Multi-Perspective Models of the Air Campaign Planning process

John Kingston and Terri Lydiard
AIAI
University of Edinburgh

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Contents

List of Figures

List of Tables

This document contains models of the Air Campaign Planning process, represented as diagrams and accompanying text. The purpose of these models is:

- To help with domain familiarization for researchers in ARPI;
- To make it easy for the researchers to find information relevant to their work;
- To take a step in the direction of making knowledge bases that the researchers can use in the implementation of their systems;
- To help Checkmate with the development of models that will suit their needs.

These diagrams are based on knowledge acquired from two staff members from ISX who were formerly part of the USAF, four members of Checkmate[1], and documents provided by these domain experts.

A full description of the Air Campaign Planning process requires analysis on two levels:

- a description of the components of an air campaign plan. The central elements of an air campaign plan are *objectives*, which describe a desired action to be taken by the air forces, at varying levels of abstraction.
- a description of the process of creating an air campaign plan. The key elements of the air campaign planning process are *activities*, which might include creating objectives or prioritizing objectives.

This document concentrates on a description of the the process of creating an air campaign plan, using a multi-perspective approach based on the CommonKADS methodology [Breuker & van de Velde, 1994]. However, the Expertise Model, which is a key component of the CommonKADS methodology, is designed to represent both a (specific) process and the domain knowledge which it manipulates; in other words, to model both activities and objectives. An analysis of objectives was performed in order to support this model; some results can be seen in Appendix C.5.

[1] Checkmate is a group of expert air planners at the Air Force Headquarters in the Pentagon, who may play a role in a JTF by augmenting the JFACC planning group or by working separately from the JFACC planning group. Checkmate was originally a war gaming center for evaluation of plans with a focus on high level strategy; for example, Checkmate modeled WWIII in Europe so that logistics, purchasing and training could be planned in the event that a crisis occurred. However, the senior Air Force officers often use Checkmate to supplement their planning staff. As a result, Checkmate personnel have real world planning experience even though it is not in the group's original charter.

1 Introduction to Air Campaign Planning

The knowledge acquisition effort which is described in this document focused on air campaign planning within a Joint Task Force (JTF). A JTF exists for one crisis (which usually implies one theater); however, there may be more than one JTF per theater. The JTF is under the control of the Joint Forces Commander (JFC).

The Joint Forces Air Component Commander (JFACC) is the functional commander responsible for the air operations within the overall campaign. The JFACC is appointed by the JFC, who usually selects the component commander contributing the greatest number of air assets to the JTF. The work of the JFACC and his staff is carried out in the Joint Air Operations Center (AOC).The JFACC reports to the JFC, who reports to the Commander in Chief (CinC) of the theater.

1.1 Plan Components

A Campaign Plan is a plan for all forces participating in a JTF and typically covers a 6 month period. Each functional component within the JTF will also have a specific campaign plan. The Air Campaign Plan also covers a 6 month period. The overall plan is represented and transformed into a Master Air Attack Plan (MAAP), from which the Air Tasking Order (ATO), or battle plan, is produced. The ATO takes 36 hours to produce and covers 24 hours. Mission Plans are derived from the ATO; a mission plan constitutes the directions for a specific sortie. Pilots then develop an Engagement Plan, which specifies the maneuvers that will be used to execute the mission plan.

1.2 Preparation for planning

Once a crisis occurs, the CinC assesses the situation, selects a Course of Action and may decide to establish a JTF. Then a warning order is given, normally 3 days in advance of the commencement of operations. Operations are initiated by a further order from the CinC, known as the Operations Order.

When a crisis occurs and the CinC decides to take some action, the CinC will provide planning guidance to the JFC. The guidance is communicated to the component commanders (e.g. the JFACC) through the JFC. The component commanders will in turn communicate the guidance to their planners. Based on the guidance, the planning staff will take between 3 days and 1 week to build a plan that may be executed.

Although the guidance (at every level) is considered to be an order rather than a suggestion, negotiation does take place. If a commanding officer proposes certain objectives or goals that are unreasonable, then participants in the planning process have the responsibility for convincing the commanding officer to take a different approach. For example, the planners may want more time. But, to buy time in a crisis, something diplomatic has to be given up. The commanding officer may not be willing to make a diplomatic sacrifice. In some such situations, the commanding officer will enforce the initial guidance; in other cases, the initial guidance may be relaxed. However the Rules of Engagement (which are part of the initial guidance from the CinC) are never negotiable.

Initial planning steps include assessing the situation and organizing the planning staff. Assessing the situation involves identifying enemy centers of gravity (COGs)[2] and air defenses as well as determining a strategy and defining high level objectives. A lot of knowledge about the theater is needed; typically the planning staff has been studying the theater for years. The types of information they know are whether the enemy has nuclear weapons, the nature of the crisis, and the history of the conflict. The planning staff have, and use, many maps with different perspectives of the theater.

When the planners cannot find required details, they will rely on contacts with people who have the information or can get the information. Typically these are intelligence people on the planning team. It's often impossible to prove the accuracy of intelligence data, because INTEL (the intelligence group) must protect their sources; however, duplication of INTEL effort between different branches, which is encouraged, may corroborate information or provide additional information. If the planners cannot obtain the required information in time (it can take 3 days for information to arrive), they will make assumptions and move to the next step.

1.3 Planning

Throughout the planning process, air planners are searching for alternatives, vulnerabilities, consequences and contingencies. The heart of the planning process consists of three stages:

- identifying and prioritizing air objectives;
- identifying and prioritizing air tasks;[3]
- identifying and prioritizing targets.

The planning may be subdivided according to different phases of the conflict, or possibly on other dimensions (e.g. geographical area).

The planning team usually consists of 8 people working 8-hour shifts (12 hours in a crisis), which is only sufficient to plan for one situation (the most likely case) and look very hard at one other alternative (probably the worst case). The planning staff hold 4-hourly meetings to discuss progress, obtain a consensus of opinion, and to make sure that there is a smooth transition between phases. The latter is very

[2]COGs are described in more detail in section C.5.

[3]The terms "task objective" or "Course of Action" may be used by some to refer to air tasks

important, since it is imperative that friendly forces are not perceived by the enemy as being indecisive.

It's important to note that the planning process does not always continue until each stage is fully completed. Often, the planning staff may only be 75% finished with some activities when it is time to move on to the next stage. This is usually due to resource constraints (insufficient staff to perform more detailed analysis), although there is also a temporal constraint; the dynamic environment in which planning takes place means that the situation may have changed by the time thorough planning is completed.

In most cases, the JFACC will not want to be involved in the planning process except for a daily briefing to make sure that guidance has been communicated correctly. This lack of involvement from the JFACC is deliberate and is designed to foster openness and innovation. The air planning team does not normally communicate with other branches either, in order to enhance creativity, and to reduce the constraints of reconciling too many points of view.

2 Introduction to the modelling technique used

The modelling technique used to model the ACP process was based on the CommonKADS methodology for knowledge modelling. CommonKADS [Wielinga *et al*, 1992] [Breuker & van de Velde, 1994] is a collection of structured methods for building knowledge based systems, analogous to methods such as SSADM for software engineering. It was developed between 1983 and 1994 with funds from the European Community's ESPRIT program. CommonKADS views the development of a knowledge based system as a modelling activity, and so the heart of the method is the construction of a number of models which represent different views on problem solving behavior. Knowledge engineers are encouraged to construct some or all of the following models:

- An *organizational* model, which represents the processes, structure and resources within an organization;
- A *task* model, which shows the tasks carried out in the course of a particular process;
- An *agent* model, which represents the capabilities required of the agents who perform a process, and constraints on their performance;
- A *communication* model, which shows the communication required between agents during a process;
- An *expertise* model, which is a model of the expertise required to perform a particular task.

- A *design* model, which culminates in the design of a knowledge based system to perform all or part of the process under consideration.

Each of these models consists of one or more diagrams, showing different perspectives on the knowledge contained within that model. For example, one perspective might model the activities which take place in an organization, while a different perspective may represent the structure of that organization. Each perspective therefore represents all acquired knowledge of a particular type. The strength of this "individual perspective" approach appears when the knowledge engineer tries to make the knowledge contained in the different perspectives consistent; the presence of certain knowledge or data in one perspective frequently highlights missing knowledge in another perspective.

This document provides CommonKADS models for the Air Campaign Planning process and its surrounding environment. The models which are included are:

- an (enriched version of) the organizational model, showing a number of different perspectives on a Joint Task Force.

- a task model, which uses the IDEF3 process modelling technique [Lydiard, 1995]. IDEF3 which represents the exact ordering of processes more precisely than CommonKADS' recommended diagram format. A full set of IDEF3 diagrams describing the whole Air Campaign Planning process can be found in Appendix B. An "asset perspective" is also included within the task model, to represents the various documents produced and resources used.

- a communication model. This model has been represented using the RAD (Role Activity Diagram) technique, which represents information more compactly than CommonKADS' diagram format for communication modelling.

- an expertise model of the processes involved in identifying and prioritizing air objectives. A number of expertise models could be built to represent various different knowledge-based activities; the expertise model which deals with air objectives provides an example of what is possible with the expertise model.

- Task structures (a single perspective from the Expertise Model) for the identification of air tasks and targets. The similarity of these task structures to the task structure for identifying & prioritizing air objectives suggests that the complete expertise model for these activities will be similar to the expertise model for air objectives.

3 Organizational Model of the ACP process

3.1 Introduction

The stated aim of modelling the Air Campaign Planning (ACP) process was to perform a "task analysis" of the ACP process. However, after initial knowledge acquisition, it was felt that there was considerable benefit to be gained from producing an Organizational Model, showing the organization which surrounds ACP, before analyzing the activities performed during the ACP process in detail. The organizational model contains information on the *activities*[4], the *agents* and the *resources* which are used in the air campaign planning process, as specified in Figure 1; each perspective is represented by a single diagram, or by text.[5]

The organizational model also contains "cross products" of these three different perspectives (again, see Figure 1), which sometimes provide the most useful information. For example, the CommonKADS Organizational Model was used to model a Social Security department; a cross-product of activities and structure was produced which highlighted an area of inefficiency, because one of the activities (archiving) was being performed by three different divisions of the department [deHoog *et al*, 1993].

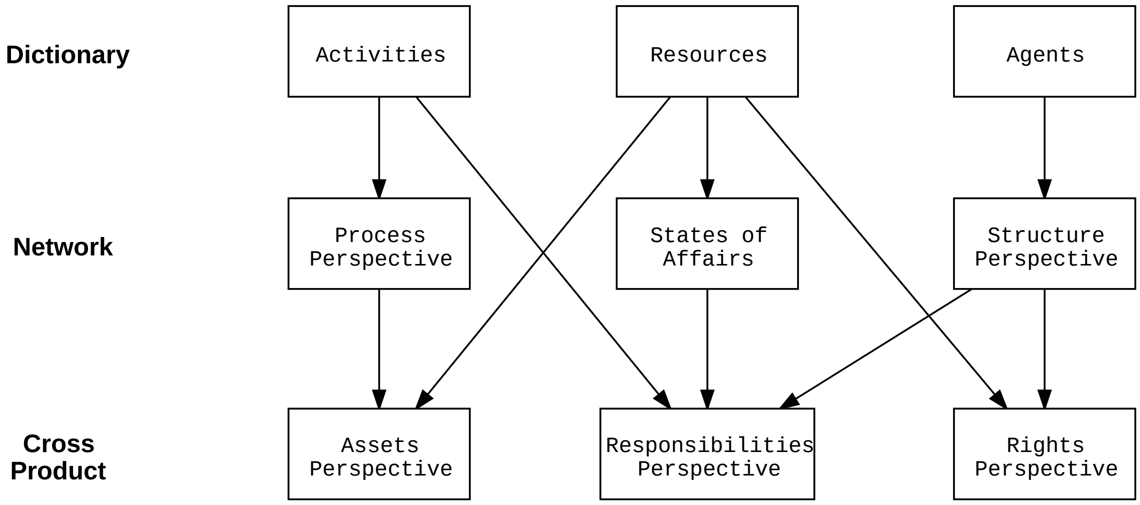


Figure 1: Organizational model: perspectives and cross-products

[4]CommonKADS actually calls these "functions" rather than "activities"; at lower levels of detail, the term "tasks" is used instead. However, for reasons which are explained in [Uschold *et al*, 1995], I have chosen to use the term "activities" throughout this document.

[5]This organizational model is a variation of the model proposed by CommonKADS. The reasons for this variation are discussed in appendix D.

The **Dictionary** perspectives are simply sets of activities (or agents or resources) which are used as a basis for building the other perspectives. The **Network** perspectives show how entities of the same type relate to one another:

- Activities *precede* each other to produce a *process*;
- Agents *report to* each other and *belong to* departments to produce an *organizational structure*;
- Resources have a particular *status*, and the existence of one or more resources with a certain status may constitute a *state of affairs*. For example, "Air Campaign Plan completed" might be a state of affairs; it would exist if the status of the **Master Air Attack Plan** was *endorsed* and the status of the **Air Tasking Order** was *endorsed*.

The **Cross Product** perspectives show how resources are produced, used, consumed or modified within the process (*Assets perspective*), what rights agents have to resources (*Rights perspective*), and the obligations and responsibilities to perform activities and to create states of affairs (*Responsibilities perspective*).

3.2 Process Perspective

Figure 2 shows the activities which represent the overall workflow of Air Campaign Planning, and also shows how these activities link to form processes.

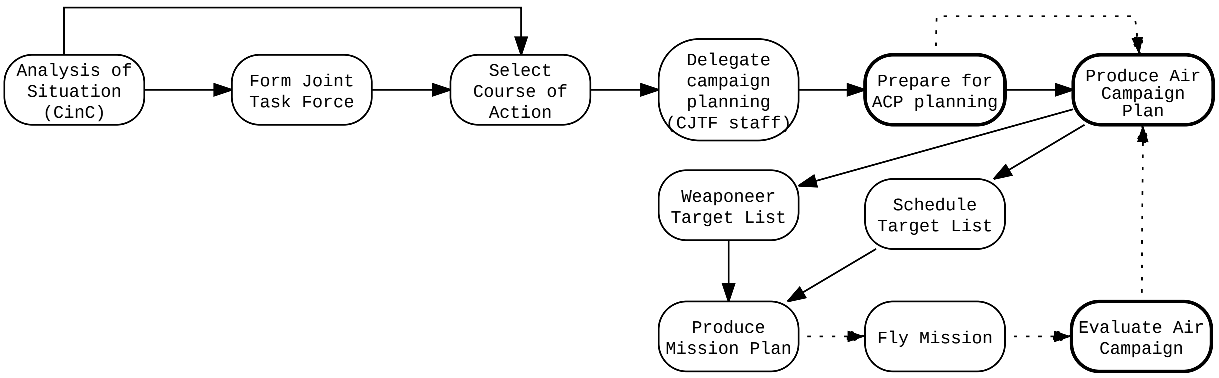


Figure 2: ACP Process Perspective

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

Description of activities:

Analysis of Situation (CinC) : This is sometimes called "crisis action planning". The Commander in Chief analyzes the political and military situation. This usually includes deciding on an approach to the problem; however, this is **not** the same as what is referred to below as a "course of action".

Form Joint Task Force : A joint task force is formed. This does not always take place, but it is usual. The CinC provides guidance to the new Joint Forces Commander (JFC). The guidance can take several forms including:

- Situation assessment of friendly and opposing forces
- Resources allocated
- Campaign, Military and Political Objectives
- Rules of Engagement
- Policies
- Political Issues
- Potential problems with weather
- Potential problems with crisis in other theaters

All of these types of guidance will change dynamically throughout the planning process as well as the execution of the plan.

Select Course of Action : The JFC selects a course of action for the US military forces to pursue.

Delegate campaign planning : The task of campaign planning is delegated to the various Joint Force component commanders (e.g. the JFACC).

Prepare for Air Campaign planning : The planning team is set up and initial information is acquired or generated. This is described in more detail in the Task and Communication models.

Plan Air Campaign : The air campaign is planned. This is described in more detail in the Task, Communication and Expertise models.

Schedule Target List : determine when each target should be attacked. This will depend on both the priority of the target and the availability of suitable aircraft. This is also carried out by the AOC Ops group. The result of this is the Air Tasking Order, which is the document which is passed to the Wings. The Ops group use a software package called CTEMS to help with scheduling. CTEMS takes the prioritized target list and suggests resources to attack these targets; it can constrained either to produce a schedule which can be completed within a particular time, or to produce a schedule which uses only the resources available in theater.

In the course of scheduling the air campaign plan, the Ops group sometimes find and report anomalies in the plan.

Weaponeer Target List : The weaponeers (part of the AOC Operations group) determine what weapons will be needed to damage or destroy particular targets, and therefore decide which types of aircraft should carry out the mission. This is done by calculating the Desired Mean Point of Impact (DMPI) and required munitions for each target. The DMPI specifies the best weapons for a target, the exact angle the target should be hit and the exact location that the target should be hit.

Weaponeering is currently one of the most time-consuming parts of the whole planning process, taking around 10 hours to complete. The weaponeers use a system known as Rapid Air Action Planner (RAAP) which suggests 5 possible options for resourcing a mission. RAAP can be time-constrained (i.e. forced to plan all missions within a particular time), but it cannot be resource-constrained (forced to plan missions using only certain aircraft). This means that the options suggested by RAAP may conflict with resource allocations explicitly required by senior officers, or resource allocations suggested by the CTEMS system. It has been suggested that the weaponeers could make use of the output of CTEMS as a starting point for weaponeering, but this is currently a subject of internal debate.

Produce Mission Plan : The Wings and/or the squadron leaders are responsible for planning how their mission(s) should be accomplished at the required time(s).

Fly mission : Once the aircraft are airborne, responsibility for the mission passes to the flight leaders. If changes to the ATO occur at this stage (e.g. a sudden change in weather), the Ops group at the Air Operations Center will communicate directly with the flight leader.

Evaluate Air Campaign : Once the mission is completed, the fliers are required to report their results to help in gauging the success of a mission. These results are collated and used as an input to further planning. Other feedback on the current situation is also obtained, including logistics assessment, assessment of readiness, identification of personnel and processing of intelligence reports. Explicitly, it includes obtaining various types of mission reports via Ops and Intel; these reports will include pilot reports, intelligence reports, and a Bomb Damage Assessment (BDA). The planners sometimes go out and obtain information, perhaps by calling an acquaintance in an operating squadron, because the "official" intelligence information can be slow in arriving.

The effect of feedback is to adjust the prioritization of task objectives and of targets. If new policy and guidance is received, the prioritization of air objectives may also change.

