Using Agent Based Modelling to Understand Capability Development

William Scott(1); Prof. Stephen Cook(1); Prof. Peter Campbell(1)

(1)University of South Australia- William.scott@unisa.edu.au; Stephen.cook@unisa.edu.au; peter.campbell@unisa.edu.au

Abstract. The processes of Capability Development (CD) within the Australian Defence Organization (ADO) are described in some detail in the Defence Capability Development Manual (DCDM) 2006. It is recognized in the manual that any process driven approach will find itself in constant need of adaptation and modification to respond to the realities of working within the Defence environment where changes in schedule, funding, personnel, requirements and technology frequently occur during the life of a capability assessment.

This paper describes work being undertaken to better understand the dynamics of the CD process using a suite of agent based models which enables us to explore the interactions between the organization elements and individual positions within the Capability Development Executive (CDE). Interviews with CDE and Defence Science and Technology Organization (DSTO) staff involved in selected Capability assessments are being used to understand how CD processes are worked through and how adaptation to the various stresses on these processes come about. This information is being used to guide development of the agent representations of behaviour in the simulation tool. The paper details the models and methods used to develop this simulation tool.

It is hoped that as the simulation becomes mature it will prove useful in understanding the effects of exogenous changes such as schedule modifications, funding changes, personnel changes or temporary postings of staff, how outcomes depend on staff types and numbers, the effects of various levels of Industry involvement, the effects of different acquisition strategies, requirements changes driven by new technology, resource contention between assessment efforts, approval delays and such other factors which may be identified as of importance. A more ambitious goal is that the tool will allow recognition of signs of impending performance problems in real assessment programs and suggest remedial actions that should be taken.

1. INTRODUCTION

The Capability Development process which is performed by the ADO as part of any acquisition action meets the definition of a Complex Adaptive System. Since the late 1990’s Agent Based Modelling (ABM) has been shown to be an effective method for developing tools for understanding organizational behaviour with an increasing number of applications to real-world business problems [2][3]. Useful insights into how organizations can be understood in a simulation context have also been developed at the Cynefin Centre for Organizational Complexity [12]. This paper describes an approach to building an ABM to better understand the CD process as it is effected by the interactions of the participants responding to the various influences which can occur during the life of a project.

2. BACKGROUND

During 2004 two of us (Scott and Cook) were involved in the formalization and description of the Capability Development Process (CDP), as set out in the Defence Capability Development Manual (DCDM), 2005, which has since been updated in the DCDM, 2006. This work led to the development of a detailed multi-level static model of the CDP which has proved useful in understanding the way in which some parts of the process interact and effect other parts of the process, usually in ways detrimental to meeting desired timelines [15][16].

During the Defence Complex Adaptive Systems (CAS) Workshop held in Canberra in 2005, several breakout sessions were arranged to study how CAS concepts might be used to inform CD process improvement, during one of which the suggestion was made that an agent based and CAS modelling approach might be capable of providing insight. This suggestion was taken up and funded by the DSTO Defence Systems Analysis Division (DSAD) after submission of a proposal by the Systems Engineering and Evaluation Centre, University of South Australia.

3. PRELIMINARY INTERVIEWS

In mid 2006 two existing CD evaluation projects were selected with the help of CDE staff for preliminary interviews. The aim of these early interviews was to provide us with some understanding of the way in which managers adapt the CD process guidelines to the realities of actual projects.

The two interviews were conducted in an informal atmosphere using an open interviewing technique [8]. This method was selected to allow interviewees to ask questions that can be open to interpretation and to allow the interviewees to answer questions in a way that enables them to emphasise aspects that are important to them. Subsequent questions were used to elicit further information, where needed, and to keep the interviewee on the topic of interest. Although the information collected was to inform a task focused on complex adaptive systems, care was taken to use familiar terminology. This helped keep the interviewees feeling informal and comfortable. With only two samples, it would be unwise to draw too much from this brief research task; however, there are some points that we can raise.

