Chapter 10-2 – VALIDATION OF THE MODEL

SUBJECT

In this chapter, we are concerned with the validation of the Conceptual Model. Of course, it is understood that in any scientific undertaking, it is impossible to have a theory, hypothesis, or model (let us call this our "model" for brevity) that is absolutely verified. We thus have to concern ourselves with the area within which the model is to be applied and the restrictions on that area of application, i.e. what are the constraints within which we know that the model works?

To answer this question, we have to think about what the model we have developed is to be used for, and also equally important, what it should not be used for. This raises further questions. Should it look as if it is capable of doing the job (face validity)? Should it contain the correct concepts and constructs (construct validity)? Should it be able to replicate a process in detail (process validity)?

APPROACH

Our Conceptual Model has been constructed with the aim of having the correct constructs and concepts. It consists of a number of variables and hypothesised links between these variables. The aim of validation in this case is thus to test whether the model has a rich enough set of such variables (i.e., has a requisite set of variables) sufficient to cover all the likely applications, and whether the links between the variables are supported by evidence where possible. It should also be easy to use in the domain of application. This leads us to consider criteria such as the following for validation:

- Requisite;
- Internally consistent;
- Authoritative;
- Has construct validity;
- Usability; and
- Unresolved differences between experts in the field have to be signalled.

To consider at least some of these aspects in detail, and with the focus on application of the model, we have taken the set of criteria developed for a Conceptual Model (in Chapter 10-1) and extracted those that are concerned with the usability aspects. This gives us the following expanded list of "useful aspects" of a Conceptual Model:

- Can support testing and refinement of causal and influence links;
- Provides a generic framework of metrics;
- Identifies natural modes of behaviour of variable sets;
- Identifies emergent behaviour;
- Suggests point of influence and pressure;
- Helps in rapid generation of ideas;

- Helps reason about constraints on validity;
- Helps understand how much of a property is enough;
- Helps identify correlations between variables;
- Supports analysis of failure modes;
- Supports studies and analysis;
- Identifies gaps in knowledge; and
- Supports customised views for different audiences.

To test these detailed criteria, we worked through two separate case studies. In Case Study 1, we considered a focussed analysis of a future complex peacekeeping and warfighting scenario with the emphasis on validating the richness of the variable set, the links between variables, and the usefulness of the Conceptual Model in supporting such a scenario-based study. In Case Study 2, we focussed on the broader tenets of Network Centric Operations, and approached the usefulness of the CM from a number of different directions. These included a detailed literature search of relevant materials, analysis of variables and links using agent-based modelling, building a process model describing the tenets of the NCO, a review of relevant human in the loop experimentation, and a historical review of leadership.

CASE STUDY 1

In Case Study 1, we focussed on the following set of criteria from the list above:

- Can support testing and refinement of causal and influence links (U1);
- Provides a generic framework of metrics (U2);
- Identifies natural modes of behaviour of variable sets (U3);
- Identifies emergent behaviour (U4);
- Helps reason about constraints on validity (U7);
- Helps identify correlations between variables (U9);
- Supports studies and analysis (U2, U10, U11, U13); and
- Identifies gaps in knowledge (U12).

Relative to the use criteria articulated in Chapter 10-1, we have thus focussed on the key groups labelled Learn More about C2 and Support C2 Aspects of Studies.

The case study approach was chosen as a relatively independent way of testing the CM because it would represent an example of use according to a pre-determined process with clear goals, and would not, therefore, be wholly dependent on the judgement of the SAS-050 team.

The objectives of this case study were:

- To test the C2 conceptual model against a specific, focussed study problem to find out if it:
  - Is an effective starting point for the specific study;
  - Facilitates requisite treatment (by identifying the full range of critical variables and relationships);

- Comprised a set of variables rich enough to differentiate adequately between different C2 Approaches;
- Encourages broad and innovative thinking; and
- Facilitates shared understanding between the nations.

- To propose improvements to the conceptual model.

The case study was conducted according to the process recommended by the *NATO Code of Best Practice for C2 Assessment*. Given the time and resources available and the principal role of the C2 Reference Model in studies, the case study focussed principally on Problem Formulation, which the COBP emphasises should be done explicitly before a Solution Strategy is formulated. Problem Formulation (sometimes called "questioning the Question") includes:

- Explicit declarations of assumptions and constraints;
- Identification of independent and dependent variables that will be evaluated; and
- Explicit declarations of high level Measures of Merit (or criteria) by which outputs will be judged for significance.

While this was the original aim, the case study actually went much further than this.

The COBP also recommends an iterative approach so that all aspects of the problem are re-visited at least twice during the study. The study was conducted from March to September 2004 (based on the Reference Model version current at that time) and involved a series of four workshop sessions that constructed a strawman problem formulation and sought to work the problem systematically. The third of these workshops used a Synthetic Environment experimentation facility to allow participants to immerse themselves in the chosen scenario before discussing the study problem.

Fuller details of the conduct of Case Study 1 are contained in Chapter 10-3.