3.3 Structure Perspective

Figures 3 and 4 show two different aspects of the organizational structure surrounding the ACP process. Figure 3 shows the structure of the US armed forces (AFFOR, ARFOR, NAVFOR, MARFOR and SOF) which may be present within a Joint Task Force. Figure 4 shows the structure of the Joint Forces Command, including the staff who produce the Air Campaign Plan and report to the JFACC, and the upper echelons from whom the JFACC receives instructions.

When viewing these diagrams, it should be borne in mind that different senior officers will choose to work in different ways; to be more precise, the CinC may alter the lines of authority or reporting requirements, in order to improve his liaison with selected groups or individuals. This means that these diagrams, particularly the upper levels of a Joint Forces Command, may be adjusted according to the CinC's own preferences.

Partial description:

Wings give missions to squadrons. There will be 3-4 **squadrons** in a wing, with 17-24 aircraft each. The personnel in a squadron will be divided into **flights**; there will be 3-4 flights, typically of 12 pilots each.

N.B. Once a mission is in progress, the term *flight* is used to apply to a subgroup of aircraft within the mission forces. A "mission flight" typically consists of 4 planes, which may be drawn from one or more "squadron flights". The Navy avoid this confusion by using the term *section* for a "mission flight".

3.4 States of Affairs

A State of Affairs indicates that one or more resources have reached a certain status which is important to the ACP process. Since most of the resources used by ACP planning are passive resources (e.g. documents), most of the important states of affairs will correspond to the completion of certain documents.

No states of affairs have yet been fully documented; however, the diagram of the Responsibilities perspective 3.7 below illustrates some possible states of affairs which might emerge as being important.

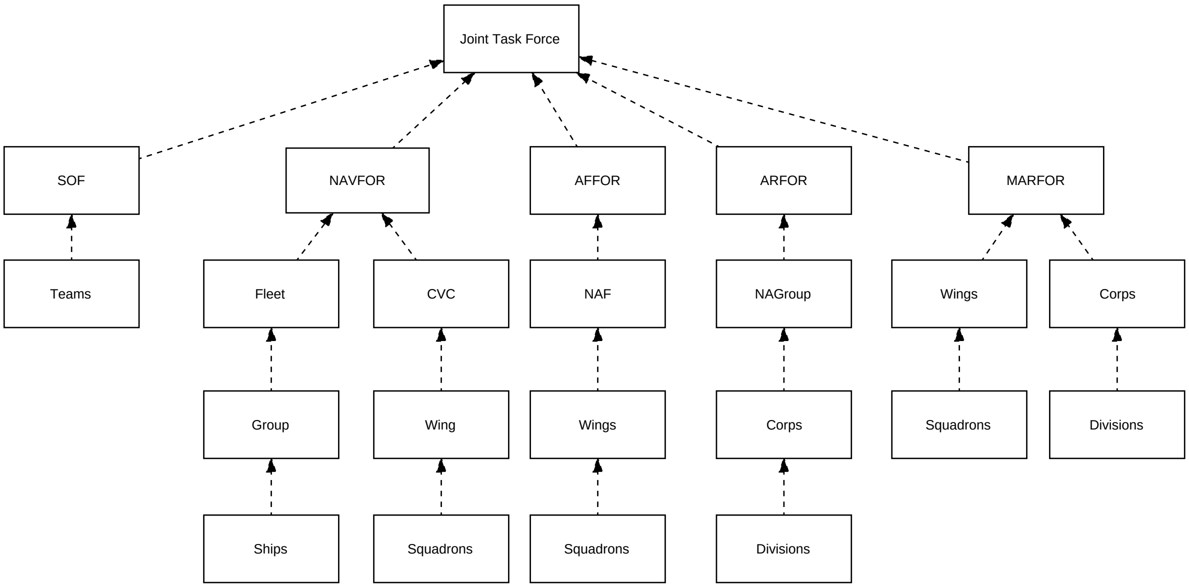


Figure 3: Structure of the US military forces

Key:

Dashed link	this department or unit is a *department of* another department or unit.

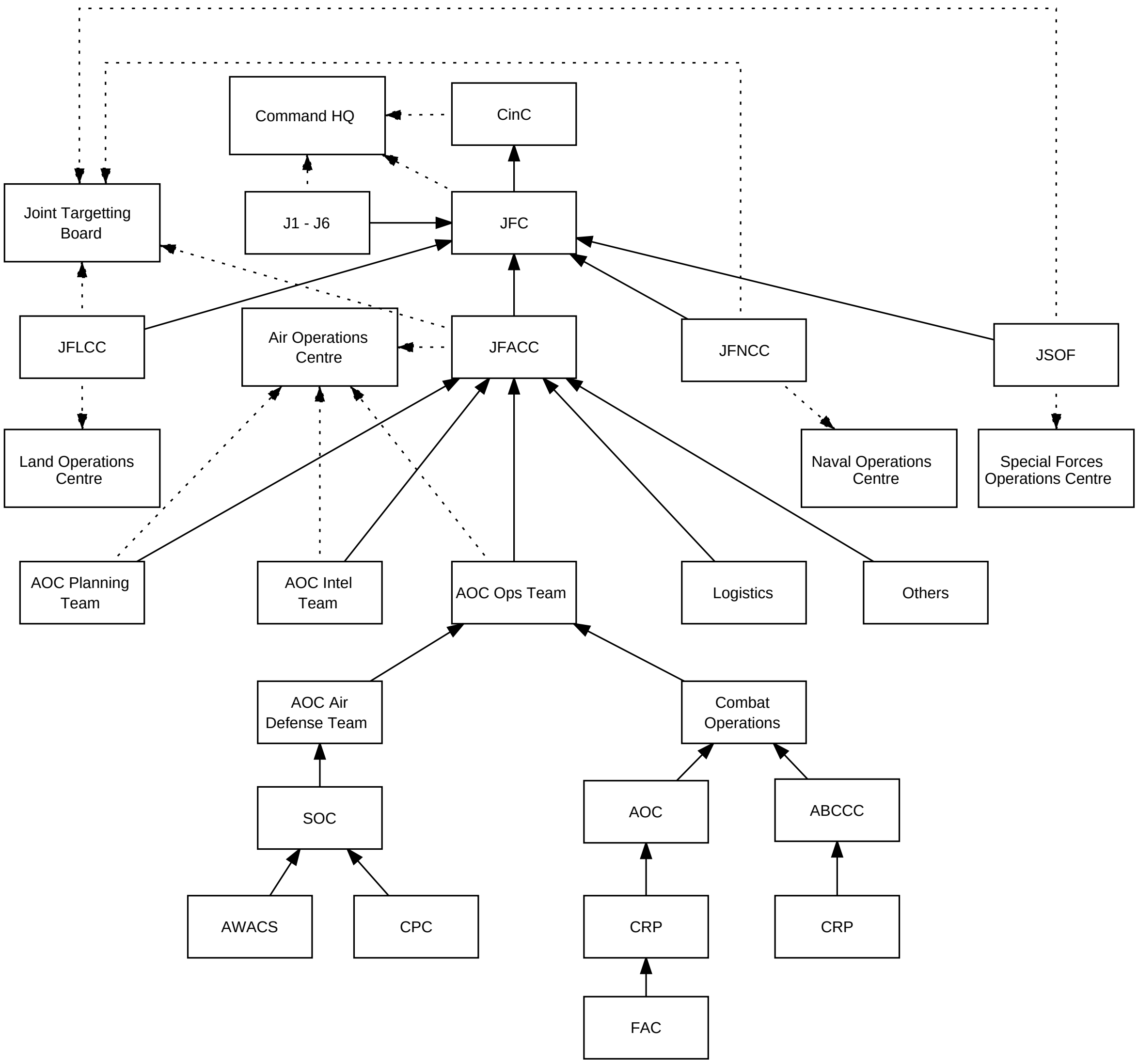


Figure 4: Structure of a typical Joint Task Force

Key:

Solid link	the first agent *reports to* the second
Dashed link	the agent *belongs to* the department

3.5 Assets Perspective

The Assets perspective (see Figure 5) takes the activities identified in the Process perspective, but instead of showing precedence relationships, it provides information regarding the resources which are produced, consumed, used or modified by the various activities. Three different types of resources are distinguished: *passive resources* (documents or files); *computer resources* (computer programs e.g. databases); and *human resources* (normally implying a source of knowledge).

3.6 Rights Perspective

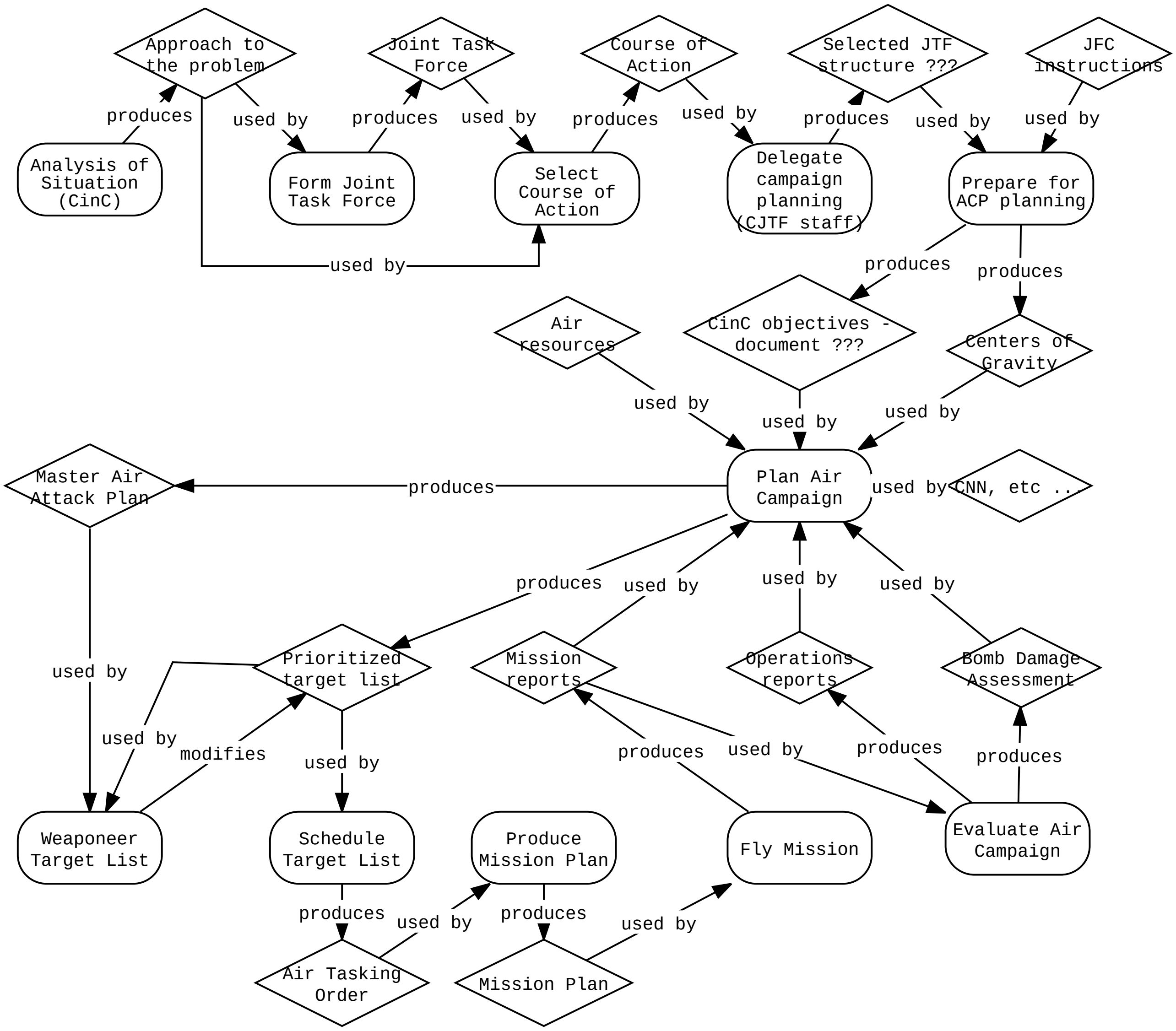
The rights perspective represents the authority of various individuals or groups to view or to alter certain resources. By representing this authority, it becomes possible to frame discussions about the consequences of changing these rights.

An example of the consequences of changing rights can be drawn from Desert Storm [Thaler & Shlapak, 1995]. General Schwarzkopf, the CinC, not only briefed all Joint Force Commanders at meetings, he also sometimes gave out guidance or instructions to an individual Joint Force Commander by telephone or in private meetings. One such instruction, given to the JFACC, was that Iraqi units believed to be below 50% of full combat strength should no longer be targeted for air strikes. This instruction was not communicated to the land commanders, who were left to wonder why the Air Force had ceased to provide them with close air support; indeed, many did not find out about this instruction until after the war! It can be seen that the CinC decided to withdraw (or neglected to provide) the JFLCC's rights to view the instructions and guidance which the CinC was providing to the JFACC, and that the result was uncertainty and possible irritation within the ground forces. Of course, there may be advantages (e.g. in security) in General Schwarzkopf's approach; but it is important to have a framework for weighing the pros and cons of a particular decision, and it is hoped that the rights perspective could provide such a framework.

Very little knowledge has been acquired on "rights" within the process of planning an air campaign. This perspective may prove much more useful if the modelling is extended to look at the precursors of air campaign planning, such as the formation of a JTF, or selection of a course of action.

3.7 Responsibilities Perspective

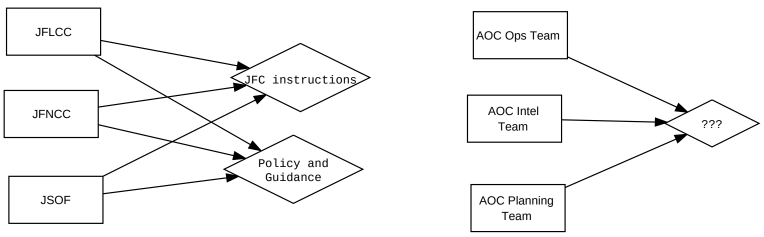
The Responsibilities perspective shows which agents are responsible to which other agents for a state of affairs, and what obligations agents have as a result of their responsibilities. As with the Rights perspective, there has been little information gathered for the Responsibilities perspective at present; the diagram in Figure 7



Key:

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

Figure 5: ACP Assets Perspective



Key:		
	Solid link	the agent has a *right* to the resource

Figure 6: Rights Perspective

illustrates the format which a diagram of the Responsibilities perspective would take.

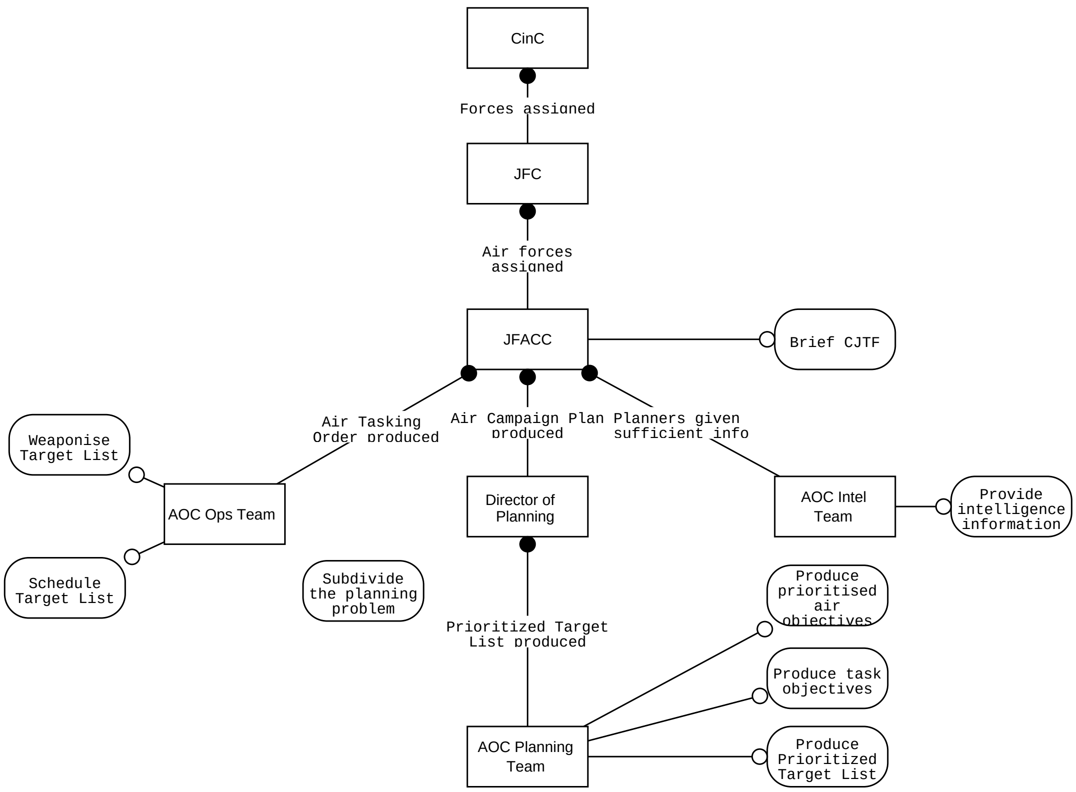
4 Task model

The CommonKADS Task Model is a more detailed version of the process perspective of the organizational model. The process perspective of the organizational model is intended to represent the overall workflow and/or control flow of an organization's primary processes; the task model describes the activities which are executed in an organizational environment, with an emphasis on deciding which activities could be suitable candidates for computer software support [Breuker & van de Velde, 1994]. The extra detail includes the inputs and outputs of these activities; the agents who can perform these activities; and any temporal restrictions on activities [6]. The results of the analysis are displayed in a diagram, showing dependencies between different activities, and (optionally) the roles of the agents who are expected to take on these activities.

Once the organizational model had been produced, a task model was produced which focused on the strategic planning of an Air Campaign Plan. The part of the process which was considered started with the CinC issuing policy and guidance to the JFACC for use within the planning process, and finished with the production of a Master Air Attack Plan (MAAP). This closely corresponds with those parts of the Air Campaign Planning process which are carried out by the planning staff at the JFACC's Air Operations Center.

One of the main purposes of the task model is to help in deciding which activities could be suitable candidates for computer software support. In order to support this decision, some further information about the activities was acquired,

[6]The full list of activity attributes can be seen in the descriptions of activities given in the models themselves. The list is not entirely derived from CommonKADS; instead, it is derived from the AIAI Enterprise Ontology [Uschold *et al*, 1995].