In the first case study the CD project team did very well to prepare a sound submission in something less than a quarter of the time that would have been required if the formal processes set out in the DCDM had been followed.
The mechanisms they employed are, nonetheless, not magical. Rather, they can be described as examples of good practice in project management, systems engineering, and personnel management. Indeed, the Defence Capability Development Manual (DCDM) allows for such process tailoring (p31). It does, however, take courage, skill, and determination to achieve a positive outcome in such circumstances. The contribution to project success of outstanding project leaders is recognised within systems engineering and the term ‘heroes’ can be found in documents such as EIA 731 [11]. Furthermore, effective project heroes are associated with a reasonable level of organisational process maturity [14].

In the second case study the project was less successful for a number of factors even though it was considered a high-priority, urgent project with very high-level endorsement. In contrast to the first case study, the project manager was less empowered and had trouble accessing human resources from areas outside of his direct control. In addition a number of changes of direction and of requirements were imposed from the outside during the CD program. The result was that even though the project participants put in a heroic effort, the project difficulties were predictable by anyone with a background in management science, even one without personal knowledge of CDE and its culture.

So how do these assessments relate to the use of agent-based modelling and complex adaptive systems based approaches to developing a better understanding of the CD process? Adaptivity within an organisation comes from its people and predominantly its leaders. It is a product of culture, environment, team dynamics, and individual traits amongst other things. We believe that it is possible to enumerate the factors that indicate the likelihood of adaptivity in a project environment and model the degree to which adaptivity can be expected to arise in a given set of circumstances. The approach we are taking is to develop a generalized dynamic representation of the CD process into which we will insert agents representing the leadership and other important positions and organizations. Each agent will be capable of progressing its state in response to its perception of the context provided by the overall state of simulation. With this approach we hope to develop a tool which will lead to insights to enhance adaptivity in the capability development environment and thus improve capability outcomes for the ADF.

4. PRELIMINARY “PROCESS ONLY” MODEL

We contracted Intendico Pty. Ltd to develop an initial or prototype model using the JACK tool, as a quick means of obtaining an executable model of CD processes. As a part of previous work described in section 2 above, the formal CD process had been captured in Functional Flow Block Diagrams (FFBD) in CORE (by Vitech). The development of the prototype model converted the CORE process diagrams into behaviour exhibited by agents by using the CORE process diagrams to provide the linkages between the activities and a typical time line of events. We worked with Intendico to develop a design which mapped these activities to the agents that will be expected to perform them. The agents in this model are the identifiable ADO elements that are directly involved in the capability development processes; for example, organisations such as DSTO or groups such as industry. Other agents represent the specific roles typically assigned to an individual such as the project officer.

JACK is an agent-based simulation tool that is marketed by Agent Oriented Systems and that has previously found considerable use in defence applications. It implements agents using a Belief-Desire-Intent (BDI) methodology. Our prototype model was designed to simulate the First Pass of a generic capability development project. The prototype is a simulation which begins with an instantiated project and simulates the activities necessary to obtain First Pass approval.

Figure 1 shows a screen capture of a sample output from the model implemented in JACK. The top row shows the various agents that are used in the simulation with the horizontal lines representing their existence (similar to UML activity diagrams). The pink horizontal lines link the vertical lines to depict the communications between the various agents. The view seen in Figure 1 compresses the time axis to show only the order of events but the display in the actual model can be adjusted to see a spatially scaled picture of the time delay of the communication processes. In the screen capture, the activities captured in the CORE model are seen as notices (identifiable as lines that begin with “>”). The horizontal lines in Figure 1 represent interactions between the agents. In the sample taken in Figure 1, the horizontal lines depict the communication that assigns the tasks to the available agents. However, communication between the agents is of greater interest as it provides insight into the necessity and intended content of the exchanges.

