Multi-Perspective Modelling of the Air Campaign Planning process*

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Abstract

This paper describes work performed to acquire knowledge about, and produce models of, the USAF Air Campaign Planning (ACP) process. The aim of this work was to produce a set of "knowledge models" which researchers in the area could refer to, rather than having each of them interview the expert planners.

It was decided that the models which were produced should be *multi-perspective* models; that is, a variety of models would be produced, each containing a particular type of knowledge about the air campaign planning process. The basis for this approach was the CommonKADS methodology for modelling organisational and expert knowledge. This paper describes the development of organisational, task and communication models to represent air campaign planning from various perspectives.

For some models, it was decided that CommonKADS' representations were not sufficiently rich, and so alternative modelling techniques (IDEF3 and Role Activity Diagrams) were used to represent the Task and Communication models. It was discovered that these techniques could be used without modification to represent CommonKADS models. An architecture is proposed, based on the Sowa/Zachman framework for Information Systems Architecture, to help determine the types of knowledge addressed by various modelling techniques

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1 Introduction

This paper describes work performed to acquire knowledge about, and produce models of, the USAF Air Campaign Planning (ACP) process. The aim of this work was to produce a set of "knowledge models" which researchers in the area could refer to, rather than having each of them interview the expert planners.

It was decided that the models which were produced should be *multi-perspective* models; that is, a variety of models would be produced, each containing a particular type of knowledge about the air campaign planning process (declarative, procedural, communications, etc), and thus representing the ACP process from a number of different viewpoints. The chief benefits of multi-perspective modelling are that it is easier to ensure complete acquisition of knowledge of each type, easier to maintain the knowledge, and easier to re-use individual models if another application should be developed.

The basis for this approach was the CommonKADS methodology for modelling organisational and expert knowledge. CommonKADS [Schreiber *et al.*, 1994; Breuker & van de Velde, 1994] is a collection of structured methods for building knowledge based systems, analogous to structured methods for software engineering; as such, it provides an *enabling technology* for the analysis of acquired knowledge and the design of knowledge based systems. It was developed between 1983 and 1994 on two projects funded by the European Community's ESPRIT program, and has recently been identified as an technology with much potential by the Strategic Directions For Computing Research working group in North America [Computing AI Working Group, 1996].

For analysis of any knowledge-based application, CommonKADS recommends the development of one or more of the six models described below. The models, which are represented using node-and-arc diagrams, relate to each other as shown in Figure 1.

- An *organisational* model to represent the processes, structure and resources within an organisation;
- A *task* model to show the activities carried out in the course of a particular process;
- An *agent* model to represent the capabilities required of the agents who perform a process, and

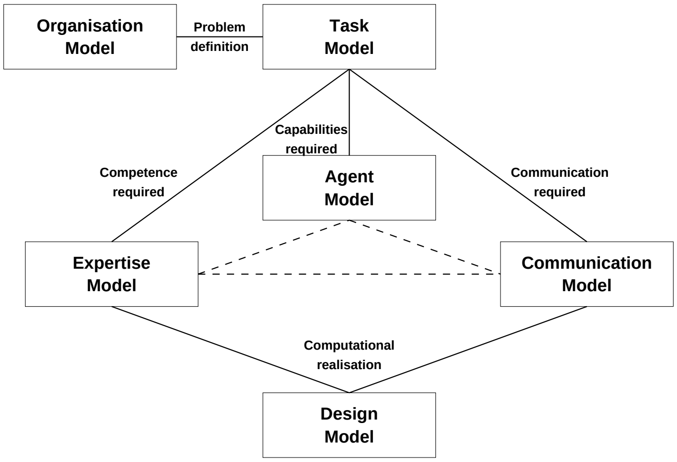

Figure 1: The CommonKADS Model Set

constraints on their performance;

- A *communication* model to show the communication required between agents during a process;
- An *expertise* model, which is a model of the expertise required to perform a particular task. This model is divided into three components:
  - declarative knowledge about the domain;
  - the inference processes required during problem solving;
  - a hierarchical classification and ordering of the inference processes.
- A *design* model, which culminates in the design of a knowledge based system to perform all or part of the process under consideration.

In order to represent the ACP process to a sufficient level of detail for other researchers, it was decided that the Organisational, Task and Communication models would be required; the Expertise model was also partially developed. The purpose of this paper is to describe the development of these models, with an emphasis on the use of different modelling techniques within a CommonKADS framework to represent the different perspectives. The paper concludes with discussion of a suggested framework for classifying and applying modelling techniques to multi-perspective modelling.