Key:

Link with black circle	the first agent is **responsible** to the second for a state of affairs (which is indicated by the label on the link)
Link with white circle	the agent is **obliged** to perform the activity

Figure 7: Responsibilities Perspective

using the "repertory grid" knowledge acquisition technique (see appendix A). The information acquired was:

- the experience required to perform an activity;
- the likelihood of a mistake when performing the activity;
- the seriousness of a mistake when performing the activity;
- the time required to perform an activity;

Task models were developed for two of the activities identified at the top level of air campaign planning. These activities were *Prepare for Air Campaign Planning* and *Plan Air Campaign*. In order to improve the quality of information which can be conveyed by the diagrams, the IDEF3 technique was used instead of CommonKADS' suggested diagram format. This technique represents the exact ordering of processes in more detail than the graphical format suggested by CommonKADS.

4.1 Task Model: Prepare for Air Campaign Planning

The task model for preparing for air campaign planning is shown in Figure 8.

Description of activities:

Obtain policy and guidance from CinC : The JFACC must receive instructions, and guidance on military and political policy, before he can initiate the planning of an air campaign. These instructions are usually written by a J3 or a J5 on the JFC's staff.

The content of the guidance is likely to be at the level of *theater political objectives* and *theater military objectives*. These may include:

- a desired end state e.g. "Red forces should be driven out of Greyland"
- time and space boundaries e.g. "NBC facilities must be destroyed"

The policy and guidance should also include Rules of Engagement which have been defined.

Attributes:

Predecessor : None (as far as Air Campaign Planning is concerned)

Successor : Assess Situation, Identify CinC objectives, Brainstorm possible Centers of Gravity

Component : None

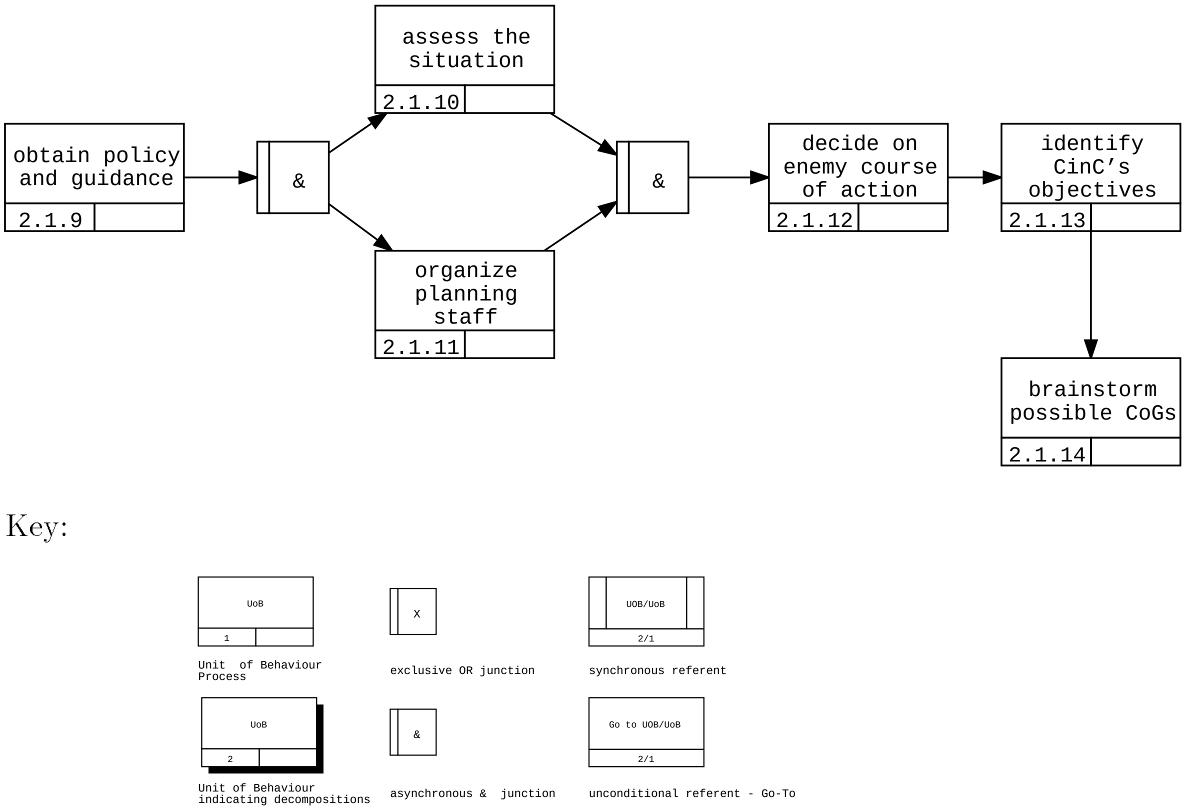


Figure 8: Task Model: Prepare for Air Campaign planning

Doer : This activity is done by the JFC, who then passes the information on to the JFACC and his staff. The JFC and the JFACC may be in the same room when the CinC expresses his policy and guidance; however, even if this is the case, the JFC will always add his own input to the CinC's guidance. There may be documented guidance, but the most elaborate guidance will always be verbal.

Owner : The JFC is responsible for obtaining guidance from the CinC and passing it on to the JFACC and his staff (principally the Chief of Plans). However, if the Chief of Plans doesn't get adequate guidance, he will start asking for it, through appropriate channels. This often requires the planning staff to write their own version of the guidance, and then present it to the JFC for correction (see "Identifying CinC objectives" below).

Interval : This activity is normally carried out simultaneously with the formation of a JTF. In the early phases of an operation, additional guidance is likely, on a daily basis.

In the later phases of an operation, the planning staff's interpretation of policy and guidance is endorsed by default – that is, if they don't hear anything, they assume that there are no problems. The guidance should be reviewed by the planning staff at least once per day, to take account of possible changes. Changes may occur if the President makes new public statements; or if allies join or leave the coalition; or if the enemy sues for peace.

Duration : 5-15 minutes. The activity doesn't usually take very long, because the JFACC will probably have already spent time considering the situation, and the policy and guidance which is obtained is likely to confirm a previously formulated hypothesis. There's also little time spent on evaluation of whether to follow the CinC's policy; it's an order, so there is no option to decide whether to follow it or not.

Experience required : Medium.

Likelihood of a mistake : Medium. The overall policy is rarely misunderstood – and if it is misunderstood, the JFACC's understanding is corrected (often painfully!) at the next briefing of the JFC, which is normally in the afternoon of the first day of planning. However, ambiguous statements may be interpreted incorrectly (see "Identify CinC objectives" below).

Seriousness of a mistake : Fairly high. It is likely that an entire days' planning will be based on wrong assumptions, and is therefore likely to be wasted.

Pre-Condition : The decision to form a JTF; the designation of components (which will include the appointment of a JFACC); the provision of guidance by the National Command Authority and/or the CinC.

Effect : The production of orders or directions, expressing the policy and guidance to be used by the planning staff.

Resource : There are formal documents (e.g. the commander's assessment) which will contain some statements about policy and guidance. These tend to be used as reference documents, because the actual policy and guidance used is based on the written statements and on verbal elaborations.

Organize planning staff : The Chief of Plans draws together a planning staff. Ideally, the groups will be pairs, with one member of the Planning unit working with one member of the Intel unit. Checkmate claim that in practice, this rarely happens.

Attributes:

Predecessor : None, as far as Air Campaign Planning is concerned

Successor : Decide on enemy's most likely course of action

Component : None

Duration : 5-15 minutes

Doer : The Chief of Plans – with strong input from the JFACC.

Owner : JFACC

Interval : Immediately after the preconditions are fulfilled, and definitely within a day of the initialization of a JTF. Checkmate say that this process is almost automatic; Doug Holmes suggested that some Chiefs of Plans might give more thought to this process than others. Once the organization has been established, there is usually no formal review; it only gets revised if the people on the job do poorly or if the Chief of Plans becomes aware of new information sources/resources.

In a long conflict, there's effectively an annual review because of annual cycling of personnel (which normally implies a new Chief of Plans).

Experience required : Fairly high.

Likelihood of mistake : Medium. The Checkmate planners disagreed on this point. It was argued that mistakes are rare, because Directors of Planning become fairly skilled at this job; but the knowledge was acquired when two of the staff members at Checkmate had just returned from an exercise on which the planning staff were badly organized.

Seriousness of mistake : Fairly high. Again, there was disagreement among the Checkmate staff. A mistake here causes inefficiency; it takes time to overcome a faulty organization. However, it was argued that faults in the organization quickly become apparent when deadlines approach, so they are normally corrected; indeed, they're often self-correcting. In addition, different styles of organization are capable of achieving the same result.

Pre-Condition : Guidance has been obtained from the CinC/JFC; a JTF has been formed; a Chief of Plans has been appointed.

Effect : The planning staff are organized into planning teams.

Resource : The planning staff are typically built up from a JFACC's existing staff, plus other officers who are known to the JFACC. The information available to the staff is crucial; in times of genuine crisis, the amount of information available to planning staff will increase e.g. 9th AF don't have good access to national data in peacetime, but are likely to be given access to that data in wartime.

Decide on enemy's most likely course of action : The JFACC must decide on the enemy's most likely course of action. This requires background knowledge as well as a good assessment of the current situation. This decision is a refinement of the analysis performed when choosing a Course of Action. The selection of a Course of Action involves a great deal of wargaming. Ideally, multiple analyses of the enemy's courses of action (best case/ worst case/ most likely) should be performed, but this is not currently done.

Attributes:

Predecessor : Assess situation, Organize planning staff

Successor : Brainstorm possible centers of gravity. In fact, this activity is probably not essential for brainstorming to begin, but it will probably be required before brainstorming can be considered to be finished.

Component : None

Duration : 1-3 hours. Taking extra time is not judged to be worth the marginal improvement obtained.

Doer : The whole planning staff, plus associated Intel personnel. Typically the planners will take the lead in this because they are the ones who are used to thinking about intent. However, Intel staff need to be closely involved; if no Intel personnel are formally assigned to the planning staff, the planners ought to get 2 experienced and knowledgeable Intel officers in as part of the discussion

Owner : The planning staff and the Chief of Plans. The key to determining ownership is to see what happens when the planners' assessments of the enemy's likely course of action disagree with the assessments of the senior officers; in this case, the planners are more likely to use their own assessments as long as the plan addresses the senior officers' concerns.

Interval : This takes place fairly quickly – within a day of the whole situation starting up. It's revisited fairly often – maybe every other day – within the first 2 weeks of the conflict. Thereafter, it's only only revisited if a major event confirms or disproves it. Monitoring the accuracy of this assessment is more the responsibility of the Intel personnel on the planning staff than of the planners themselves.

Experience required : Fairly high.

Likelihood of mistake : Medium. The emphasis here is on making a decision which is "good enough". The assessment of the enemy's likely course of action could probably be made more accurate, but the marginal improvement is usually judged to be not worth the extra time required.

Seriousness of mistake : Very high. Despite the seriousness of mistakes on this activity, mistakes do happen; the beginning of Desert Storm is a good example, when few planners correctly predicted Saddam Hussein's dig-in-and-wait strategy. Fortunately, this strategy was less damaging than the one which had been predicted.

Effect : The output of this process is a hypothetical projection of the current situation, focusing selection of important Centers of Gravity. The projection is typically represented as an assessment of enemy intent, usually in note form. If the activity is carried out by using Red and Blue teams to plan the conflict from the perspective of both sides (which is considered to be a good approach), a consensus on enemy intent tends to emerge within the planning staff.

It's a very important process; if you can predict the enemy's plans, you have a huge advantage.

Resource : The primary resource requirement for this activity is experienced staff. Other resources may include

- intelligence documents (eg current reports);
- news (which differs from open source documents because it's current);
- News about Grey (neutral) countries may be relevant;
- Background information, such as cultural information about the enemy country, similar to that required by the "Assess Situation" activity.

Identify CinC objectives : The JFACC must identify CinC objectives (i.e. campaign objectives, military objectives, political objectives, and maybe even national objectives) from the policy and guidance which he has received from higher echelons. It's actually possible that the JFACC might negotiate these objectives, though it's unlikely (unless explicitly invited) until the later stages of planning, when the JFACC may have a good case for the negotiation of objectives, based on analysis of centers of gravity and available resources. The JFACC must also identify the CinC's preferred prioritization of these objectives.

Attributes:

Predecessor : Obtain policy and guidance from CinC/JFC

Successor : Brainstorm possible centers of gravity.

Component : None

Duration : 1-3 hours

Doer : In theory, the JFACC performs this task, and communicates the results to the Chief of Plans. In practice, however, the guidance may include phrases such as "decisive air power", which are insufficiently specified for planning purposes. This activity may therefore involve feedback between the planning staff and the JFACC, in which the exact intent is determined by rephrasing the policy and guidance. Sometimes, the guidance given is so vague that a member of the planning staff writes his own interpretation of the guidance, in the form of a set of objectives, and then asks the senior officer to state whether these objectives accurately reflect his intent. Checkmate say that, when they have acted as planning staff, they have never known a JFACC to provide them with a set of objectives which did not need further clarification.

This process is particularly common in the case where the JFACC does not explicitly specify objectives; but if he does, the planning staff still need to clarify and review the objectives for completeness. This "sceptical review" is an accepted part of the planning staff's function; indeed, it seems to lie at the heart of several of the processes carried out during air campaign planning.

Owner : Chief of Plans

Interval : This activity is done once, and only revisited if there is an explicit change in the CinC's objectives

Experience required : Fairly high.

Likelihood of mistake : Medium. There are many nuances in the language used which need to be understood, and the reader also requires a lot of previously acquired contextual information to understand the objectives fully.

Seriousness of mistake : Very high. If the objectives are not correctly identified at this stage, the JFC should (eventually) correct them, but not until planning effort has been wasted. If, however, the JFC or JFACC approves a set of objectives which are incorrect or ambiguous, it is possible that the mistakes will not be noticed for a long time, perhaps not until missions have been flown.

Pre-Condition : Policy and guidance has been obtained from the JFC.

Effect : This activity produces a clear understanding of the CinC's objectives. A clear understanding of these objectives is crucial, since they form the starting point for the planning of an air campaign.

Resource : Resources used for this activity include:

- Policy and guidance from the JFC;
- news (CNN, general context);
- Public statements from the President. Doug Holmes commented here that, when he was flying missions in the fluid political situation of Vietnam, he would try to conform his actions to the President's public statements;
- News interviews with CinC or JFC;
- Any available information source!

Assess situation : Assess the military (and political) situation, using background information and local knowledge. This updates the planning assumptions that went into the selecting of a Course of Action (see Figure 2). The updating of these assumptions includes the validation of constraints and restraints, and of the political situation.

This activity requires looking at the situation assessment produced when determining a course of action, and trying to identify and correct any weaknesses with this assessment. The factors considered will include:

- Political situation;
- environment (geographical, cultural, meteorological, topological constraints on action);
- alliances (friends, enemies, neutrals).

The situation assessment provides planning and evaluation context, which is referenced all the time as things change in the real world. This context is used as a frame of reference for communications. Note that the primary use of this frame of reference is to foster communication between the JFACC and the staff who are directly responsible to him; the frame of reference is probably only fully understood by the JFACC, the planners, and the other personnel in the Air Operations Center. It may filter further upwards through the planning hierarchy until it supports the President's picture of events, but it isn't understood by individual pilots.

There is not much lateral communication (between different components of the JTF), which is unfortunate, as failure to agree a common situation assessment between different components can cause problems. The AOC planning meetings will be attended by the Liaison Elements from the other components, but they don't formally report back to their own component commanders. In addition, there is no guarantee that the JFC will agree with a component commander's assessment of the situation; taking Desert Storm as an example, the JFC considered the Republican Guard to be an important center of gravity for the Red forces, whereas the JFLCC did not consider them to be particularly important.

Attributes:

Predecessor : can be concurrent with **Obtain policy and guidance from CinC/JFC**

Successor : Decide on enemy's most likely course of action

Component : None

Duration : 1-3 hours

Doer : JFACC (perhaps in conjunction with the JFC and/or the planning staff, if appointed)

Owner : Chief of plans (or JFACC)

Interval : See **Obtain policy and guidance**. However, the situation assessment always gets enriched over time.

Experience required : Fairly high.

Likelihood of mistake : Medium.

Seriousness of mistake : Very high.

Pre-Condition :

- Policy and guidance, when available;
- availability of the documents named in Resources below;
- Staff with experience relevant to the situation;
- maps

Effect : The output of this activity is a set of informal notes and situation maps. There is a portion in the formal campaign plan document which is intended for recording the situation assessment, but it's unlikely to be written up at this point.

Resource : This activity uses intelligence documents, open source documents (such as the CIA World Fact Book, and maps), results of air surveillance missions, personal experience & training, and CinC's policy and guidance.

Brainstorm possible centers of gravity :

This involves a group of planners meeting together and trying to identify as many enemy centers of gravity as possible. Centers of gravity can be specified at different levels of abstraction; a suggested hierarchy of centers of gravity can be found in appendix C.5. The brainstorming activity generates centers of gravity which are suitable for inserting into air objectives. At this level, centers of gravity may take one of a number of forms:

- objects, such as "key command centers";
- actions, such as "production of chemical products";
- aspects, such as "air superiority" or "freedom of navigation";
- capabilities, such as "radio transmission capability".

Centers of gravity are considered under the following five headings:

- Leadership;
- Key production;
- National infrastructure;
- National population;
- Fielded forces.

Attributes:

Predecessor : Identify CinC objectives

Successor : Plan Air Campaign

Component : None

Doer : Planners

Owner : Chief of Plans (probably)

Interval : This is typically carried out as soon as the CinC's objectives are understood.

Duration : 1-3 hours

Experience required : No information is available from the repertory grid analysis, although anecdotal evidence suggests that the experience required for this activity is high.

Likelihood of mistake : No information available

Seriousness of mistake : No information available

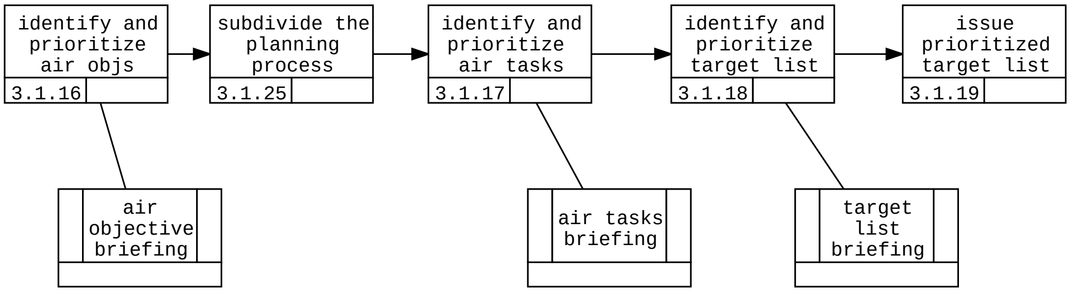
Pre-Condition : Higher level "centers of gravity" have been identified in the CinC's objectives

Effect : Generates a list of possible centers of gravity

Resource : CinC objectives, a pre-defined hierarchy of centers of gravity (this may be wholly or partially implicit in the planners' experience)

4.2 Task Model: Plan Air Campaign

The task model for planning an air campaign is shown in Figure 9.



