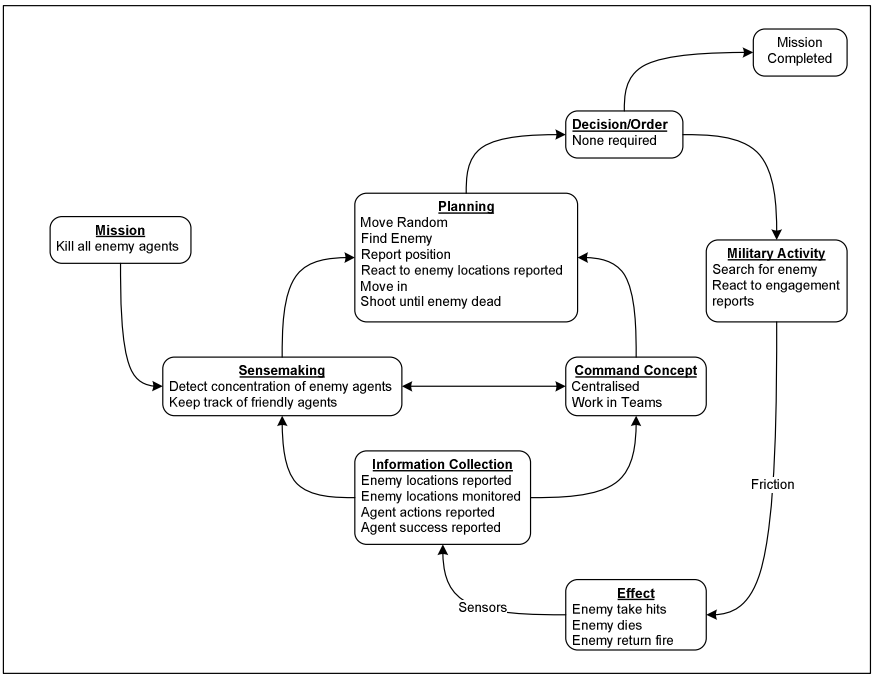

Figure 7: C2 Concept Three

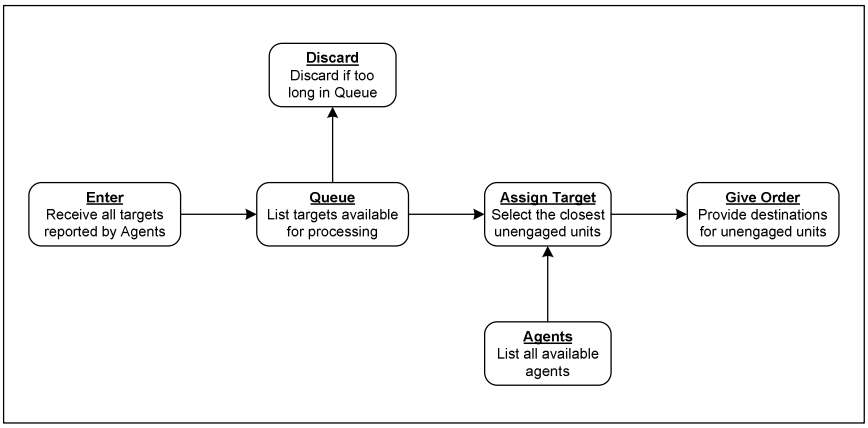

Figure 8: HQ Implementation in Anylogic

3.2.4 Experimentation

Experimentation consists out of simulated combat between Blue and Red forces. Success will be determined by the ability of one set of agents to kill all the other agents. The number of agents left when the opposing forces have been defeated will determine the level of success. The combinations of different C2 concepts assigned to the two opposing forces will determine the different setups, as provided in Table 1.

Table 1: Layout of Experiments

No	Blue Forces	Red Forces
1	C2 Concept One	C2 Concept One
2	C2 Concept Two	C2 Concept One
3	C2 Concept Three	C2 Concept One
4	C2 Concept Three	C2 Concept Two

Experiment 1 is the baseline to measure the effect of similar C2 concepts. The numbers of the Blue and Red agents will be recorded over time, up to 250 time units. Ten simulation runs of each experiment were executed to calculate an average result for each experiment.