2 Knowledge acquisition

Knowledge acquisition was initially carried out using interviews. These interviews provided much useful knowledge, and also highlighted the existence of a number of relevant documents, from which a lot of knowledge was acquired. Two other knowledge acquisition techniques were also used: analysis of protocols acquired during a sample planning scenario provided useful information about the priorities, ordering, and necessary information for the planning process; and the repertory grid knowledge elicitation technique [Gaines & Shaw, 1993] was used at a later stage to determine which activities within the planning process might benefit from knowledge based system support.

The knowledge that was acquired showed that air campaign planning is hierarchically organised. When a crisis occurs, the Commander in Chief (CinC) provides planning guidance to the Joint Forces Commander (JFC). This guidance is communicated to the component commanders (e.g. the Air Component commander), who will in turn communicate the guidance to the air campaign planners. Based on the guidance, the planning staff will take between 3 days and 1 week to build a plan that may be executed. The acquired knowledge also showed that certain documents (such as the Master Attack Plan and the Air Tasking Order) form the outputs of key activities, and constitute a major method of communication within the planning process.

3 CommonKADS models

The acquired knowledge was then classified into appropriate CommonKADS models.

3.1 Organisational model

The CommonKADS organisational model [de Hoog *et al.*, 1993b] is a collection of diagrams, each taking a different perspective on an organisation. CommonKADS recommends and suggests formats for diagrams of the organisational structure, activities, power/authority relationships and various resources. These models analyse each type of knowledge individually; "cross products" can also be developed which combine the knowledge from two different perspectives.

There may be various reasons for developing an organisational model:

- The model may be intended to describe the organisation in a way which facilitates identification of organisational needs and opportunities. By giving detailed but separate description of the activities, the structure which contains agents who perform activities, and the resources required for activities, it becomes easier to identify insufficient or excessive constraints on agents, under- or over-resourcing, and other potential areas for improvement.
- By emphasising knowledge-based activities in the modelling, this model can be used as a basis for *knowledge management* within an organisation. Knowledge management, which is a growing area of interest, involves surveying, categorising, analysing and synthesising knowledge-based activities, codifying and organising knowledge, appraising and evaluating knowledge and related activities, and deciding how to leverage, apply and control the knowledge [Wiig, 1993].
- The model can be used as part of a feasibility assessment of a proposed knowledge based system. A good example of this can be found in [de Hoog *et al.*, 1993a], which describes a feasibility study into developing a KBS to support decision making within

a social security department, in order to reduce the time taken to process social security applications. A "cross product" of the organisational activities and organisational structure showed that decision making was distributed among several departments, and only occupied a small proportion of the total processing time for an application.

- The model may simply be required to provide a comprehensible, high level overview of an organisation for specialists who work in a narrowly focused area, and who need to know how their work relates to the rest of the organisation.

The modelling of air campaign planning was carried out for the final reason: to provide an overview of the air campaign planning process to ARPI researchers who are developing systems to perform knowledge-based planning and other tasks. The organisational model was also adapted according to the demands of the domain; specifically, the representation of power/authority relationships was considered superfluous by the experts, which is unsurprising in a model of a military organisation, where all authority is inherent in the organisational structure.

The resulting organisational model consisted of diagrams of activities (such as Figure 2), agents within an organisational structure, and resources. These were then combined to produce "cross products"; Figure 3 shows an early version of the cross product between activities and resources.

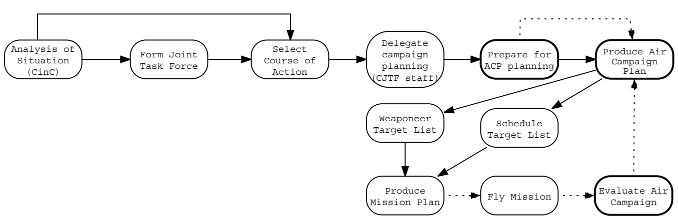

Figure 2: Air Campaign Planning: Top Level Activities

Key:

Solid link	the first activity *precedes* the second
Dashed link	there is an *information flow* from the first activity to the second.