Key:

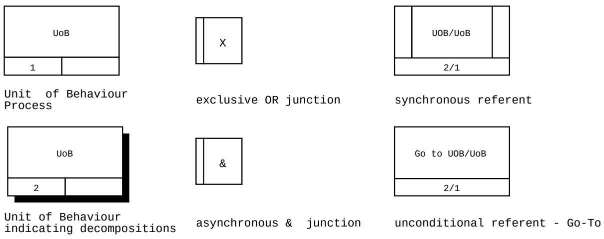


Figure 9: Task Model: Plan Air Campaign

Description of activities:

Identify and prioritize air objectives : Given a list of CinC objectives, and a set of possible centers of gravity, the planners must devise air objectives which, when achieved, will fulfil all of the CinC objectives.

Attributes:

Predecessor : Prepare for Air Campaign Planning

Successor : Subdivide the planning problem, Brief JFC

Component : Several; see section 6.

Doer : Planners

Owner : Chief of Plans

Interval : The identification and prioritization of air objectives usually occupies a significant proportion of the first day of the planning cycle.

Duration : 3 hours - 1 day

Experience required : Very high. Identifying and prioritizing air objectives is a more difficult activity than doing the same for air tasks; prioritizing targets is the easiest task of the three, though the difference is not great.

Likelihood of mistake : Fairly high; although there isn't much experience available concerning mistakes in these activities.

Seriousness of mistake : Medium.

Pre-Condition : CinC objectives and possible centers of gravity must be available.

Effect : A prioritized list of air objectives is produced. This list is used by the JFACC to brief the JFC; the briefing will also identify the justification for selection and prioritization of the air objectives. This justification should be heavily, or even totally, based on the CinC objectives.

Resource : CinC objectives, hierarchy of centers of gravity

Subdivide the planning problem : The production of the Air Campaign Plan is subdivided to allow the planners to focus on different aspects of the problem. The subdivision will use one or more of the following criteria:

- Chronological phase of the conflict. This is the most popular way of subdividing the planning problem. The first phase almost always has priority, because phase 1 of a plan is used to gain control of the crisis, stabilize the situation and set up for the next phases.
- Classes of air objectives (air superiority, interdiction, reconnaissance, etc.);

- Centers of gravity;
- Logistics/personnel/operations/etc;
- Geographical area.

It would be helpful to use a further subdivision, in which the best case scenario, worst case scenario, and most likely scenario were examined independently. However, this would require breaking down the planning team into smaller groups, which is usually infeasible due to lack of personnel.

The planning team will also establish metrics for evaluation of the effectiveness of a phase; the metrics may include cost, logistics, intelligence reports (from the JFACC's intelligence staff, commonly known as INTEL), and resources.

Attributes:

Predecessor : Identify and prioritize air objectives

Successor : identify, prioritize & sequence air tasks

Component : None

Doer : Chief of Plans

Owner : Chief of Plans

Interval : This activity usually takes place after air objectives have been identified and prioritized.

Duration : 5-15 minutes

Experience required : Medium

Likelihood of mistake : Fairly low

Seriousness of mistake : Medium

Pre-Condition : Air objectives must be defined.

Effect : The effect of this activity is to speed up certain aspects of the planning, or to plan certain aspects more thoroughly.

Resource : Air objectives

Brief JFC : The JFC is briefed by the JFACC every day; this usually means that the first day's briefing covers the identification and prioritization of air objectives, while the second day's briefing covers the air tasks. The JFACC explains the objectives and the current state of the campaign plan. The JFC is likely to provide feedback, saying that the plan has been prepared incorrectly, or that there are further instructions which the planners need to take into account. These instructions might include extra rules of engagement (e.g. "the President says don't attack within 50 miles of the enemy capital city"); extra CinC objectives (e.g. "it's important to disrupt the enemy's anti-tank capability"); or they may be concerned with interaction with the other forces in the JTF (e.g. "coordinate better with land forces", "deconflict your plan with SOF"). Deconfliction of plans is handled by the Ops group.

Attributes:

Predecessor : Identify & prioritize air objectives OR Identify, prioritize & sequence air tasks

Successor : None

Component : None

Doer : Planners

Owner : Chief of Plans

Interval : Once per day, usually in the afternoon

Duration : 30 minutes - 1 hour; occasionally up to 2 hours

Likelihood of mistake : Fairly low.

Seriousness of mistake : Fairly low; the JFC will correct mistakes

Experience required : Fairly high. This is a complex activity. Doug Holmes hinted at the reason for the complexity when he stated that this activity required a lot of evaluation "because there's a lot of tradeoffs in what you say and what you do".

Pre-Condition : Some or all of the appropriate objectives have been produced.

Effect : Further CinC objectives may be generated, and/or deconfliction requirements may be highlighted.

Resource : CinC objectives, hierarchy of centers of gravity.

Identify, prioritize & sequence air tasks : This activity is similar in principle to the identification and prioritization of air objectives; it requires identifying air tasks to fulfil each air objective, instead of identifying air objectives to fulfil each CinC objective. However, it is typically much less time-consuming than identifying air objectives. This may be because it is a somewhat simpler activity than identifying and prioritizing air objectives. However, the distinguishing of prioritization from sequencing is not currently performed clearly, and the introduction of this distinction may lead to changes in the requirements for this activity.

Attributes:

Predecessor : Subdivide the planning problem,

Successor : Brief JFC, Produce Prioritized Target List

Component : Several; see Figure 18

Doer : Planners

Owner : Chief of Plans

Interval : The identification, prioritization and sequencing of task objectives usually occupies half of the second day of the planning cycle.

Duration : 1-3 hours

Experience required : Fairly high

Likelihood of mistake : Medium

Seriousness of mistake : Fairly high

Pre-Condition : Air objectives and a hierarchy of centers of gravity are available.

Effect : A sequenced list of air tasks is produced. The sequencing is related to the priority of air objectives, except where some air objectives require certain pre-conditions (e.g. disruption of early warning systems). This list is used by the JFACC to brief the JFC; the briefing should also identify the justification for selection and prioritization of the air tasks.

Resource : CinC objectives, hierarchy of centers of gravity

Identify and Prioritize Targets : This activity requires selecting targets to fulfil each air task. It is simpler than the identification and prioritization of air objectives, and probably simpler than identifying air tasks; however, there are a lot of targets to identify (typically hundreds).

Attributes:

Predecessor : identify, prioritize & sequence air tasks

Successor : Issue target list

Component : Several; see Figure 20

Doer : Planners

Owner : Chief of Plans

Interval : The identification and prioritization of targets usually occupies the remainder of the second day of the planning cycle.

Duration : 30 minutes - 1 hour.[7]

[7]This is based on the repertory grids acquired from Checkmate. However, this figure contradicts the opinions of the experts from ISX. This needs to be verified.

Likelihood of mistake : Fairly high

Seriousness of mistake : Medium

Experience required : Fairly high

Pre-Condition : Air tasks and information about possible targets are available.

Effect : A prioritized list of targets is produced. The prioritization is based on importance **and** on the necessary sequencing of certain activities (such as disrupting key radar installations). The distinction between the two reasons for prioritization is not explicitly recorded, but probably should be.

Resource : Air tasks, information about possible targets and associated defenses

At this point, the list of targets is sent to the Joint Targetting Board, who will discuss it and alter it to produce a revised Target List. This modified target list is then incorporated into the Master Air Attack Plan (MAAP), which is passed to the Ops group for weaponeering and scheduling. Scheduling is performed using the CTEMS system, which identifies if there are suitable resources available to strike the suggested targets; weaponeering is performed using the RAAP system. These activities result in the Air Tasking Order (ATO), which specifies missions to be flown.

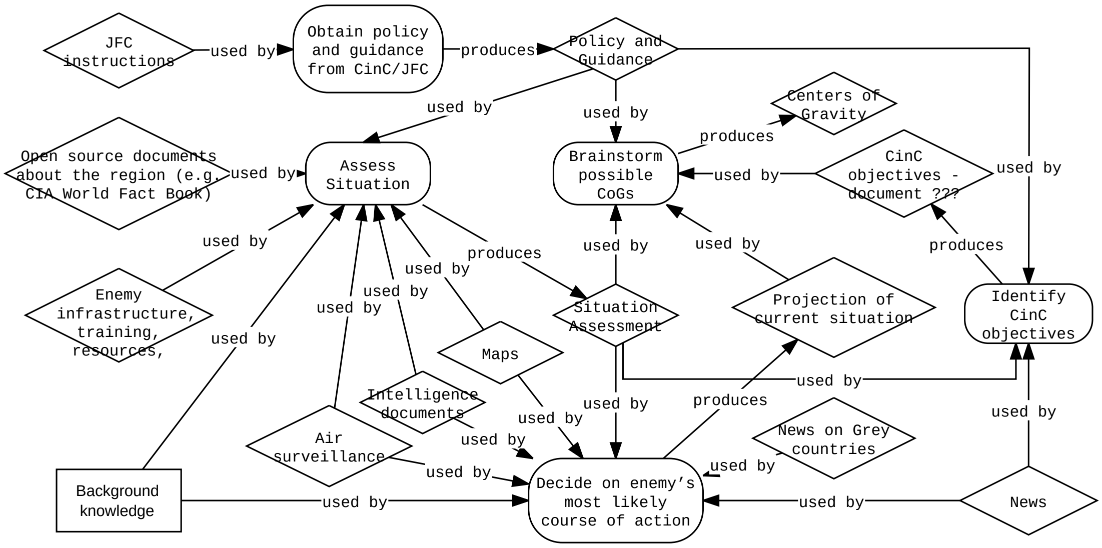
Sometimes, the the JFACC or another senior officer will provide specific guidance to the schedulers and the weaponeers; for example, if there is a shortage of munitions, he will direct that certain munitions are reserved for certain targets. The planners will usually take this guidance into account during planning.

There may be occasions where a target which is identified as worthy of attacking by air could be targeted by Army helicopters or ground-based SOF forces with equal or greater efficiency. In such cases, there will first be informal liaison between the AOC planners and the appropriate land forces to determine if it's feasible for the land forces to take on the operation; if so, the JFACC will include a request for these forces in his briefing for the JFC.

Interaction with land forces gives the relevant land forces rights to view the Master Air Attack plan, for the sake of deconfliction of operations.

4.3 Task Model: Prepare for Air Campaign Planning: Assets Perspective

The assets perspective for preparing for air campaign planning is shown in Figure 10. It shows the activities identified in the Task Model, along with the resources which are produced, used, modified and consumed by these activities.



Key:

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

Figure 10: ACP Assets Perspective: Prepare for ACP planning

Partial description:

Situation Assessment is usually comparatively short in its written form; perhaps a paragraph in a document, or the first 2 slides in a briefing. The format varies between different operational theaters; in some cases, this assessment will be incorporated into the formal air campaign plan.

Campaign Objectives and Military Objectives do not usually appear in a document these days; instead, they appear in the Objectives Viewer of ACPT (the Air Campaign Planning Tool). However, a slot for these objectives appears in formal campaign planning templates, so if ACPT did not exist, a document describing these objectives would be produced.

Projection of current situation : This is typically represented in note form, although it would be advantageous if it were made more formal.

Description of enemy Centers of Gravity : There is currently no pre-defined list of centers of gravity (although the hierarchies shown in appendix C.5 are intended to supply a pre-defined framework for analysis). There are editors in ACPT which allow centers of gravity to be specified.

4.4 Task Model: Plan Air Campaign: Assets Perspective

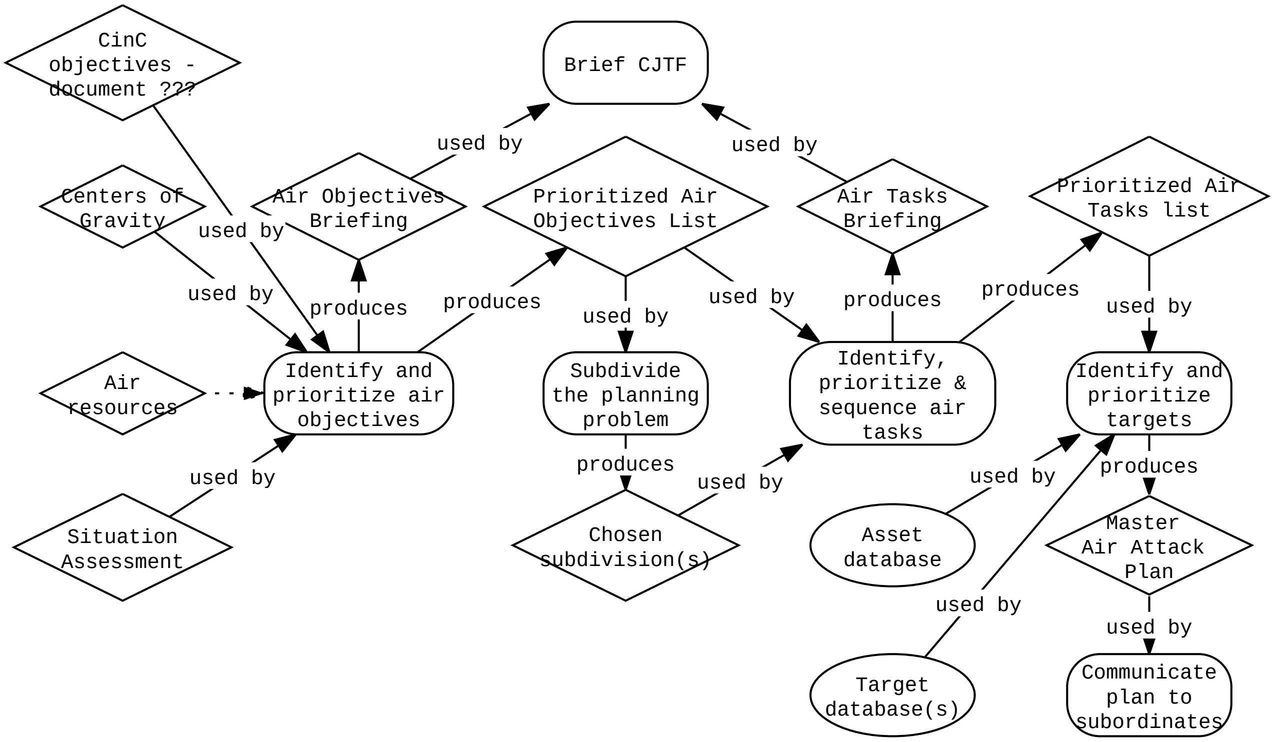
The assets perspective for preparing for air campaign planning is shown in Figure 10. It shows the activities identified in the Task Model, along with the resources which are produced, used, modified and consumed by these activities.

Prioritized Air Objectives List : A list of the air objectives defined, with associated priorities. Not all formal ACPs include this list, although Doug Holmes said that if he were a JFACC, he'd want this list on a daily basis.

Air Objectives Briefing contains:

- An interpretation of the situation assessment;
- A list of identified enemy Centers of Gravity, with justification for that list;
- A list of air objectives, with justification for each. The justification typically takes one of three forms: "it's obvious", "conventional wisdom says to do this", or a specific justification;
- A rationale for the prioritization of air objectives.

The prioritization of air objectives usually correlates closely with the sequencing (temporal ordering) or air objectives.



Key:

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

Figure 11: ACP Assets Perspective: Plan Air Campaign

Prioritized Air Tasks : A ordered list of the air tasks.

Air Tasks Briefing : probably similar to the air objectives briefing, but concentrating on air tasks rather than air objectives.

Chosen subdivisions can be described in a few lines of text, in a briefing or in ACPT.

Asset Database and **Target database**: these currently exist, but no information has been obtained about their location, format or contents.

Master Air Attack Plan : this is the formal document which is produced at the end of the planning of an air campaign.

5 Communication Model

The communication model represents all communication between different agents, as well as the content of the communication. This information can conveniently be represented in a single *role-activity* diagram, which shows which activities are carried out by which agents, and identifies points at which communication takes place [Ould, 92 3]. The communication model is shown in Figure 12. N.B. For implementation purposes, a more detailed model of communication will be required, showing which agent takes the initiative, the exact format of transactions, and any other key information (such as time-critical transactions).

The purpose behind role-activity modelling is to look beyond the activities which make up a process to the roles of the actors reponsible for carrying out those activities. This form of modelling has two effects. The first effect is in providing support to the individual role actors by being clear about their roles, and in identifying with whom they are required to interact at each stage of the process in order to complete their role. The second effect is in identifying inefficiencies in the process itself.

One indication of inefficiency within a process is the presence of a large number of interactions between particular roles. In general, interactions involve the transfer of information between roles. Verbal transfer involves personal contact between the role actors, which requires finding convenient times for meetings, telephone conversations etc. Transferring information via textual means requires an efficient transfer mechanism and the motivation of the receiving role actor to act on that information within a reasonable time. Delays within a process are particularly prevalent where more than two roles are involved, or where the role actors are separated geographically.

The following diagram presents a high-level model of some of the roles and activities occurring within the ACP process. The model shows a certain amount of interaction between the JFACC and the planners, and between the JFACC and the Ops role. However it is thought that this is unlikely to cause a problem within the the ACP process as the role actors are all contained within the Air Operations Center; indeed they are usually situated within the same room. It is possible that some of the roles indirectly influencing the production of the ACP but outside the scope of this model, such as interaction between the JFC and all his Component Commanders, and interactions between the Component Commanders themselves, may be more likely to be the cause of inefficiencies and bottlenecks. However this type of role interaction will be dependent on the battle situation and the personalities of the Commanders involved.

The notation used in order to produce the communication model is given in the accompanying table.[8]

6 Expertise Model

The purpose of the Task Model is to identify activities which would benefit from support, particularly computerized support. It is common for some activities within a task model to be identified as *knowledge-based* activities; that is, activities which require significant expertise, experience or knowledge to enable them to be carried out well. The most appropriate technique for representing these activities in CommonKADS is to use the *inference structures* and *task structures* that form part of the CommonKADS Expertise Model.

There are at least three activities within the Task Model described above which can usefully be modelled using the CommonKADS Expertise Model; they are the identification and prioritization of air objectives, the identification, prioritizing & sequencing of air tasks, and the identification and prioritizing of targets. This document contains a full expertise model for the identification and prioritization of air objectives, and task structures (partial expertise models) for the other two activities. It can be seen that the task structures for all three activities are similar, which suggests that the full expertise models for these three activities will have many similarities.

The Expertise Model is a model of the expertise required to perform a particular activity. It is the most detailed of all the CommonKADS models (see Appendix D

[8]This notation is based on that described in STRIM, a method for business process re-engineering developed by Praxis Systems plc.