What We Learned

Case Study 1 demonstrated that the Reference Model contained the majority of the variables needed to describe the different C2 Approaches considered, but that it needed more development in terms of completing the map of linkages between those variables for which it was to be capable of sustaining rigorous analysis.

The case study demonstrated the power of rigorous systematic analysis and the value of having a well formed Reference Model to sustain it.

The case study indicated that the type of C2 problem for which the Reference Model was being developed might not be reducible to a small number of key variables and relationships, presaging the need for rigorous and systematic methods of use for the Reference Model.

Of the eight criteria for a good Reference Model that Case Study 1 was expected to inform, it was able to say something useful about five:

- *Can support testing and refinement of causal and influence links*: The case study showed how the Reference Model could be used to test study specific conceptual models.

- *Helps reason about constraints on validity*: The case study clearly identified the extent to which study problems in the C2 area can be reduced in complexity without losing key factors.
- *Helps identify correlations between variables*: The case study showed how the Reference Model, when complete enough, could form the basis for study-specific conceptual modelling, thus allowing correlations between variables to be inferred.
- *Supports studies and analysis*: The case study could not use the Reference Model for its intended purpose because of its (then) incompleteness, but the exercise allowed a much more complete Reference Model to be developed.
- *Identifies gaps in knowledge*: The use of the Reference Model in the study was, in the end, more about identifying gaps in itself rather than in the team's comprehension of the case study problem.

Overall, Case Study 1 demonstrated that, even in its immature state, the Conceptual Model went a long way towards providing the kind of support envisaged in the criteria above. However, completeness of the causal network of variables is a critical pre-requisite to exploiting this potential. The case study was of great value in informing the further development of the model; if a similar exercise were carried out now with a more mature model it would be of significant benefit in further validation.

CASE STUDY 2

Literature Review

The aim of the Literature Review was to review the existing literature in order to support and refine the CM. It addressed several questions. Are specific variables and relationships in the CM supported by the literature? Do we need additional variables and relationships? We addressed the following specific aspects of Validation:

- Can support testing and refinement of causal and influence links (U1);
- Provides a generic framework of metrics (U2);
- Helps reason about constraints on validity (U7); and
- Identifies gaps in knowledge (U12).

Most of these are in the foundation group Learn More about C2.

The literature review was carried out in two phases, and efforts were made to ensure that the group carrying this out achieved a comprehensive and objective appraisal of the relevant supporting literature. This was done in a number of ways, including peer review of each other's work, announcement of the review, requests for relevant literature, and peer review of work in progress by those attending the 9th International Command and Control Research and Technology Symposium (ICCRTS) in Copenhagen (14-16 September 2004).

The result of the two phases of work was a detailed review of 29 highly relevant pieces of literature, drawn from conference papers, peer-reviewed papers in relevant journals, technical reports from NATO nations, and books. Full details of each review are in Chapter 10-4. Here we focus on the highlights of the review. Papers are identified by the lead author and by the number by which they are listed in the Case Study 2 Chapter under either Phase 1 or Phase 2, so that the relevant contribution can be accessed easily.

What We Learned

Highlights from Phase 1 of the Literature Review:

- There was support in the literature for shared awareness and team values increasing team performance (Mathieu et al., Phase 1).
- A rich expansion of the concepts in the C2 Approach was possible (Moffat, Phase 1).
- Further possible variables and relationships in the C2 Approach were identified related to personality, training, and experience (Dodd et al., Phase 1).
- There was literature support for the Behaviours part of the CM and emphasising the importance of Agility as a Measure of Merit (UK MoD paper, Phase 1).
- Additional possible variables were identified related to networks in the Value View of the CM, and theoretical analysis supported the link between information, shared awareness, and Measures of C2 Effectiveness, and the link between information, collaboration, and force effectiveness (Perry et al., Phase 1).
- The "Myths" of Network Centric Warfare were explored from a critical perspective (Cantos 1,2,3, Phase 1).
- Knowledge creation, collaboration, learning, and related key variables were identified to enrich and support the CM (Gauvin et al., Phase 1).
- A "Command Concepts" approach to C2 led to some possible changes to the associated CM variables and relationships (Builder et al., Phase 1).
- Metrics were identified related to Network Centric Warfare, which added to those in the CM (McInerney et al., Phase 1).
- There was literature support for the advantages of networking (Gompert et al., Phase 1).

In the second phase of the Literature review, we focussed on Performance and Agility as key aspects of the CM.

Highlights from Phase 2 of the Literature Review:

- The essence of the meaning of Command as human-centred, and of Control as process-centred (McCann and Pigeau, Phase 2).
- The representation of Command in terms of proactive rather than reactive constructs, based on Mental Models and hypotheses (Bryant, Phase 2).
- How belief propagates in Social networks (Behrman, Carley, Phase 2).
- Situation Assessment as a key ingredient (Endsley, Edgar, Phase 2).
- Natural and "Engineered" Complex Adaptive Systems are an insightful way of capturing state change over time and aspects of agility (Grisogono, Phase 2).
- Agility and self-organisation are at the heart of modern flexible production processes (Neubert et al., Phase 2).
- Key factors in headquarters performance from a human-centred perspective (Mathieson et al., Phase 2).
- Critical appraisals (Kaufman, McMaster, Phase 2).