4. Data

4.1 Experiment 1: C2 Concept 1 vs C2 Concept 1

Experiment 1 is the baseline experiment to demonstrate that similar C2 processes or the lack thereof will result in similar casualty graphs. A sequence of screen captures in Figure 9 shows a typical run of this experiment. Note the “frontline” created where the agents meet in the centre of the screen. Since the agents operate autonomously, a large number of agents are wandering away from the “frontline” and are wasted resources. In many cases the outcomes were determined by the initial success or “head start” of a group of agents. The darker areas represent the Red agents while the lighter areas represent the Blue agents.

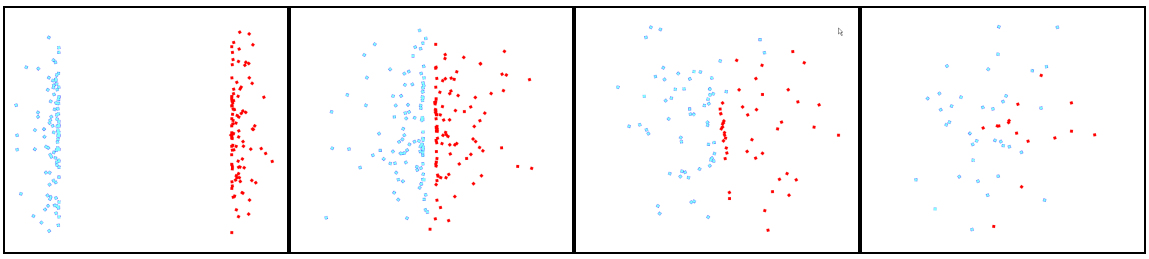

Figure 9: Experiment 1 Sequence of Screen Captures

This proves that the simulation does not advantage the one set of agents over the other. As seen in Figure 12, the average graph of the first 10 runs ends up with similar graphs for the Blue and Red Forces.

4.2 Experiment 2: C2 Concept 2 vs C2 Concept 1

Experiment 2 investigates the effect of limited and decentralised C2 on the success of the Blue agents as opposed to none for the Red agents. C2 Concept Two allows an agent to call in assistance of the closest agents, not engaged, to an engagement. This is performed without situation awareness of the whole environment. A sequence of screen captures in Figure 10 shows a typical run of this experiment. Again, outcomes were determined by the initial success or "head start" of a group of agents. It seems that in some cases Blue agents were diverted away from critical areas to where other Blue agents were in contact with Red agents.

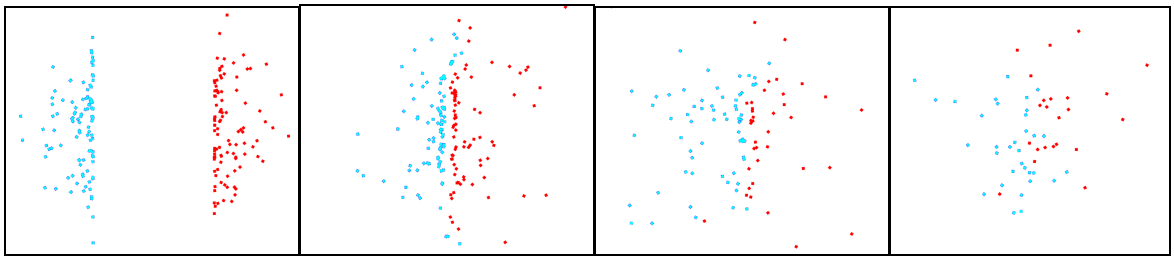

Figure 10: Experiment 2 Sequence of Screen Captures

Figure 13 is a graph of the averages of the first 10 simulation runs. It seems to be counter productive and have no improvement on the success of the mission.