The major advance provided by the agent-based model over the model implemented in CORE is its ability to expand the model into a greater number of potential feedback loops. In CORE, the development of feedback loops is difficult as the feedback lines are not permitted to cross. CORE is also limited by the way the diagrams are displayed. Complex feedback models can be difficult to read and the layout of the loops can be counter intuitive. The JACK model achieved the same level of capability at the prototype stage and will be easily expanded to include multiple feedback loops. The model can also be refined to allow the agents to tailor the CD process. This ability to tailor the process adds realism to the model, promotes good Systems Engineering practice, and aligns the model with the DCDM stipulation to tailor projects execution to individual project contexts.

5. IDENTIFICATION OF AGENTS REQUIRED IN THE SIMULATION

We are following a standard approach for developing an agent based model for simulating an organization. [2] Our earlier work has provided the identification of processes within the CDE and supports the necessary segmentation of the workflow. We have made a preliminary identification of the agents which we believe will be required by the simulation (See Table 1) although we expect that this selection will be modified by...
experimentation as we develop more understanding of the domain.

The next step to be undertaken is mapping the agents onto the segmented workflow processes and specifying what the agents do in each case. Agents will of course map to many workflow segments and will have numerous roles in doing so.

The agents will then be inserted into the process model, with modifications being made as we discover more about the way in which actual processes proceed.

At this stage we expect that a subset of these agents will be developed initially to aid in the further exploration of the processes and interactions which it is important to simulate, and to identify those which can perhaps be left out, or at least represented only at a low level of detail.

6. AGENT REPRESENTATION PROCESSES

There are a number of human behaviour models that have been proposed for application to agent based modelling. We are currently researching several possible models to see which will be most effective. The JACK tool which we have used to build the process model uses a Belief-Desire-Intention (BDI) model [4], so we are investigating the application of this representation model. We are also investigating the Parallel-rooted, Ordered, Slip-stack, Hierarchical (POSH) model of Bryson [5] and a directly heuristic agent implementation based on an approach similar to the Framework for Addressing Cooperative Extended Transactions (FACET) developed at Argonne National Laboratory [6][10].

The BDI method for implementing agents is well established and has been used for many applications. However, we think it remains to be demonstrated that it can adequately describe the complex interactions of all the agents that will be required to simulate of CD processes across the CDE organization. POSH seems to provide an excellent means of agent action selection because it is based on the concept of modular primitive action elements which each agent can then use to make its state transitions according to the perceived simulation context in which it finds itself. This removes the necessity for specifying each interaction transition of the agents and is very similar to the concepts used in FACET.

Use of a FACET type of approach has the attraction that we will be able to incorporate very recent work on individual and organizational behaviour in a heuristic manner [9][17][1].

A research topic that we have identified as key to the success of this simulation tool lies in how to represent in the appropriate agents the difference in effect between agents knowing that it has incomplete knowledge or understanding to complete a task, as against not knowing that it has incomplete knowledge or understanding.

7. PLANS FOR “EMERGENT BEHAVIOUR”

A major goal for our work is to develop a tool which will support the exploration of innovative approaches to the management and execution of CD projects. To accomplish this requires that the agents develop new behaviours as a result of context change within the simulation as time progresses. The meaning of context change in this sense is the changes in state of all the agents in the simulation with time. In order to develop new behaviour patterns at least some of the agents must be able not only to change their state in response to context changes, but also to develop new methods of bringing about those state changes.
Genetic algorithm (GA) methods have shown considerable success in providing the means for agents to exhibit this type of behaviour [7]. We plan to research several issues involved in the use of GA’s in this application area. Specifically the GA’s must be structured and the measures of effectiveness and measures of performance must be chosen such that the evolution of the system is the result of a balance between exploration and exploitation of new behaviour [13]. If this balance is not maintained experience shows that the agent system is likely to move either to a static state or to one which churns too rapidly for any one useful pattern to emerge.

We also intend to have the agent based system tool be capable of evolving undesirable behaviour. Looked at from this direction we believe there will be lessons to be learned if we can simulate known counter productive behaviours such as continuation of decision processes that have become less relevant with time because of external context changes as exogenous type factors and the effects of postponement of difficult decisions by project team members as examples of endogenous factors.