STRIM consists of 2 phases:

- the informal fact-gathering phase consisting of role activity diagrams (RADs) for modelling the process, and more traditional entity-relationship-attribute diagrams for modelling the data.
- a formal descriptive phase consisting of a textual language SPML.

The diagrams have been produced using the RADitor software system.

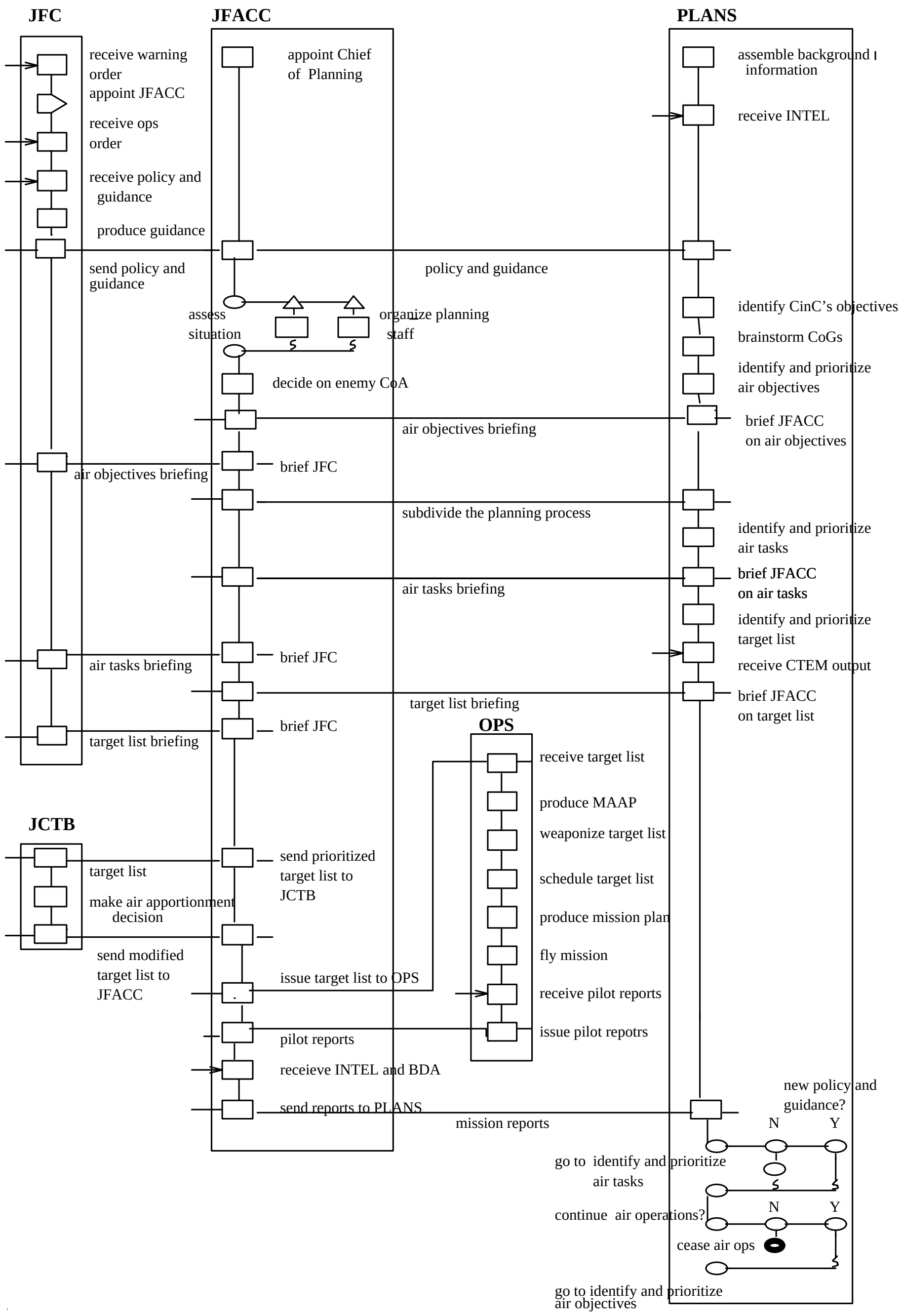


Figure 12: Communication Model

Role Activity Model Notation

Attribute	Icon and Definition
process	a set of roles, the overall activity that is taking place
role	shown as a block. Primary structuring concept. A role is a a sequence of activities performed by a single person or a department.
activity	The details of how the activity is carried out are unimportant. The activity is performed by the role actor which may be a person or computer or combination of the two. The role may exist whilst the actor changes, and one actor may perform more than one role. A number of types of activity exist:
actions	shown as a square. These are performed by a role in isolation.
interactions	shown as an action in one role box connected by horizontal lines to an action in one or more other role boxes. Interactions indicate that more than one role is involved in carrying out an action. Information may be passed passed between roles during an interaction.
start role	shown as a pentagon, causes another role to be created
external events	generally ignored but if needed shown as an action with a line arrow going into the left hand side.
state	shown as a circle and used to indicate the start or end of a branch in the actions carried out within a single role, or used as a go-to referring back to an earlier activity within the role.
refinements	indicate that some activities are alternatives or can be carried out concurrently. Refinements start and finish with a state and are of two types:
part refinement	shown as two triangles, apex upwards, indicating concurrency
case refinement	shown as two circles and indicating alternatives

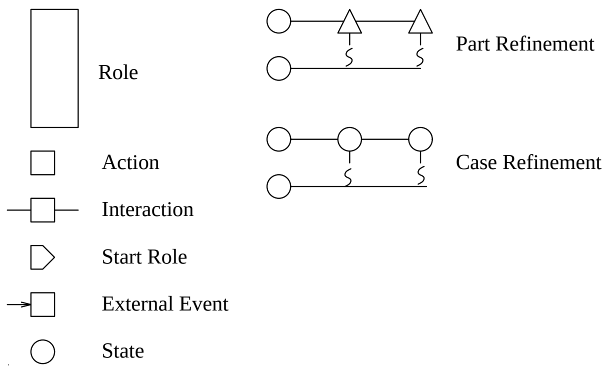


Table 1: Notation for Role Activity Diagram

for more information). This model is divided into three components, each of which is represented by one or more diagrams:

- several *domain models* representing domain knowledge (concepts, objects, and relationships between them);
- an *inference structure* representing procedural knowledge (the types of steps which may be taken to solve a problem, and the types of knowledge which are used by these steps);
- a *task structure* representing control knowledge (control and ordering information on the inference steps).

The task structures can be considered as a lower level decomposition of certain activities in the Task Model. There is no need for an accompanying Asset perspective, however, because the inference structures supply information about interactions between activities and domain knowledge.

6.1 Identifying and Prioritizing Air Objectives

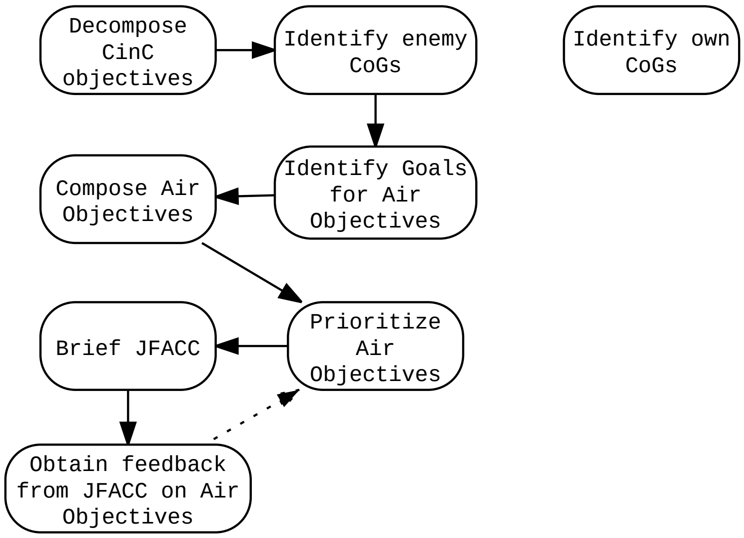
6.1.1 Task Knowledge

Description of activities:

Decompose CinC objectives : Break down the CinC objectives into their component verbs, nouns and modifiers. This should be a simple activity if the CinC objectives have been specified clearly.

Identify enemy Centers of Gravity : This activity is carried out by each planning team. Their task is to analyze the enemy's military forces, infrastructure, leadership, population and economy to look for limitations and vulnerabilities. The planning staff will use intelligence documents and books for details. The planners then use this analysis to identify key points in enemy territory which, if damaged or destroyed, would seriously disrupt the enemy's intended or actual undesirable operations. These key points are known as *Centers of Gravity*. For example, the planners might consider the command and control of enemy troops to be a possible weak point. Some troops are trained to not think on their own so loss of command and control would result in immediate chaos. In this situation, enemy command and control centers would be considered to be centers of gravity.

This activity takes half a day, which is a long time for a single activity. Despite this, the planners are aware that they don't identify all the centers of gravity, because of lack of time.



Key:

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

Figure 13: Task Structure: Identify and Prioritize Air Objectives

Attributes:

Predecessor : Brainstorm possible centers of gravity, Identify CinC objectives

Successor : Identify Air Objectives

Component : None

Activity type : Refine

Duration : Half a day

Doer : Planners

Owner : Chief of plans

Interval : Shortly after centers of gravity have been generated,

Experience required : Fairly high

Likelihood of mistake : Fairly high

Seriousness of mistake : Medium

Pre-Condition : CinC objectives have been obtained and defined in a suitable format.

Effect : Centers of gravity are identified

Resource : The identified centers of gravity are recorded in text in JPT when objectives are defined; no information is available on whether they are recorded in any other form.

Identify actions for air objectives : This activity is carried out by each planning team. Their task is to identify objectives for the air forces to achieve. These objectives should be chosen to fulfil all the CinC's objectives. Typical air objectives might be "gain air superiority" or "carry out interdiction operations".

Planners usually take a breadth-first approach to the identification of objectives.

Attributes:

Predecessor : Identify enemy centers of gravity

Successor : Prioritize air objectives

Component : Identify relevant actions; estimate cost of an action; select an action

Activity type : Select

Duration : 1-3 hours

Doer : Planners

Owner : Chief of plans

Interval : After CinC objectives have been acquired and agreed.

Experience required : Fairly high

Likelihood of mistake : Medium

Seriousness of mistake : Medium

Pre-Condition : None

Effect : an action is selected for each center of gravity

Resource : CinC objectives

Identify own Centers of Gravity : This is an activity which is similar to the identification of enemy centers of gravity. However, it is currently performed to a lesser level of detail than the identification of enemy CoGs (see appendix C.5), probably because of time restrictions.

Compose air objectives : combine an action, a center of gravity and a modifier into a single objective. This is a trivial task, unless the modifier needs adapting from the one provided in the CinC objective.

Prioritize Air Objectives : This requires decisions about which air objectives are the most important. The key factor in this decision is the priority of the CinC objective(s) which are fulfilled by this air objective. However, a number of factors make this a complex task: the time delay between missions taking place and the enemy's capabilities being affected; the multiple calls on air power (e.g. requests from the land forces for close air support); and any importance or priority attached to the centers of gravity themselves (e.g. enemy weapons of mass destruction).

Attributes:

Predecessor : Identify actions for air objectives

Successor : Brief JFACC

Component : Specify the priority of the CinC's objectives; specify "goodness" of an action; determine if an action addresses multiple objectives; calculate the priority of the air objective.

Duration : 30 minutes - 1 hour

Doer : Planners

Owner : Chief of plans

Interval : After all air objectives have been defined

Experience required : Fairly high

Likelihood of mistake : Fairly high

Seriousness of mistake : Fairly high

Pre-Condition : None

Effect : A prioritized list of air objectives is produced

Resource : Set of defined air objectives

Brief JFACC and **Obtain feedback from JFACC on Air Objectives**: The JFACC is briefed every day, usually at a set time. On the first day of planning, he will be briefed on the chosen list of air objectives, with justifications for prioritization. He will give feedback on his opinion of the air objectives, especially their relevance to the campaign objectives and military objectives; he may also give specific instructions for modifications, based on his knowledge of operations which the Director of Planning is not aware of.

Attributes:

Predecessor : Prioritize Air Objectives

Successor : None

Component : None

Duration : 10-30 minutes

Doer : Chief of plans

Owner : Chief of plans

Interval : See description above

Experience required : Fairly low

Likelihood of mistake : Fairly low

Seriousness of mistake : Fairly low

Pre-Condition : None

Effect : Changes to the air objectives, or to their prioritization, are specified.

Resource : Prioritized Air Objectives

6.1.2 Inference Knowledge

The inference knowledge for the identification and prioritization of air objectives is represented in Figures 14 through to 16. It consists of a number of *inference steps* (ellipses) and *knowledge roles* (rectangles). The inference steps, which are labelled according to the type of inference which is being performed, correspond to activities in the task structure; the knowledge roles correspond to one or more items of domain knowledge. Static knowledge roles (which are distinguished by having a thicker border) indicate knowledge which is *not* transformed in any way by the problem-solving process. A "double ellipse" for an inference step indicates that that step is a composite inference step, which is broken down to a lower level of detail in a subsequent diagram.

Inference steps:

decompose-1 : corresponds to the activity "Decompose CinC objectives";

refine-2 : corresponds to the activity "Identify enemy Centers of Gravity";

select-3 : corresponds to the activity "Identify actions for air objectives";

compose-4 : corresponds to the activity "Compose air objectives";

calculate-5 : corresponds to the activity "Prioritize Air Objectives".

Knowledge roles:

CinC objectives : a list of the CinC's objectives, after clarification by the planners;

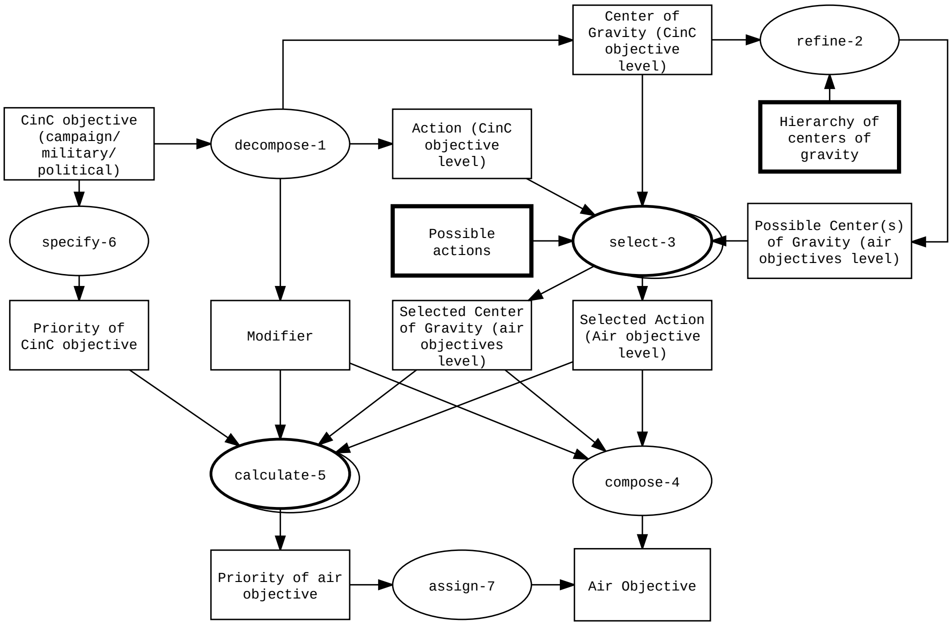


Figure 14: Inference Structure: Identify and Prioritize Air Objectives (top level)

Action (CinC objective level) : The general format of objectives is, "Perform ACTION on CENTER OF GRAVITY with optional MODIFIER". This knowledge role represents the ACTION component of the CinC objective.

Center of Gravity (CinC Objective level) : This knowledge role represents the CENTER OF GRAVITY component of the CinC objective.

Center(s) of gravity (air objectives level) : The centers of gravity at the "air objectives level" are more specific than those at the "CinC objectives level". This knowledge role represents one or more CoGs which fully specify the higher level CoGs. For example, if the CoG at the CinC objectives level was "production of chemical products", then the CoGs at the air objectives level might be "raw material production", "raw material distribution", and "manufacturing of chemical products".

Hierarchy of centers of gravity : The links between CoGs at the CinC objectives level and the related CoGs at the Air objectives level can be represented within a hierarchy. The hierarchy is particularly appropriate because it has multiple levels; CoGs at the air objectives level are specified further to the level of air tasks, before being specified yet further into actual targets. A proposed hierarchy of CoGs can be found in Appendix C.5.

Action (Air Objective level) : The action which must be applied to a CoG at the Air Objectives level in order to fulfil the action required by the CinC on the higher level CoG. For example, "disrupt production of chemical products" might lead to selection of the action "destroy" on "manufacturing of chemical products".

Air Objective : Each identified center of gravity is combined with its selected action to constitute an air objective. Any modifier applied to the CinC objective is applied to the Air Objective, unless the planners have introduced additional modifiers as part of the selection of objectives. For example, preventing production of chemicals before a certain time might require cutting off the supply of raw materials several weeks earlier.

Priority of air objective : The importance of achieveing an air objective. This list is genuinely a prioritized list; the issue of necessary sequencing does not affect the priority of air objectives, although it has a noticeable effect on the prioritization of air tasks, and of targets.

Little information has been gathered so far on this process; the inference steps given below are extrapolated from what has been gathered, and from previous experience with activities requiring selection.