4.3 Experiment 3: C2 Concept 3 vs C2 Concept 1

Experiment 3 implements centralised C2 for the Blue agents as opposed to no C2 for the Red agents. An HQ exists that gathers information from Blue agents and build a situation awareness picture. Each Blue agent reports the location of a Red agent it detects. Based on the situation awareness picture the HQ directs unengaged agents towards the positions of known Red agents. The result is a concentration and coordination of resources. A sequence of screen captures in Figure 11 shows a typical run of this experiment. It can be noted that a concentrated force of Blue agents participate in the engagement. From Figure 14 the success of centralised C2 is clearly visible.

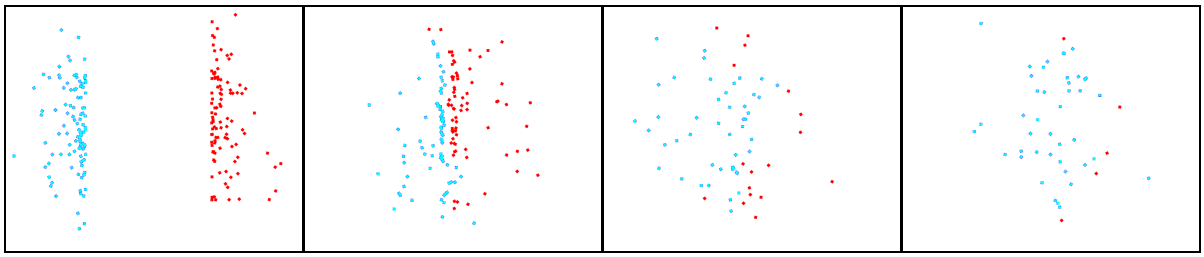

Figure 11: Experiment 3 Sequence of Screen Captures

4.4 Experiment 4: C2 Concept 3 vs C2 Concept 2

Experiment 4 implements centralised C2 in opposition to decentralised C2. An HQ exists that gathers information from Blue agents and build a situation awareness picture. Each Blue agent reports the location of a Red agent it detects. Based on the situation awareness picture the HQ directs unengaged agents towards the positions of known Red agents. The result is a concentration and coordination of resources. From Figure 15 the success of centralise C2 is clearly visible. The decentralised C2 as employed by the Red forces has no effect on the outcome of the engagements.