With its combination of perspectives, the CommonKADS Organisational model provides a good overview of an organisation and its activities. However, there is a need for a more detailed analysis of the Air Campaign Planning process in order to supply researchers and developers of potential automated planning and decision support tools with sufficient information on where automated support is required, and therefore on where their tools might be used. As a result, it was decided that the CommonKADS Task and Communication Models needed to be developed as well.

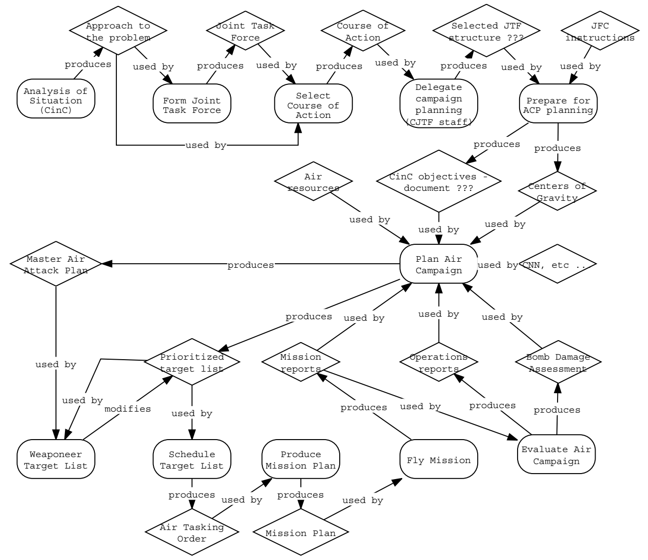

Figure 3: Air Campaign Planning: Cross Product of Activities and Resources

Key:

Labelled link	the activity *produces/consumes/uses/modifies* the resource
Diamond	Passive resource
Rounded rectangle	Activity

3.2 Task Model

The CommonKADS Task Model [Duursma, 1993] expands one of the organisational activities identified in the organisational model into a more detailed view of the processes required to perform that activity. The underlying assumption is that this organisational activity has been identified as a source of an organisational weakness or opportunity, and so the activity should be investigated in more detail, with a view to automating certain sub-processes, or improving the knowledge management of sub-processes in other ways.

CommonKADS recommends a format for Task model diagrams. CommonKADS' recommended representation has the benefits of simplicity and clarity, but certain key information is relegated to textual annotations rather than being represented graphically. The representation of processes has been addressed by a number of different methods and techniques, each of which has its own strengths and weaknesses; for this project, where the primary aim was to communicate detailed information to other researchers, it was decided that CommonKADS' representation for the Task model was not adequate. The Process Flow Network recommended by the IDEF3 method was used instead.

IDEF3 is a process capture technique which was designed to be tolerant of incomplete and inconsistent descriptions, and to be flexible enough to deal with the incremental nature of the information acquisition process. It provides both a process-centred view of a system, via the *Process Flow Network*, and an object-centred view of a system via the *Object State Transition Network*.

A process flow network displays a sequence of *Units of Behaviour* (UOB) which represent activities, actions, processes or operations. These are linked together by precedence arcs. Where the process flow diverges (fan-out) or converges (fan-in) junction boxes are used. Junctions are of the AND, OR or Exclusive OR type and can be synchronous or asynchronous. This notation may impose timing constraints on the process flow. For example, a synchronous fan-in junction indicates that the incoming processes must complete simultaneously before the next UOB can begin.

In addition to UOBs and junctions, process flow networks can include referents, elaboration forms and UOB decompositions. Referents are used to indicate context-sensitive information and may refer to any other type of UOB such as an elaboration form, another process flow network, an object state transition network, an entirely different scenario, a note, or act as a GO-TO within the network. In some cases referents may impose timing constraints on the process so there is the option to be synchronous or asynchronous as needed. An elaboration form holds specific textual information for each UOB such as the object used by it, constraints acting on it, facts about it and a description of it. Decompositions enable each step of the process to be broken down into more detailed process descriptions, allowing descriptions to be held at varying levels of abstraction. This is indicated on the diagrams by a shadow on the parent UOB box.

An example of an IDEF3 process flow network can be seen in Figure 4.