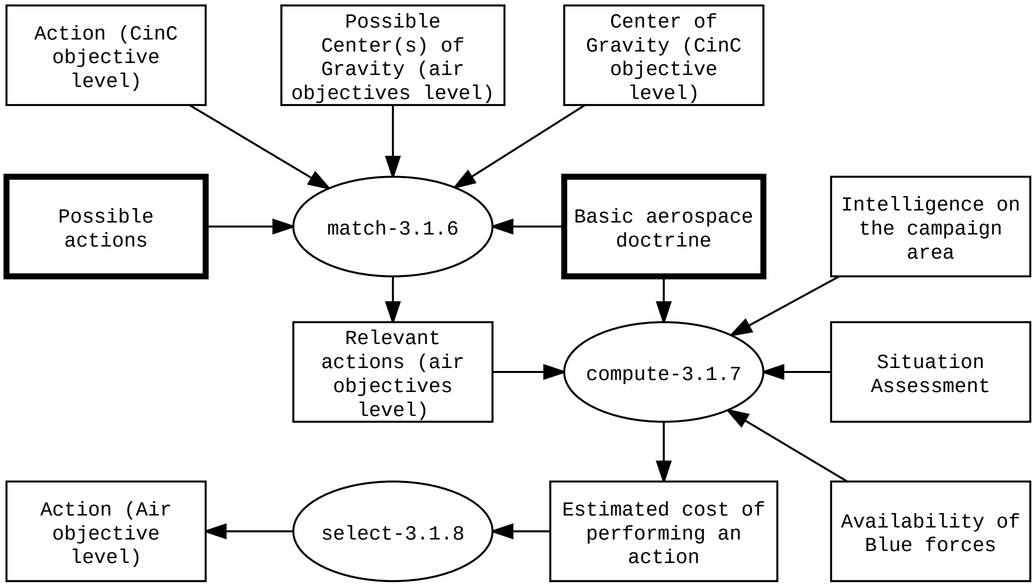


Figure 15: Inference Structure: Select action (expansion of *select-3*)

match-3.1.6 : This inference step, which corresponds to the sub-activity *Identify relevant actions*, involves looking up the list of possible actions and listing all relevant actions.

compute-3.1.7 : This inference step, which corresponds to the sub-activity *Estimate cost of an action*, requires consideration of the likely cost of performing a particular action on this center of gravity. No information has yet been gathered on how the cost is calculated; perhaps it is based on expected losses, and/or the opportunity cost (taking away certain specialized resources from other operations), and/or other factors. It may also be weighed against the likelihood of success.

select-3.1.8 : This inference step, which corresponds with the sub-activity *Select an action*, involves selection of the best action. In theory, this is simply a case of choosing the action with the best balance of cost vs. likelihood of success. In practice, the decision is more complicated, since the most appropriate action against one center of gravity will affect the action for other CoGs; for example, if the action "destroy" is applied to manufacturing plants, then no action is required against raw material supply to these plants, since it will cease of its own accord.

Possible actions : Possible actions to perform on a center of gravity. The list of possible actions will vary depending on the center of gravity being addressed;

for example, infrastructure-related CoGs will typically have a different list of possible actions from CoGs which related to fielded forces.

Basic aerospace doctrine : This consists of guidance given in the "purple book" [ed. Lt. Col. B.B. Burley III, 1993], as well as information gathered from experience by the planners; it suggests acceptable actions and preferred approaches.

Relevant actions : Actions which may be relevant for a particular CoG, given the CinC objective.

Estimated cost of an action : The estimated cost; perhaps a numerical measure?

Availability of Blue forces : The current and expected availability of friendly military forces. In theory, this is not considered by the planners, but only by the Ops group and the weaponeers; in practice, the planners will take it into account when considering what actions are possible, and the likely cost of actions.

Situation Assessment and **Intelligence on the campaign area**: These are derived from the "Prepare for Air Campaign Planning" process, shown in Figure 8.

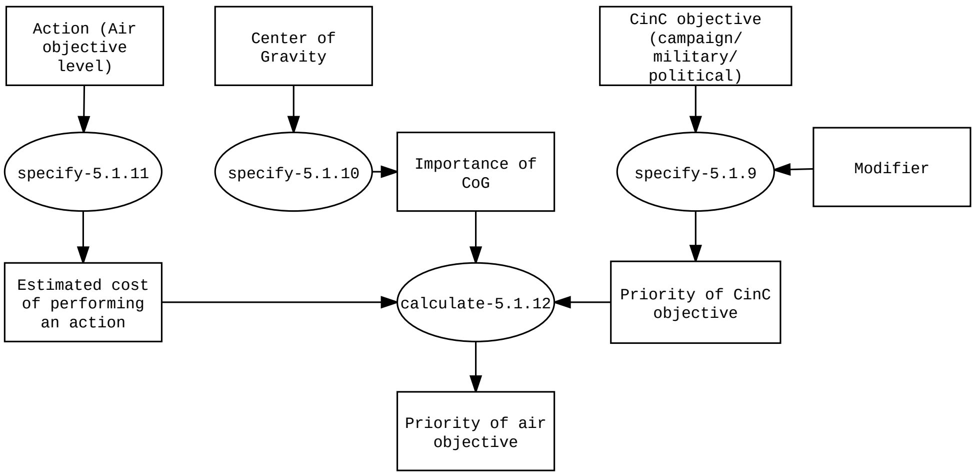


Figure 16: Inference Structure: Calculating priority (expansion of *calculate-5*)

Very little information has been gathered on this process so far, so the descriptions given below are largely hypothetical.

specify-9.1.9 : Specify the priority of the CinC's objectives. The (approximate?) priority of the CinC objectives is usually identified by the planners when the CinC objectives are identified. If a CinC objective has a temporal modifier, this may also affect the priority of that objective.

specify-9.1.10 : Specify the estimated cost of an action. This has already been calculated (see **compute-3.1.7** above), and should only need to be looked up.

specify-9.1.11 : Specify the importance of the center of gravity. This is likely to be a calculation. The importance is related to the priority accorded to the CinC objective, but also takes into account any *a priori* importance of the center of gravity (at the air objective level); for example, manufacturing plants may be considered to be more important than mineral mines. In addition, it is possible that affecting some lower level centers of gravity (e.g important transportation nodes) may fulfil more than one of the CinC's objectives; this should also be taken into account.

calculate-9.1.12 : Calculate the priority of the air objective. This is a cost/benefit analysis.

Importance of CoG : The importance of the center of gravity, compared with the centers of gravity in other air objectives.

Priority of CinC objective : The priority of CinC objectives, as defined by the CinC or the JFC (and, quite possibly, clarified by the JFACC or the planners).

6.1.3 Domain Knowledge

Domain knowledge for this activity has been acquired by analyzing a list of CinC objectives, air objectives and air tasks which was provided by Checkmate. This list can be found in appendix C.1.

The domain knowledge for identifying and prioritizing air objectives consists of three major concepts:

- Centers of gravity (e.g. **national roadways**);
- Actions applied to particular centers of gravity (e.g. **Disrupt** or **Destroy**);
- Modifiers which constrain the actions, such as time modifiers (e.g. Destroy the bridge **before noon tomorrow**); geographical modifiers (e.g. Disrupt all radar sites **within 100km of the capital city**); or categorical modifiers (e.g. differentiating weapons of mass destruction from other weapons).

A grammar for expressing objectives is currently being prepared as part of the IFD-4 work; it is hoped that this grammar will specify more precisely the possible combinations of these concepts within each type of objective.

Centers of gravity: The centers of gravity which were acquired have been structured into a hierarchy. At the top level, the hierarchy is divided according to Col. Warden's 5-way classification of possible centers of gravity:

- Leadership;
- Key Production;
- National Infrastructure;
- National Population;
- Fielded Forces.

The hierarchy is sufficiently detailed that it needs to be spread over several diagrams (Figures 44 to 55 in appendix C.5). An example is shown in Figure 17.

The hierarchies should be read from left to right; the top level centers of gravity are on the left, and the lowest level CoGs are on the right. The links between levels are *subclass* links; that is, a center of gravity at any level (except the top level) should be considered to be a subclass of the center of gravity at the next level up. The blank boxes are place-holders in parts of the hierarchy which ought to be expanded in order to produced a fully detailed hierarchy of CoGs.

The key observations which lead to this hierarchical structuring were:

- Many centers of gravity appear to be decomposable into a lower level of abstraction. For example, **national roadways** can be decomposed into **nodes**, **choke points** and **segments**; similarly, **choke points** can be decomposed into **bridges** and **tunnels**.
- In many cases, centers of gravity at the same level of abstraction have a similar decomposition. For example, both **national roadways** and **national railways** are sub-CoGs of **transportation**, so they are at the same level of abstraction; and both of them decompose into **nodes**, **choke points** and **segments**. The reason for the similar decomposition is that both national roadways and national railways are networks. The power of this observation becomes clear when it is applied to other types of network, such as the electrical network; these, too, have nodes (e.g. power stations), choke points (e.g. certain transformers) and segments (e.g. overhead power lines).

From analysis of the objectives, it becomes clear that different levels of abstraction (usually) map to different types of objective. CoGs at the third level of the hierarchy are typically specified within a CinC objective (e.g. "Disrupt flow of military equipment on **national roadways**"); CoGs at the fourth level of the hierarchy are typically specified within air objectives (e.g. "Deny use of key **choke points** on the roads"); and CoGs at the fifth level of the hierarchy are typically

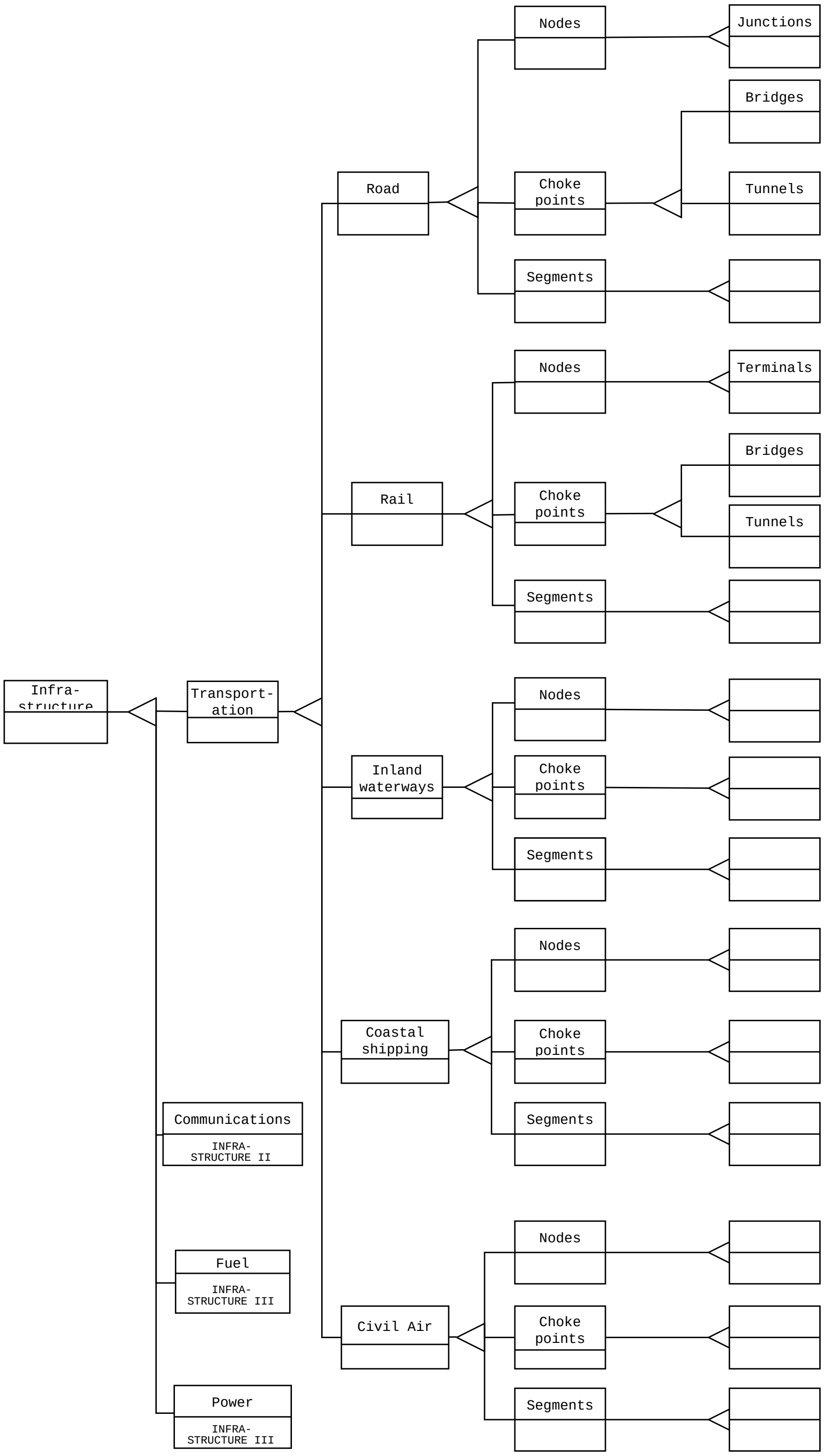


Figure 17: Centers of Gravity related to Transportation

specified within air tasks (e.g. "Destroy **bridges** on roads between the capital and the southern border"). Targets should be considered as the sixth level of the hierarchy, although it is not feasible to display them in this document. The 5 levels of the hierarchy therefore correspond to:

1. Col. Warden's 5 categories of centers of gravity;
2. A (proposed) subcategorization of the 5 categories;
3. Centers of gravity at a suitable level of abstraction for use in CinC objectives (the "CinC objectives level");
4. Centers of gravity at a suitable level of abstraction for use in air objectives (the "air objectives level");
5. Centers of gravity at a suitable level of abstraction for use in air tasks (the "air tasks level").

A key component of the hierarchies which contributes to the goal of identifying all relevant centers of gravity is the identification of *intra-hierarchy links*. These show where a center of gravity in a different hierarchy is relevant to a center of gravity in this hierarchy. The name of the related hierarchy is displayed in the bottom half of the CoG node. For example, Figure 48, which is shown on page 95, includes "Couriers" as a center of gravity. Since communication by courier is dependent on a good transportation network, an intra-hierarchy link to "Transportation" (which appears in Figure 47) is shown as the decomposition of the "Couriers" center of gravity.

Actions: The types of actions which appear in objectives include words such as *disrupt*, *destroy*, *deny use*, and *attrit*. The full list of actions is currently under discussion, including discussions on whether some actions are only appropriate for certain types of CoG. A typical set of actions is given below:

Action	Definition
Disrupt	Temporarily reduce effectiveness
Degrade	Permanently reduce effectiveness
Isolate	Reduce effectiveness to zero until further notice
Destroy	Permanently reduce effectiveness to zero

Table 2: Actions, ordered by effect

Center of Gravity	Modifier
Geographical	
`US citizens`	in the region
`YOC forces`	north of Desired Area
Temporal	
`YOC economic centers`	until the flow of military resources is sufficiently slow
Categorical	
`YOC political control` `YOC military control`	YOC armed forces

`YOC political control`
`YOC military control`
`electricity`
`petroleum products`
`national television systems`
`national radio systems`
`national computer systems`
	YOC population

Table 3: Modifiers: CinC Objectives Level

Modifiers: The general format of objectives is "Perform ACTION on *center of gravity* with `modifier`". The modifiers are optional, but many CinC objectives and air objectives, and some air tasks, have associated modifiers. These modifiers may be:

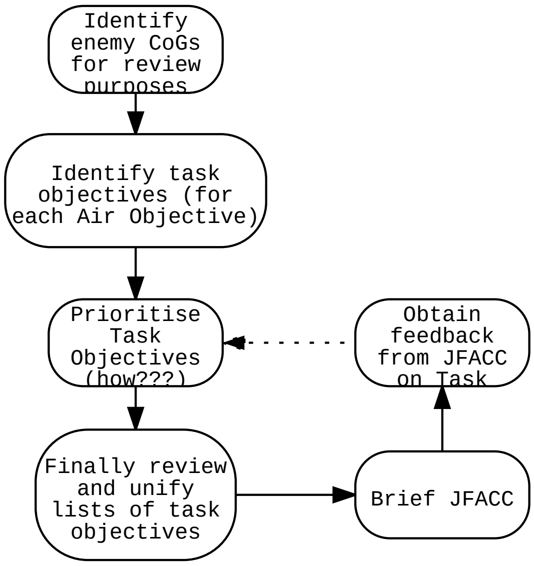
- geographical (e.g. "Destroy SAMs **beyond 100km of the DMZ**");
- temporal (e.g. "Sustain (Blue) forces **for a minimum of 45 days**");
- categorical (e.g. "Deny use of national roadways for the transport of **military equipment**").

The form and content of permitted modifiers is currently under discussion. A list of (almost) all the identified modifiers was prepared; it can be seen in tables C.7 and 4 on page 107. A selection of modifiers are shown in table 3.

6.2 Prioritizing Air Tasks

6.2.1 Task Knowledge

The task structure for producing and sequencing air tasks can be seen in Figure 18. One of the main discoveries from this modelling exercise has been that the processes involved in producing prioritized air objectives, producing prioritized air tasks and producing a prioritized target list are very similar (see Figures 13, 18 and 20). This observation, coupled with the hierarchies of centers of gravity (which suggests a similar format for domain knowledge in each of these three activities), suggest that the entire expertise models for these three activities will be very similar. It would, however, be instructive to identify any differences between these three models.



Key:

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

Figure 18: Task Structure: Identify, prioritize & sequence Air Tasks

Description of activities:

Identify enemy Centers of Gravity for review purposes : Although the air objectives have already been designed to target enemy Centers of Gravity, it's helpful to review the Centers of Gravity at this stage of planning.

Identify air tasks (for each Air Objective) : Identifying task objectives for the air force to achieve consists of choosing air tasks which provide the maximum fulfilment of the air objectives, based on the air objectives chosen and on identified enemy Centers of Gravity.

For example, if "disrupt command and control" had been specified as an Air Objective, possible air tasks might include:

- attack command posts
- attack lines of communication

- jam radios
- kill men by attacking barracks
- isolate men
- isolate roads
- destroy communication centers

Prioritize air tasks is largely based on the prioritization of corresponding air objectives, although there may be other influences if certain air tasks can fulfil more than one air objective.

Finally review and unify lists of tasks occurs at a meeting, to bring together all the air tasks in a single list and to ensure that all air objectives are addressed by air tasks.

Brief JFACC and **Obtain feedback from JFACC on Air Tasks**: The JFACC's second briefing normally describes both identified air tasks and identified targets, since the identification of air tasks is a relatively quick activity. However, significant feedback may well be produced, enough for the planning staff to require a third day of planning to iteratively refine the lists of objectives and targets to meet the JFACC's requirements.