We concluded from the review that significant support had been identified in the literature for some of the relationships in the CM. A rich set of additional variables and relationships had also been identified.

PROCESS MODEL

The aim of developing this NCO process model was to help understand some of the key variables and linkages that the CM should be able to represent. This related particularly to the criterion U1 in the group Learn More about C2.

What We Learned

The model was enhanced to ensure that it was rich enough to reflect this process.

AGENT-BASED MODELLING (ABM)

The aims of these activities were to:

- Identify advantages, limitations, and gaps of the CM to support the development of an agent-based model for testing NCO hypothesis. This relates particularly to the use criteria U1, U6, U12, and U13.
- Assess the capabilities of agent-based models to support the specification of relationships hypothesized in the CM. This relates particularly to the Uses Criteria U4 and U9.

These Uses Criteria relate particularly to the group Learn More about C2.

The agent-based modelling activities are also part of the example instantiation of the CM. The detailed discussion and results are shown in Chapter 10-7.

What We Learned

Bringing forward the results of the example instantiation, here is what we have learned:

- Because most of the variables in ABM are very basic, one cannot directly map ABM variables to the CM variables. However, using aggregation and de-aggregation, the variables and relations within the CM provide a valuable basis for the development of an ABM. Relations in the CM provide a basis for interdependencies between variables from which to select those modelling behaviours of agents.
- ABM models have a high potential for further refinements of the CM. The variables and behavioural rules in ABM provide indicators for CM variables and relations. In the course of ABM experiments, often surprising relations emerge that are not explicitly modelled but arise from the dynamic combination of a large set of simple rules. Further investigations of these emerging relations will have to provide the evidence that such relations are worthy to be part of the CM.

HUMAN IN THE LOOP EXPERIMENTS

As with the process model, the aim of reviewing the Human in the Loop literature was to help understand some of the key variables and linkages that should be able to be represented in the CM. This relates particularly to the criterion U1.

The references of the literature that were reviewed are P. Essens et al., "Military Command Team Effectiveness: Model and instrument for assessment and improvement," M. Spaans, "An assessment of the Dutch Battlefield Management System," and A. Worme, "Human Centric Implications of Network-Centric Operations." All were used as general background in helping to construct the CM.

What We Learned

The briefings reviewed were used as general background in the initial development of the CM.

HISTORICAL CASE STUDY

In principle, historical case studies are an excellent approach to validate hypotheses embedded in models. However, rarely can sufficient data be retrieved for that purpose from historical accounts. One notable exception is the 1980 BDM report compiled by General William De Puy (U.S. Army, Ret.) based on a series of structured interviews to elicit, in conjunction with a series of war games, the knowledge of the German WW2 Generals Balck and von Mellenthien in reviewing plans for defending against Soviet attacks in the Fulda gap. From a first look at this document, the impression was won that it contained a wealth of useful information for validating parts of the CM. Even though C2 is not addressed in any detail in the DePuy report, and with reference to organisational aspects only, in their statements the German Generals referred to a series of human factors and behavioural parameters that they regarded as important for success in battle based on their extensive field experience in World War II, especially in situations when they fought successful battles against a numerically superior enemy.

Therefore, a text analysis was done with the aim of developing a structured basis for the development of a conceptual model that reflects the experience of both generals as a contribution to the validation of the C2 conceptual model (CM). Based on some 30 relevant variables identified in the report, and more than 15 statements in which variables were explicitly related to each other, influence diagrams were developed showing the links between environmental and institutional parameters and human characteristics and individual and team behaviours related to battle performance. A comparison showed that the existing CM covered most of the variables and relationships identified from the DePuy report. In particular, the accounts of the German Generals emphasize the need for flexibility and maintaining the initiative, and understanding higher intent.

What We Learned

- The experience captured in historical accounts offers valuable clues as to the potentially most important individual and team characteristics/variables and their relationships and may be helpful to focus on core variables in a specific C2 context.
- Variables identified from historical case studies can be used to develop hypotheses on relationships, which then can be examined in the light of empirical studies.
- Psychological research supports some of the relationships between variables that were identified from the Balck / von Mellenthin accounts.
- The majority of the identified variables are covered by the CM, however some variables important in a warfighting context were missing and were subsequently added.
- The CM is helpful in structuring historical accounts of military operations to provide a basis for the validation of models.

LACK OF TOOLS

Relative to the Uses Criteria, in particular Support C2 Aspects of Studies and Exploring New C2 Concepts, we found that there were very few tools and combinations of tools available that allowed us to visualise and navigate through the variables. Consequently, we are not sure that we have fully explored all of the variables and the linkages. For example, during the agent-based modelling, it was very difficult to identify the key parts of the CM relating to the problem.