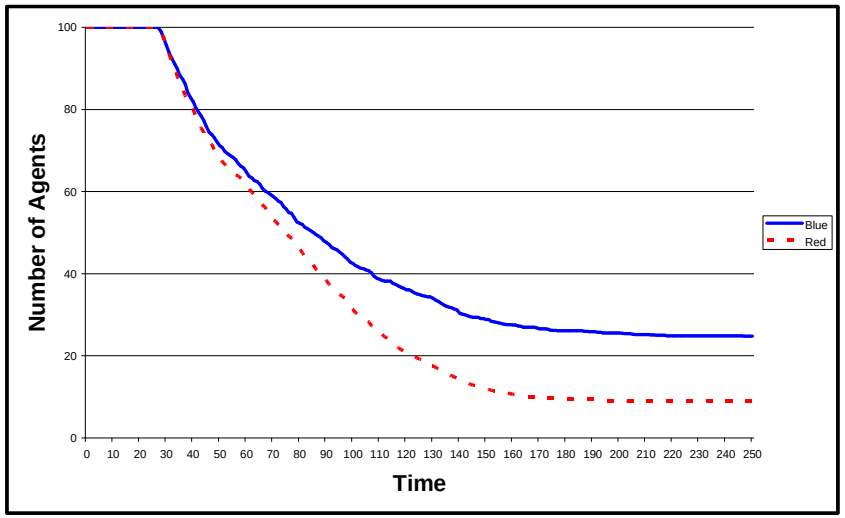

Figure 12: Red vs Blue Agents for Experiment 1

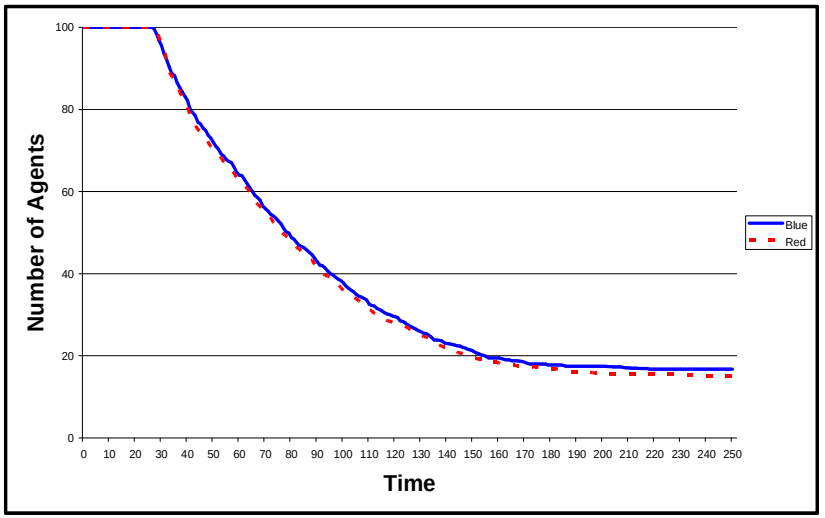

Figure 13: Red vs Blue Agents for Experiment 2

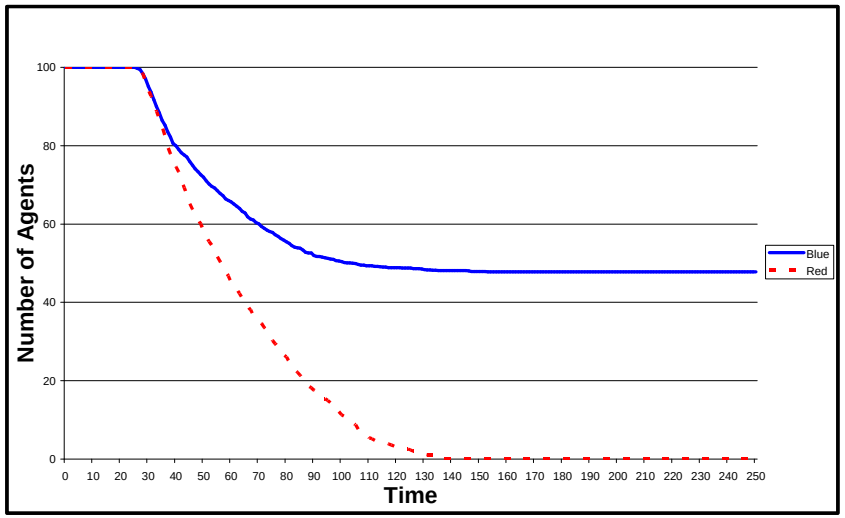

Figure 14: Red vs Blue Agents for Experiment 3

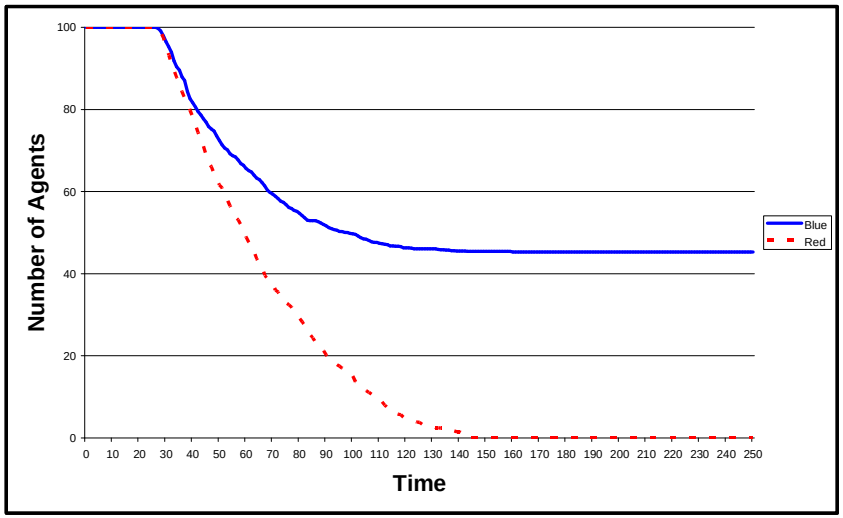

Figure 15: Red vs Blue Agents for Experiment 4

4.5 Experiment Summary

A summary of all the experiment results are provided in Table 2. Note the difference in results from Experiments 1 and 2 versus Experiments 3 and 4. In the latter there is a clear improvement in the outcomes for the Blue force.