6.2.2 Inference knowledge

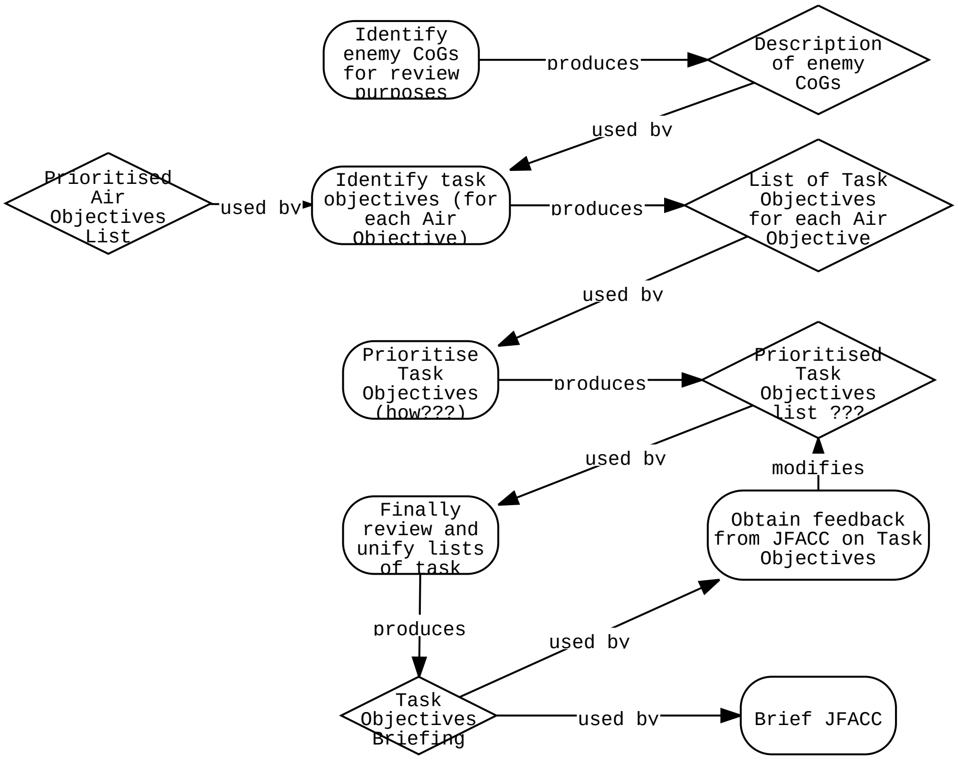
At present, the only information available which resembles inference knowledge for the activity of producing and sequencing air tasks is the "assets perspective" diagram shown in Figure 19. However, as discussed above, the inference structure is likely to be similar to the inference structure for identifying & prioritizing air objectives, shown in Figures 14 through 16.

6.2.3 Domain Knowledge

As discussed above, the domain knowledge for air tasks consists of actions, modifiers, and centers of gravity taken from the hierarchy shown in appendix C.5; for information on these, read section 6.1.3 on page 54 on domain knowledge for air objectives. The hierarchy shows that a certain level of CoGs are specific to air tasks. It is possible that certain actions or modifiers are specific to air tasks; this is still under discussion.

6.3 Prioritizing Targets

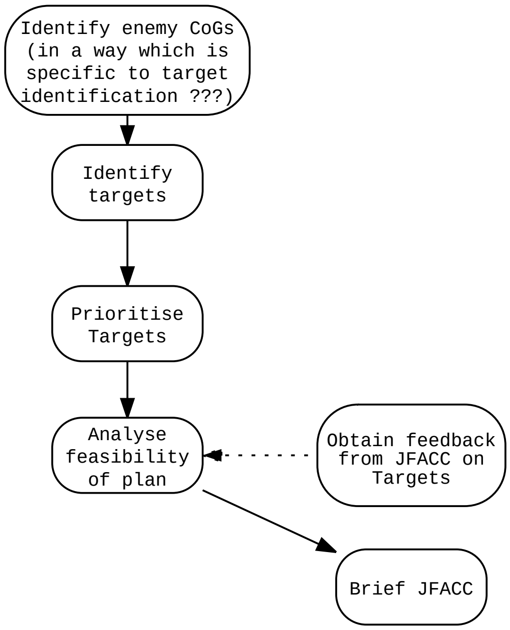
6.3.1 Task Knowledge



Key:

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

Figure 19: ACP Assets Perspective: Prioritize Air Tasks



Key:

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

Figure 20: Task Structure: Produce Prioritized Target List

Identify enemy Centers of Gravity : Although the air objectives have already been designed to target enemy Centers of Gravity, it's helpful to review the Centers of Gravity at this stage of planning. No information has yet been acquired on any special features of Centers of Gravity which are specific to target identification.

Identify targets : Identifying targets consists of choosing targets which provide the maximum fulfilment of the air tasks, based on the task objectives chosen and on identified enemy Centers of Gravity.

Prioritize targets should largely be based on the prioritization of corresponding air tasks. In practice, the planners spend a lot of time discussing the list of targets and moving certain targets up or down the prioritization; this action effectively incorporates the review and unification of the target list.

Analyze feasibility of plan is a computerized process. The format of the output is not yet known.

Brief JFACC and **Obtain feedback from JFACC on Targets**: see description of **Obtain feedback from JFACC on Air Tasks** above.

6.3.2 Inference knowledge

At present, the only information available which resembles inference knowledge for the activity of producing a prioritized target list is the "assets perspective" diagram shown in Figure 21. However, as discussed above, the inference structure is likely to be similar to the inference structure for identifying & prioritizing air objectives, shown in Figures 14 through 16.

6.3.3 Domain Knowledge

As discussed above, the domain knowledge for air tasks and targets consists of actions, modifiers, and centers of gravity which implicitly form the sixth level of the hierarchy shown in appendix C.5; for information on these, read section 6.1.3 on page 54 on domain knowledge for air objectives. It is possible that certain actions or modifiers are specific to targets; this is still under discussion.

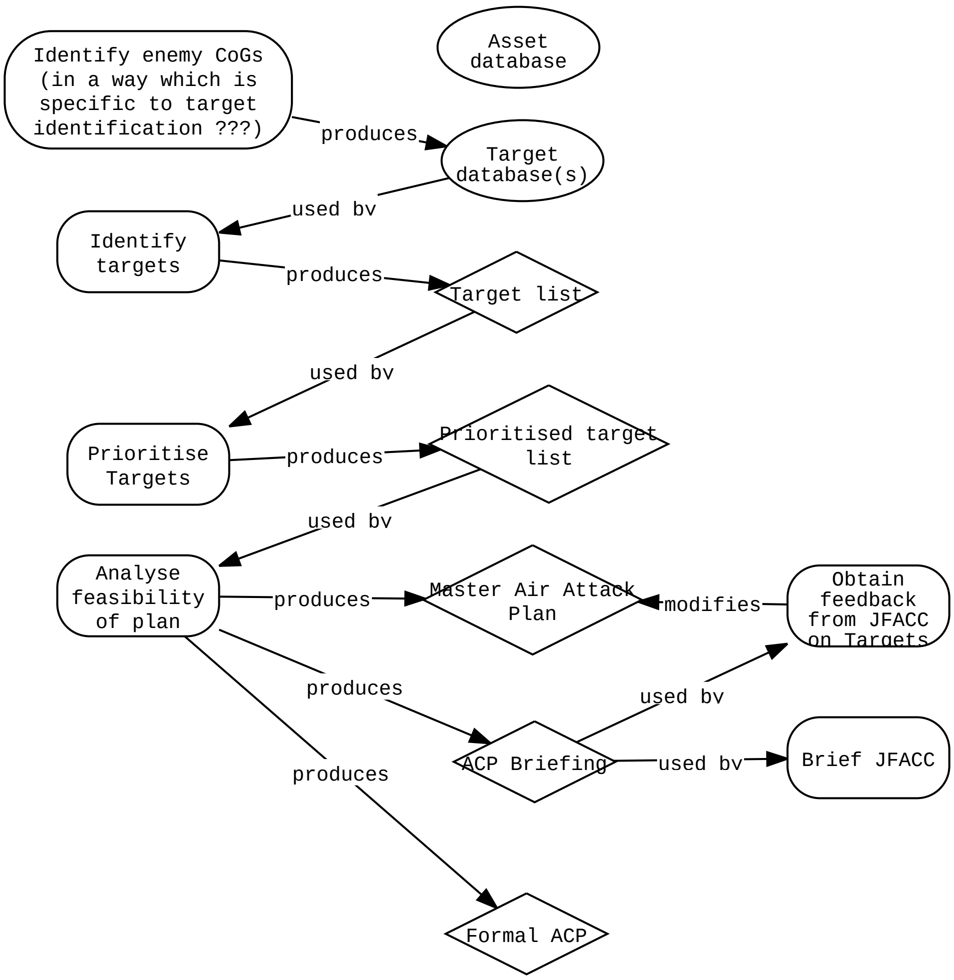


Figure 15: ACP Assets Perspective: Prioritize Targets

Key:

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

N.B. The asset database is not connected to any activity because it is not currently used by the planners.

Figure 21: Prioritize Targets: Assets Perspective

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A Knowledge acquisition using repertory grids

A.1 Repertory Grids

The repertory grid technique for knowledge acquisition [Gaines & Shaw, 1993] is derived from the personal construct theory of George Kelly [Hinkle, 1970]. A grid is drawn with each activity forming a separate column in the grid.[9] The rows are labelled with attributes against which each activity can be classified on a 1-5 scale. Four of these attributes were provided from past experience; two more, "Analytic vs Synthetic" and "Evaluation required" were elicited[10] from Doug Holmes, who was the first expert with whom this technique was used. Each expert was then asked to fill in the grid with numbers between 1 and 5, representing their opinion of the values of various attributes. For example, Figure 22 shows that, in Checkmate's opinion, identifying campaign objectives and military objectives takes very little time (1 = Short), but requires considerable experience (4 = Fairly Much). There is much useful information to be gained from this technique, by:

- obtaining and recording a complete set of information for each attribute of each activity;
- comparing grids between different experts to identify consensus and conflict [Shaw & Gaines, 1989];
- statistical analysis of the scores provided (see section A.1.4);
- recording the 'asides' which the expert mentions as he is completing the grid.

A.1.1 Criteria used to fill in the grid

Ideally, each expert should be questioned on the criteria he has used for filling in the repertory grid. However, the grids completed by Checkmate were filled in remotely, so this questioning has only been performed for a few key scores where the experts had differing opinions. Doug Holmes filled in his grid interactively (i.e. with the knowledge engineer present and occasionally prompting for information), and his comments about the criteria which he used for assigning values to attributes, gathered from the "aside" comments which he made, are given below:

[9] The repertory grid technique is normally used for acquiring attributes and values of concepts. In this case, the concepts are replaced by activities, in order to ascertain some important information about these activities.

[10] These attributes were elicited using the *triadic elicitation* technique; choosing three domain items at random and asking the expert to specify any attribute on which one of the three items differs from the other two.

	Plan Air Campaign	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicat plan to subordinat	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	3	4	4	4	3	4	4	3	4	4	4	4
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	5	5	3	5	4	4	4	4	4	4
1 = Rare 5 = Frequent	Likelihood of mistake	3	2	3	3	2	3	2	3	2	3	3	3
1 = Short 5 = Long	Time required	2	2	4	4	2	4	3	2	2	4	4	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	4	4	3	3	3	2	3	4	3	3	3	2
1 = Little 5 = Much	Evaluation required	4	2	4	5	2	4	3	2	3	4	4	4

Figure 22: Attributes of ACP Activities(Task Model level): Checkmate (amalgamated)

Experience required : The criterion which Doug was using here was the rank of the officer who normally carried out the activity; 3 indicated an activity which was normally assigned to a major, 4 an activity normally assigned to a lieutenant-colonel, and 5 an activity which normally required a colonel to perform it.

Seriousness of mistake : Doug's criterion here was the length of time for which a mistake could go uncorrected in the planning process. For example, an incorrect decision on the enemy's most likely course of action could go uncorrected until the end of the war (thus meriting a high score), while a mistake in obtaining policy and guidance from CinC/JFC will always be corrected at the first briefing.

Likelihood of mistake : No comments made.

Time required : Doug stated that he was considering activities within a 3-day time frame (the length of an average planning cycle), so a small number indicated an activity taking a few minutes, whereas a large number indicated an activity taking hours or even a whole day.

Analytic vs Synthetic : No comments made.

Evaluation required : No comments made.

A.1.2 Results

Repertory grids were eventually obtained from five experts; Doug Holmes, Joe Roberts (a former member of Checkmate) and three current members of Checkmate staff. The full set of grids can be seen in section A.1.5. Doug and Joe held the opinion that the Checkmate staff would be able to provide more accurate values for the repertory grid than they could, so the final analysis was done on a repertory grid which amalgamated the scores of the three Checkmate staff (see figure 22). The Checkmate staff largely agreed with each other on most of the attributes; where they did not agree, they were asked to provide explanations. These explanations often related to underlying assumptions; some of these explanations have been incorporated into the descriptions of activities given below, and a few values have been weighted according to the explanations given. The main area of disagreement was on the **Analytic vs Synthetic** attribute; it was felt that the knowledge engineer had given the Checkmate staff insufficient explanation on the meaning of this attribute, and so it was excluded from further analysis.

The results of the repertory grid technique were subjected to statistical analysis (see Figure 24). This analysis showed a strong correlation between the scores provided for **Experience required** and the scores provided for **Seriousness of mistake**; there was also a strong correlation between the scores provided for **Time required** and the scores provided for **Evaluation required**. The former correlation suggests an underlying philosophy, that it is more important to avoid serious mistakes than to minimize the total number of mistakes; the latter correlation is to be expected, since evaluation takes time. It is usually superfluous to include two strongly correlated attributes in the task model; **Evaluation required** has therefore been eliminated from the task model. However, both **Seriousness of mistake** and **Experience required** have been retained in the task model. This is done because the experts made a number of aside comments about the seriousness of mistakes which can be displayed with this attribute; while the level of experience required is an easy statistic to acquire and verify. It is easy because different levels of experience required correlate with the rank of the officer required to perform an activity, and the correlation can be checked easily using the heuristic used by Doug Holmes (see section A.1.1).

A.1.3 Repertory grids: expertise model level

The repertory grid technique was also applied to the activities which appear in figures 13, 18 and 20, in order to see if useful information could be obtained from this technique. Little analysis has been completed on these repertory grids so far. An example of an "expertise model" level repertory grid – the one acquired from Doug Holmes – is shown in Figure 23.

A.1.4 Statistical analysis of repertory grids

Once the grid has been completed, it's possible to perform statistical clustering on the value supplied, to see if there is any implicit categorization of the activities reflected in the scores provided for each activity. Figure 24 shows the results of performing statistical cluster analysis on the scores in the grid shown in Figure 22;

	Prioritizing air objectives, tasks, targets	Identify enemy CoGs (in each sub-area)	Identify Air Objectives (for each sub-area)	Prioritize Air Objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs (in a way which is specific	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	5	4	4	5	5	3	3	3	5	4	3	3	3	5	5	5
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	3	4	4	3	3	3	4	3	3	2	3	4	4	2
1 = Rare 5 = Frequent	Likelihood of mistake	3	3	2	2	3	2	2	2	2	2	2	1	3	2	2	3
1 = Short 5 = Long	Time required	5	3	2	1	4	3	2	2	2	3	3	4	4	2	4	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	2	4	1	4	3	2	4	1	4	3	2	4	1	1	4	4
1 = Little 5 = Much	Evaluation required	2	3	5	4	1	2	3	5	4	1	2	1	5	5	2	3

Figure 23: Attributes of ACP Activities (Task Model level): Doug Holmes

Figure 25 shows the results of cluster analysis on the grid shown in 23. This gives some idea of the (subjective) similarity of activities on the attributes identified in the grid. The result of cluster analysis is a "taxonomic" hierarchy, in which the "classes" are actually nodes identifying the percentage of similarity between activities, or groups of activities. For example, in Figure 25, the identification of enemy Centers of Gravity is carried out 3 times (when prioritizing Air Objectives, Task Objectives and Targets); the latter two are scored identically (100% similarity) whereas the prioritization of Air Objectives only merits 79% similarity with these two.

It is often instructive to ask the expert why certain activities are considered similar or different. In the example above, Doug suggested that this phenomenon was due to the fact that it's harder to identify Centers of Gravity at the first attempt; once the task has been done once, at a high level, it is less difficult at lower levels of detail. In another example, Doug was asked why "Identify Targets" was so different from the other activities (see Figure 25). By looking at the scores in the grid, it can be seen that "Identify Targets" is the only activity which requires a lot of time but does not require much evaluation or experience. This observation led the knowledge engineer to suggest that "Identify Targets" might be a suitable activity for automation using conventional (i.e. not knowledge-based) computing; Doug replied that such a task was already being undertaken.

A.1.5 Full set of acquired repertory grids

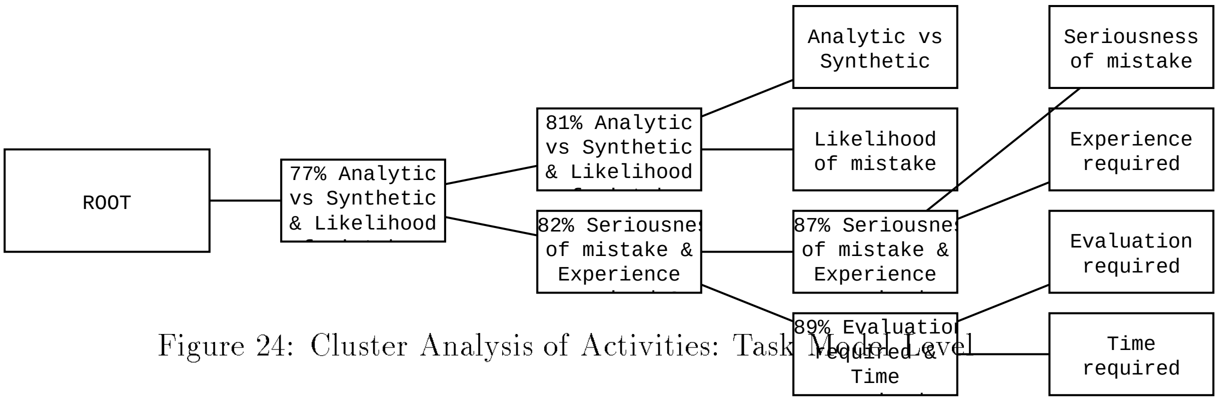

Figure 24: Cluster Analysis of Activities: Task Model Level

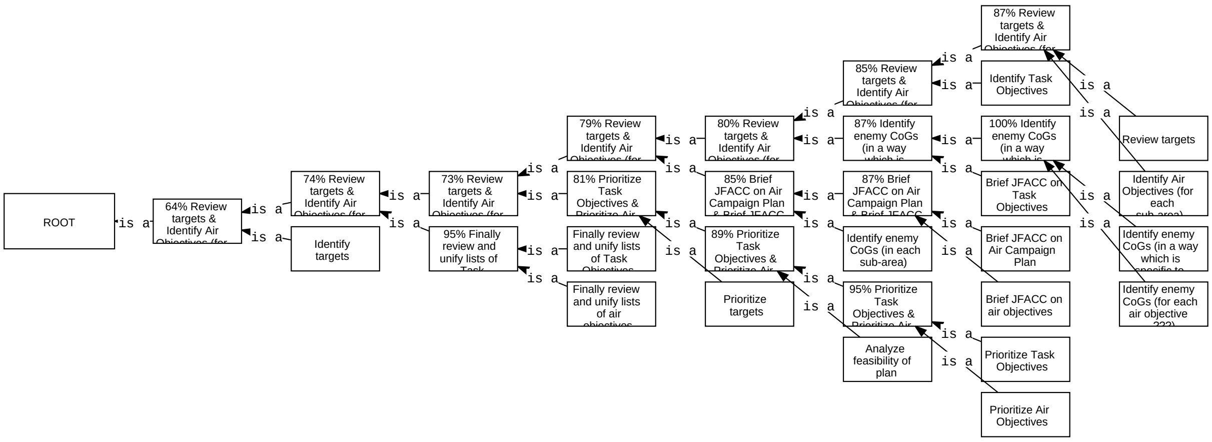

Figure 25: Cluster Analysis of Activities: Expertise Model level

	Plan Air Campaign (J Allison)	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicat plan to subordinat	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	2	5	4	5	4	4	4	4	5	5	5	3
1 = Trivial 5 = Very serious	Seriousness of mistake	4	5	5	5	4	5	5		5	5	4	4
1 = Rare 5 = Frequent	Likelihood of mistake	2	4	3	3	3	4	3	3	2	2	3	3
1 = Short 5 = Long	Time required	1	2	3	4	2	3	3	2	2	3	4	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	4	4	3	2	2	3	4	5	4	2	2	2
1 = Little 5 = Much	Evaluation required	4	2	5	5	3	4	4	2	4	5	5	5