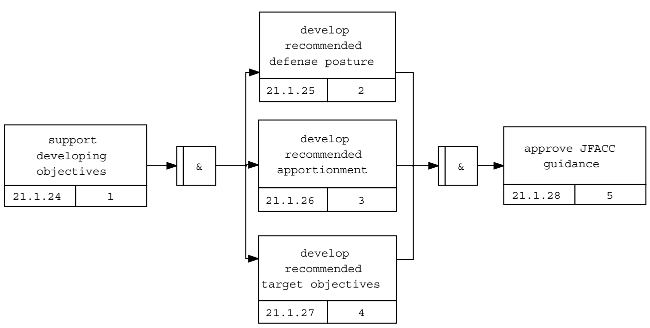

Figure 4: An IDEF3 Process Flow Network diagram

3.3 Agent and Communication Models

The CommonKADS Agent and Communication models support the Task model by identifying other information about the sub-processes being modelled. The Agent model represents the capabilities and skills of the agents (staff, clients, or computer programs) who perform each activity within a sub-process; the Communication model represents all communication which must take place between agents in order for a process to be completed.

One of the primary uses of the Agent model is to determine which roles can be performed by a human, which by a computer, and which by a human and computer working together. As this was not a major purpose of the modelling exercise, it was decided that an Agent model was not required. A Communication model was required, however, because effective transfer of information from one person or working group to the next is an important factor in the completion and efficiency of the planning process.

As with the Task model, CommonKADS' recommended format for communication modelling (described in [Waern *et al.*, 1994]) was not the richest technique available, and it was decided that a model rich in detail was required for this project. Role Activity Diagrams (RADs), a representation developed by a UK consultancy [Ould, 1992-3], were used instead. RADs are designed to represent all communication transactions succinctly; they represent the initiator of each communication; they link communication to activities, thus providing an explicit link with the Task Model; and they allow textual annotations to represent details. Part of the RAD which was developed for Air Campaign Planning can be seen in Figure 5.

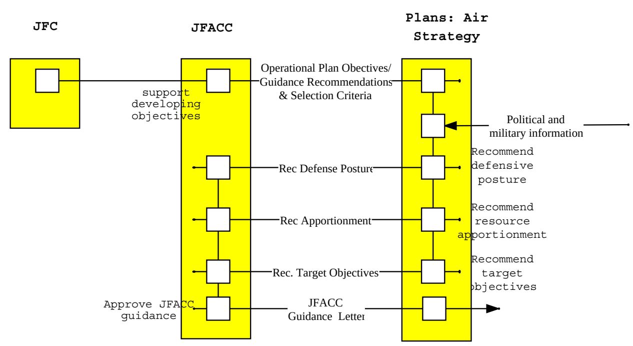

Figure 5: Role Activity Diagram showing initial communication in the air campaign planning process. Each shaded box represents a person or group of people.

3.4 Matching modelling techniques to perspectives

An important observation which was made was that IDEF3 Process Flow Networks and RADs could be used *without modification* to represent the CommonKADS Task model; this implies that these techniques model a single perspective on an organisational process. If this observation can be extended to other modelling techniques, then it should be possible for organisations to use CommonKADS as a modelling framework within which existing techniques can be used where appropriate, and CommonKADS' recommended techniques can be used for perspectives on knowledge which are not covered, or inadequately covered, by existing techniques. This would allow introduction of a CommonKADS approach without discarding work previously performed using other modelling techniques, and would reduce the learning curve for CommonKADS.

However, there is currently no systematic way of selecting a suitable technique to represent a particular perspective without having detailed knowledge of the capabilities of every possible technique.

As part of the ACP modelling effort, the authors of this paper met with a "modelling cluster" of researchers within the overall project who were interested in wider modelling issues. At the suggestion of one of the participants, the Sowa/Zachman framework for Information Systems Architecture [Zachman, 1987; 1992] was proposed as a basis for classification of modelling techniques.

The Information Systems Architecture (ISA) framework, which can be seen in Figure 6, classifies information and/or systems on two dimensions: *perspective* and *level of abstraction*. The six categories in the perspective classification are represented succinctly by the words *What, How, Who, When, Where* and *Why*. In other words, the ISA framework is suggesting that, to model an information system completely, it is necessary to determine what information will be used; how it will be processed; who will use it; when in the process each item of information is needed; the location at which each piece of information is needed; and the underlying strategy. These perspectives map closely to the perspectives recommended by CommonKADS:

- the Task model shows *how* information is processed;
- the Agent model shows *who* handles the information
- the Communication model shows *where* the information is needed
- part of the Expertise model defines the flow of control that specifies *when* activities occur
- both the Organisational Model and the Expertise model have components describing *what* information needs to be processed.