Our initial research plan is to develop the tool to be able to have at least some of the agents respond to differing factors. By trust we mean for example, the perception by project managers of the ability of various team members to perform their assigned tasks on time and to a required standard, where team members will include individuals, committees and other branches of the ADO which have input to the First and Second Pass decisions.

8. FURTHER INTERVIEWS AND USE CASE DEVELOPMENT FOR PARTIAL VALIDATION

Validation of this type of model is always an issue. In the classical sense validation is not possible as there is no known way to cover the huge array of possible states and transformations which the system is capable of reaching. But this type of tool has the purpose of enabling exploration of possible future states, not of predicting them. We plan to do a partial validation by exploring with further interviews a range of different situations that initiated, and at least one where there is some clear industry involvement. These interviews will also allow us to gain a deeper understanding of the interactions of the real agents in a CD project than we have been able to gain so far from the preliminary interviews, thereby helping us to improve the representation processes that the model agents use in the simulation. The selection of projects types will be evaluated and extended as needed to ensure that we have covered a sufficient range of variation to enable the construction of the use cases we plan to use to provide the credibility to the tool that will be needed for an initial adoption within ADO. The use cases will be designed to explore the correspondence between what the user s are looking for in the tool and what it can deliver to them. Once the tool is in the hands of the users a further step in “validation” occurs if it is found to be useful in their working environment.

9. APPLICATIONS

We see a number of ways in which this tool can be employed to improve both individual CD projects and the overall management approach used by the CDE. Our goal is to develop the simulation into a tool for the dynamic updating of interdependency effects by CDE managers and in particular to begin to address the effects on project performance arising from the types of issues the staff have with the CD process. These include:

a. The direct effects on individual programs of such factors as staff changes or shortfalls, past and projected schedule slippages, requirements changes, option proliferation, etc. We will develop this list with stakeholder participation as to the most useful factors and the perceived availability of data to support such functions,

b. The effects of resource contention and other factors on programs running at the same time – ie. interdependency between programs, and

c. Evaluation of multiple program inter-dependencies on delivered capability as a result of delayed or missing capability elements.

Table 1: Preliminary Agent List

<table>
<thead>
<tr>
<th>High Object</th>
<th>Level</th>
<th>Agent Instance</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person</td>
<td></td>
<td>Project manager, team member, committee member, CCDE, other</td>
<td>Agents will model these as positions, not individuals</td>
</tr>
<tr>
<td>Organization</td>
<td></td>
<td>CDE, DSTO, DMO, CIO, Finance, 1st. Pass and 2nd. Pass committees, Industry or Company, other</td>
<td>Can be expressed as either a single agent, or as the collection of their member agents</td>
</tr>
<tr>
<td>Infrastructure</td>
<td></td>
<td>Communications system, computer system, software program, other</td>
<td>To account for effects of tool availability</td>
</tr>
</tbody>
</table>

arise in CD and then to use this information to make the simulation more robust. Specifically we plan further interviews with CDE staff and others as appropriate to cover a range of possible program states, such as some that are still in progress, at least one which is about to be

10. SUMMARY AND DISCUSSION OF FURTHER WORK

At the time of writing this paper we have gathered interviews information from two projects, developed an
initial implementation of the formal CD process for the 1st. Pass portion using the JACK tool and developed our ideas and concepts as to what agents will need to be implemented in the simulation tool. Current research is focused on three areas – the selection of the most appropriate agent model or models to use, the identification of effective MOE’s and MOP’s along with the implementation of a trust model for the agents and increasing our understanding of the nature of the CD project process by means of further interviews and the development of use cases to test the simulation against realistic scenarios.

One important area which we have not yet addressed is the design of the user interface. We intend that this work will begin by interactions with the prospective users once we have an executable model capable of acting as a demonstrator.

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