Table 2: Summary of Experiment Results

Run	Experiment 1: Concept 1 vs 1		Experiment 2: Concept 2 vs 1		Experiment 3: Concept 3 vs 1		Experiment 4: Concept 3 vs 2	
	Blue	**Red**	**Blue**	**Red**	**Blue**	**Red**	**Blue**	**Red**
1	**34**	0	**37**	0	**40**	0	**40**	0
2	**53**	0	**46**	0	**46**	0	**40**	0
3	**11**	3	0	**38**	**45**	0	**50**	0
4	0	**29**	**26**	0	**48**	0	**43**	0
5	**32**	0	**15**	0	**43**	0	**34**	0
6	0	**36**	**39**	0	**45**	0	**37**	0
7	**43**	0	0	**33**	**64**	0	**57**	0
8	**43**	0	**5**	1	**59**	0	**52**	0
9	**32**	0	0	**36**	**52**	0	**46**	0
10	0	**20**	0	**42**	**36**	0	**54**	0
Average	**24.8**	**8.9**	**18.8**	**15.2**	**47.8**	**0**	**45.3**	**0**

5. Discussion

At face value it is clear that applying different C2 concepts, by means of a few simple rules, improved the probability of success of an engagement outcome. The implementation of C2 allows more agents to participate in engagements resulting in a concentration of resources. This is clear in the application of a centralised C2 ("HQ") with a situation awareness built from inputs from agents. Even with the implementation of delays, inherent to C2 processes and equipment, this proves to provide a winning edge in combat. The outcomes of engagements with similar strategies are dependant on the results or momentum at the beginning of the conflict

5.1 C2 Concept One

According to this concept, victory is heavily dependent on luck. Agents behave in a "shoot on sight"-like behaviour. Reaction time is the fastest but the quality of decisions made is the lowest. This concept's main advantage is that it can react fast, and its only chance of victory is by getting a few early kills in before the other two concepts have a chance to react.

5.2 C2 Concept Two

By using this concept, one can see small groups forming and cooperating to achieve goals. This concept seems to fail as soon as the group encounters a larger group. It has no real means of recruiting someone to the group other than by someone stumbling onto their conflicts. These groups usually suffer large casualties during formation of the groups early on in the simulation due to their slow reaction time compared to Concept 1, but after their groups have grown sufficiently in number they tend to overpower the uncoordinated units of Concept 1.

5.3 C2 Concept Three

This approach has the slowest response time but it is able to assess a greater awareness picture that is used to assist decision making. Unengaged units are directed towards areas of conflict and assist their allies. This results in larger group formations and unified execution of objectives. This approach yielded the best results of all tested concepts.

6. Conclusion

The models used in the experimentation were developed from established C2 concepts based on literature. From implementing these models it became clear that various forms of the OODA loop exist

at different levels of an organisation. By skipping stages of the OODA loop results in limited success, see C2 concept one.

From the experiments applying these models in an ABM conflict scenario the advantages of C2 is observed. A central situation awareness picture does provide an ability to concentrate resources in defeating an opponent. Although these models are simplified at this stage, it provides a basis for future investigation into C2.

This effort is only the beginning of complex investigations into C2. The utility of ABM has still to be grasped and the pitfalls understood. Deeper research, using the foundation established in this report, is required to investigate C2 and the different aspects thereof.

7. Future Work

As mentioned before, this experimentation effort is only the first stab at simulating and evaluating C2 concepts. This forms the basis for extensive future assessments of higher fidelity models. Areas identified for future investigations are:

- Refine C2 models in terms of the following:
  - Realistic system delays.
  - Implementing actual doctrine
- Different warfare tactics (flanking, detecting and exploiting breakthroughs etc.)
- Increase the complexity of the simulation environment by adding obstacles.
- Add objectives other that destroying the opponent force. Typical objectives may include:
  - Capture the flag.
  - Defending territory.
  - Convert population.

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