CommonKADS does not have an explicit "strategy" perspective; however, the library of "problem-solving methods" within the Expertise Model, and some aspects of the Design Model, are considered sufficient to support and represent *why* a particular way of representing knowledge has been chosen.

The second classification which appears within the ISA framework is *level of abstraction*. The framework suggests that each perspective should be modelled at six levels of abstraction, ranging from the *scope* of the system through *enterprise, system* and *technology* models to *components* and *functioning systems*. These terms are intended to be generic terms which can be customised for each particular application; for example, in the design and construction of a business system or building, the six levels of abstraction might correspond to the considerations of the *planner*, the *owner*, the *designer*, the *builder*, the *sub-contractor* and the *user*. By combining these different levels of abstraction with the different

Framework Software, Inc.	Information Architecture	Functional Architecture	Network Architecture	Organization Architecture	Dynamics Architecture	Strategy Architecture
Planner	Information Subject Areas	Functions	Locations Affected	Rosters	Major Events	Philosophy & Strategies
Owner	Entity Relationship Models	Context Diagrams	Business Unit Associations	Organization Charts	Event Models	Enterprise Strategies
Designer	Logical Data Models	Activity/ Process Models	Site-Link Topologies	Design Teams	System Event Diagrams	Information System Strategies
Builder	Database Architecture	Application Architecture	Network Connections	Construction Teams	Technology Event Diagrams	Technology Strategies
Sub-Contractor	Data Aquisition Components	Program Module Components	Network Components	Task Forces	Component Dynamics	Component Management Strategies
User	Databases, Data and Information	System Applications	Network Systems	System Users	System Events	System Impact

Figure 6: The Information Systems Architecture framework

perspectives on information, 36 possible classifications are created.

The four intermediate levels of abstraction identified by the ISA framework have direct correspondence with levels of abstraction identified by CommonKADS. The enterprise level corresponds with the Organisational Model, the system level with the Task, Agent & Communication models, the technology level with the Expertise Model, and the component level with the Design Model. The scope level, which defines what is inside and outside the boundaries of the information system, is implicitly represented by the presence or absence of knowledge items in CommonKADS models, while the functioning system level clearly corresponds to implemented KBS systems.

From this analysis, it can be seen that the CommonKADS approach to knowledge modelling can be mapped to the perspectives and levels of abstraction recommended by Sowa and Zachman in their framework for Information Systems Architecture. Given that CommonKADS is a proven enabling technology for KBS development, this analysis suggests that:

- CommonKADS could usefully be extended in certain areas to increase its coverage of the framework. Some of this work is already taking place; for example, the Communication model was originally seen as a way of modelling communication at the system level in order to identify communication bottlenecks and difficulties, but has been applied at the technology level (e.g. [Kingston, 1992] because it provides a useful tool for modelling inter-system communication, and for defining requirements for user interfaces).

- Other techniques could be used in conjunction with CommonKADS, to augment or extend its capabilities. The benefits of using known techniques in conjunction with CommonKADS include reduced learning curves, richness of representation, and re-use of existing models. This project has shown how IDEF3 Process Flow Networks and Role Activity Diagrams can be used to augment certain aspects of CommonKADS modelling; it is not difficult to imagine circumstances where knowledge modelling would benefit from representation of the *what* perspective at the system level, which could be accomplished using IDEF3's Object State Transition Networks, or other techniques.

- The ISA framework could be used to inhibit techniques from being used where they are not appropriate. There is a danger that the known technique will be over-used, because people who are familiar with a technique believe that they can "hack" a solution; however, classifying techniques using the ISA framework promises to identify techniques that should be appropriate for modelling particular types of knowledge, as well as making explicit the limits of these techniques.

3.5 Summary

The CommonKADS methodology is an enabling technology for the analysis and design of knowledge based systems. It recommends analysis of knowledge by producing mutiple models showing individual perspectives on knowledge, and this multi-perspective approach is one of its main strengths. CommonKADS has proved to be very helpful for producing a well-defined model of air campaign planning; however, because of the richness of models required, CommonKADS was augmented with alternative modelling techniques that are able to replace the CommonKADS modelling techniques for certain perspectives.

The Sowa/Zachman framework for Information Systems Architecture takes a similar multi-perspective view on the representation of information and knowledge to the approach taken by CommonKADS. The ISA framework is capable of identifying specific areas where CommonKADS can be improved; if a suitable classification can be agreed, then there is potential for the ISA framework to identify modelling techniques which are suitable for representing different types of knowledge.

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