Figure 26: Repertory Grid (Task Model level): Major Allison

	Plan Air Campaign (M Alred)	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicat plan to subordinat	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	3	5	4	5	4	4	3	3	2	4	4	4
1 = Trivial 5 = Very serious	Seriousness of mistake	4	5	3	4	2	4	3	4	3	3	4	4
1 = Rare 5 = Frequent	Likelihood of mistake	5	3	3	4	3	3	2	3	2	4	4	3
1 = Short 5 = Long	Time required	2	2	4	5	3	4	3	2	2	4	4	2
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	5	3	4	4	2	2	2	1	1	5	4	2
1 = Little 5 = Much	Evaluation required	4	3	4	5	2	3	2	2	2	4	4	3

Figure 27: Repertory Grid (Task Model level): Major Alred

	Plan Air Campaign (M Cardenas)	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicat plan to subordinat	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	3	3	5	3	2	5	4	3	4	5	5	4
1 = Trivial 5 = Very serious	Seriousness of mistake	5	2	5	5	2	5	4	5	4	5	5	4
1 = Rare 5 = Frequent	Likelihood of mistake	2	1	2	2	2	2	2	2	1	3	3	3
1 = Short 5 = Long	Time required	2	2	4	2	2	4	4	2	2	5	5	4
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	4	4	1	4	4	1	3	5	5	2	2	3
1 = Little 5 = Much	Evaluation required	4	2	4	4	2	5	3	2	2	4	4	4

Figure 28: Repertory Grid (Task Model level): Major Cardenas

	Plan Air Campaign	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicate plan to subordinates	Brief CJTF	Produce prioritized air objectives	Produce prioritized task objectives	Produce prioritized target list
1 = Little 5 = Much	Experience required	2	3	4	4	4	3	4	3	4	5	4	3
1 = Trivial 5 = Very serious	Seriousness of mistake	3	3	4	3	3	4	4	3	4	5	4	3
1 = Rare 5 = Frequent	Likelihood of mistake	2	2	3	3	1	3	2	1	3	3	3	3
1 = Short 5 = Long	Time required	1	2	4	1	2	4	4	2	3	4	4	4
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	1	4	2	1	1	2	1	4	4	3	3	3
1 = Little 5 = Much	Evaluation required	1	4	3	2	4	4	4	1	4	5	5	5

Figure 29: Repertory Grid (Task Model level): Doug Holmes

	Plan Air Campaign (Joe Roberts)	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicate plan to subordinate	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	1	4	3	4	2	4	3	3	4	4	4	3
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	3	4	2	3	4	3	4	4	4	4
1 = Rare 5 = Frequent	Likelihood of mistake	1	3	3	2	2	3	3	2	2	3	3	2
1 = Short 5 = Long	Time required	2	2	4	2	2	4	4	2	3	5	5	5
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	1	4	2	2	2	2	2	3	4	3	3	3
1 = Little 5 = Much	Evaluation required	1	3	4	3	3	4	4	2	3	4	4	4

Figure 30: Repertory Grid (Task Model level): Joe Roberts

	Plan Air Campaign (Joe Roberts)	Obtain policy and guidance from CinC/JFC	Organize planning staff	Assess Situation	Identify campaign objectives and military objectives	Subdivide the planning problem	Decide on enemys most likely course of action	Review enemy course of action	Communicate plan to subordinate	Brief CJTF	Produce prioritize air objectives	Produce prioritize task objectives	Produce prioritize target list
1 = Little 5 = Much	Experience required	1	4	3	4	2	4	3	3	4	4	4	3
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	3	4	2	3	4	3	4	4	4	4
1 = Rare 5 = Frequent	Likelihood of mistake	1	3	3	2	2	3	3	2	2	3	3	2
1 = Short 5 = Long	Time required	2	2	4	2	2	4	4	2	3	5	5	5
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	1	4	2	2	2	2	2	3	4	3	3	3
1 = Little 5 = Much	Evaluation required	1	3	4	3	3	4	4	2	3	4	4	4

Figure 31: Repertory Grid (Task Model level): Checkmate amalgamated

Scale	Prioritizing air objectives, tasks, targets	Identify enemy CoGs (in each sub-area)	Identify Air Objectives (for each sub-area)	Prioritize Air Objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs (in a way which is specific to	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	4	4	4	4	5	4	4	4	4	5	0	5	3	5	5	3
1 = Trivial 5 = Very serious	Seriousness of mistake	4	3	4	4	5	3	3	4	3	4	0	4	3	5	5	3
1 = Rare 5 = Frequent	Likelihood of mistake	4	4	3	2	4	3	3	3	3	3	0	4	3	5	4	3
1 = Short 5 = Long	Time required	5	4	4	3	4	3	3	4	3	3	0	5	3	5	4	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	4	2	2	4	4	2	2		2	4	0	3	3	1	3	3
1 = Little 5 = Much	Evaluation required	5	4	4	4	4	4	4	4	5	4	0	5	5	5	2	5

Figure 32: Repertory Grid (Expertise Model level): Major Allison

Scale	Prioritizing objectives (M Alred)	Identify enemy CoGs (in each sub-area)	Identify Air Objectives (for each sub-area)	Prioritize Air Objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs (in a way which is specific to	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	4	4	3	4	2	4	4	4	4	2	4	3	3	4	3	2
1 = Trivial 5 = Very serious	Seriousness of mistake	3	3	3	3	2	3	4	3	3	2	4	3	2	4	3	2
1 = Rare 5 = Frequent	Likelihood of mistake	4	3	2	3	2	3	3	3	3	2	3	3	3	4	2	1
1 = Short 5 = Long	Time required	4	4	2	3	2	4	3	2	2	2	3	3	2	4	2	2
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	4	4	3	3	2	4	4	3	2	2	2	2	2	4	2	1
1 = Little 5 = Much	Evaluation required	4	4	4	3	1	4	4	4	4	1	4	3	3	4	2	2

Figure 33: Repertory Grid (Expertise Model level): Major Alred

Scale	Prioritizing air objectives, tasks, targets	Identify enemy CoGs (in each sub-area)	Identify Air Objectives (for each sub-area)	Prioritize Air Objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs (in a way which is specific to	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	5	5	5	4	3	5	5	5	5	3	4	4	2	5	4	2
1 = Trivial 5 = Very serious	Seriousness of mistake	5	5	4	4	5	5	5	4	4	5	3	4	2	5	5	2
1 = Rare 5 = Frequent	Likelihood of mistake	2	2	3	2	2	2	3	3	2	2	3	2	3	4	2	3
1 = Short 5 = Long	Time required	4	5	4	3	3	4	5	4	3	3	3	3	2	5	3	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	1	1	2	3	5	1	3	2	3	5	2	2	4	2	5	3
1 = Little 5 = Much	Evaluation required	4	4	5	3	2	4	4	4	3	2	2	2	3	5	2	3

Figure 34: Repertory Grid (Expertise Model level): Major Cardenas

	Prioritizing air objectives, tasks, targets	Identify enemy CoGs (in each sub-area)	Identify Air Objectives (for each sub-area)	Prioritize Air Objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs (in a way which is specific	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	5	4	4	5	5	3	3	3	5	4	3	3	3	5	5	5
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	3	4	4	3	3	3	4	3	3	2	3	4	4	2
1 = Rare 5 = Frequent	Likelihood of mistake	3	3	2	2	3	2	2	2	2	2	2	1	3	2	2	3
1 = Short 5 = Long	Time required	5	3	2	1	4	3	2	2	2	3	3	4	4	2	4	3
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	2	4	1	4	3	2	4	1	4	3	2	4	1	1	4	4
1 = Little 5 = Much	Evaluation required	2	3	5	4	1	2	3	5	4	1	2	1	5	5	2	3

Figure 35: Repertory Grid (Expertise Model level): Doug Holmes

	Repertory Grid	Identify enemy CoGs (in each sub-area)	Identify air objectives (for each sub-area)	Prioritize air objectives	Finally review and unify lists of air objectives	Brief JFACC on air objectives	Identify enemy CoGs (for each air objective)	Identify Task Objectives	Prioritize Task Objectives	Finally review and unify lists of Task Objectives	Brief JFACC on Task Objectives	Identify enemy CoGs	Identify targets	Prioritize targets	Analyze feasibility of plan	Brief JFACC on Air Campaign Plan	Review targets
1 = Little 5 = Much	Experience required	4	4	4	4	3	4	4	3	4	3	4	4	3	4	2	3
1 = Trivial 5 = Very serious	Seriousness of mistake	4	4	3	3	3	4	4	3	3	3	4	3	2	3	2	3
1 = Rare 5 = Frequent	Likelihood of mistake	3	3	2	2	2	3	3	2	2	2	3	3	2	3	2	2
1 = Short 5 = Long	Time required	3	4	3	3	3	4	4	3	3	3	4	4	3	3	3	2
1 = Analytic 5 = Synthetic	Analytic vs Synthetic	1	4	1	1	4	1	4	1	1	4	1	1	1	1	4	1
1 = Little 5 = Much	Evaluation required	4	4	5	2	2	4	4	5	3	2	4	4	4	4	2	3

Figure 36: Repertory Grid (Expertise Model level): Joe Roberts

B The IDEF3 modelling technique

The following collection of IDEF3 diagrams represent the Air Campaign Planning process as elicited from a number of experts. The notation and benefits of this method are discussed in an accompanying document [Lydiard, 1995].

Five processes are shown at the highest level. Each of these is decomposed into subprocesses which are related to their parent by the numbering system. This consists of a prefix formed from the parent UoB reference number, the number of the decomposition and a unique reference number.

Concurrency between subprocesses within a single decomposition is illustrated using asynchronous & junctions. The fan-out junction indicates that both subprocesses must start, and the fan-in junction indicates that both of those subprocesses must complete before the next subprocess can initiate.

The decomposition of UoB 3 "plan the air campaign" refers to various briefings. These are shown as synchronous referents which indicate that the referent process (the briefing) must initiate and complete before the focus process is considered to be complete.

Finally the decomposition of UoB 5 "evaluate air campaign" uses exclusive OR junctions showing that if new policy and guidance has been received either the air campaign will cease or the air objectives will need to be reviewed as indicated by the unconditional Go-To referent, which loops the process back to 3.1.16 "identify and prioritize air objectives". When there is no new policy and guidance the air tasks will need to be reviewed, as indicated by the unconditional Go-To referent, which loops the process back to UoB 3.1.17 "identify and prioritize air tasks".

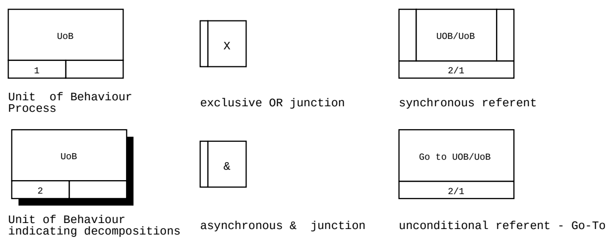

Figure 37: Key to IDEF3 diagrams

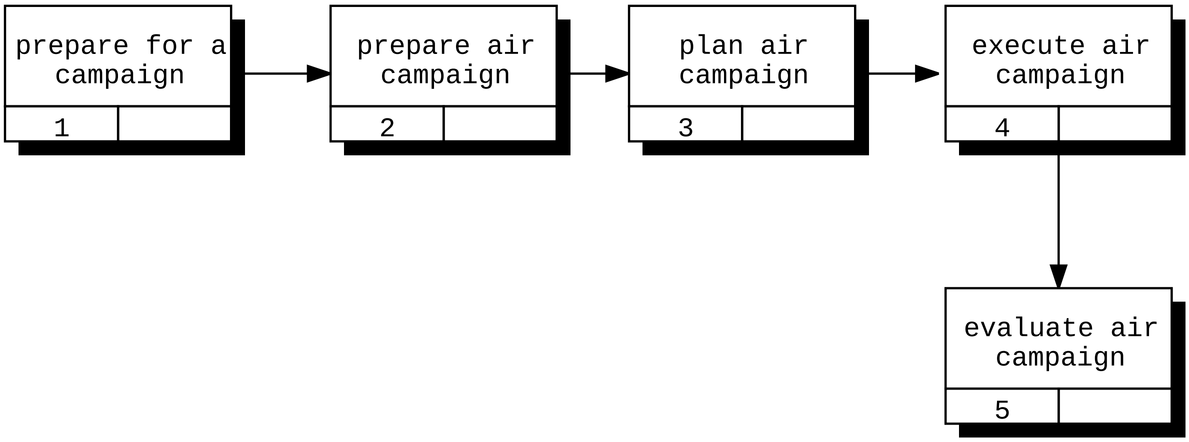

Figure 38: Air Campaign Planning: Top Level Processes

C Domain knowledge for Air Campaign Planning

C.1 List of objectives

This list of objectives has been derived from a document supplied by Checkmate in November 1995, giving objectives which have been defined in planning for actual military exercises.

This document describes these objectives using the following template:

PERFORM ACTION on `Center of Gravity` with optional modifier.

Some objectives are rephrased to enable them to fit this template. The action and the Center of Gravity are highlighted by using SMALL CAPITALS and `teletype font` respectively.

The code numbers at the beginning of each objective show which higher level objectives are addressed by the lower level objectives; for example, air objective B5.1 fulfils CinC objective B5.

C.2 CinC objectives

C.2.1 Leadership

A1: ISOLATE and NEUTRALIZE `YOC political control` of armed forces

A2: ISOLATE and NEUTRALIZE `YOC political leadership` from the population

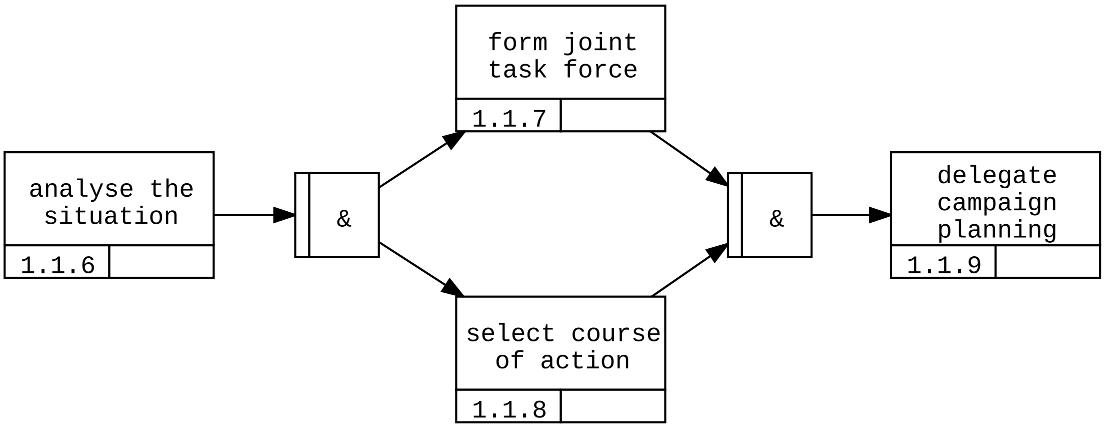

Figure 39: Preparing for an Air Campaign

A3: *Ensure regional stability by reducing Yellowland Orangeland Cooperative (YOC).* This is a national or political objective which should really be considered at a higher level of command than the other CinC objectives. However, it has been rephrased to:

REDUCE `Yellowland Orangeland Cooperative (YOC)` to ensure regional stability

A4: *Provide for Stability of the Region.* This too is a national or political objective; it is too loosely defined for rephrasing to be possible.

A5: PROTECT the lives of `US citizens` and `forces` in the region. This is probably better categorized as a National Population objective.

A6: ISOLATE and NEUTRALIZE `YOC military control` of armed forces

A7: *Isolate and neutralize YOC military's effect on population.* For consistency with objective A6, this has been rephrased to:

ISOLATE and NEUTRALIZE `YOC military control` on population

C.2.2 Key Production

B1: *Separate YOC military structure from primary electrical sources.* In order to match objective B2, this has been rephrased to:

DENY USE of `electricity` to YOC military structure.

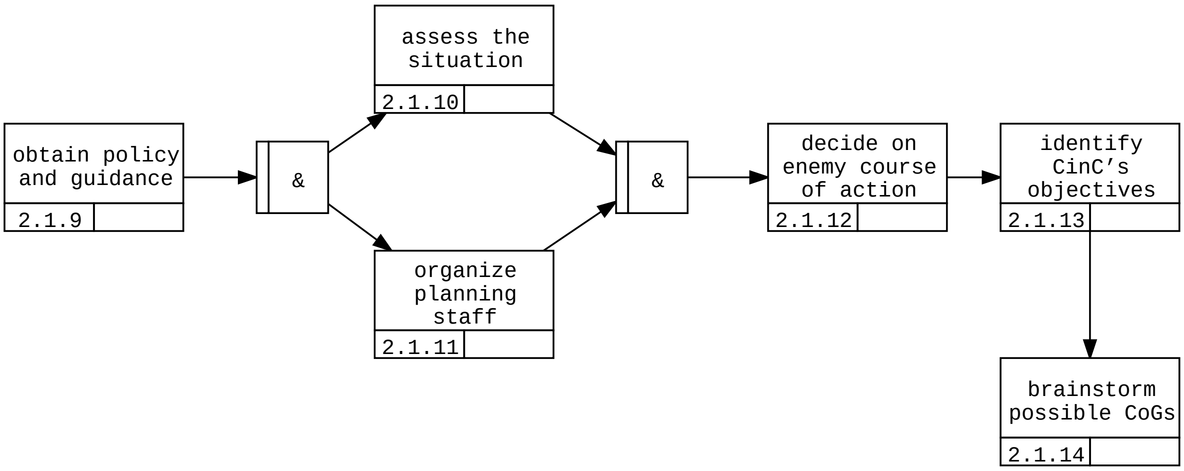

Figure 40: Preparing for Air Campaign Planning

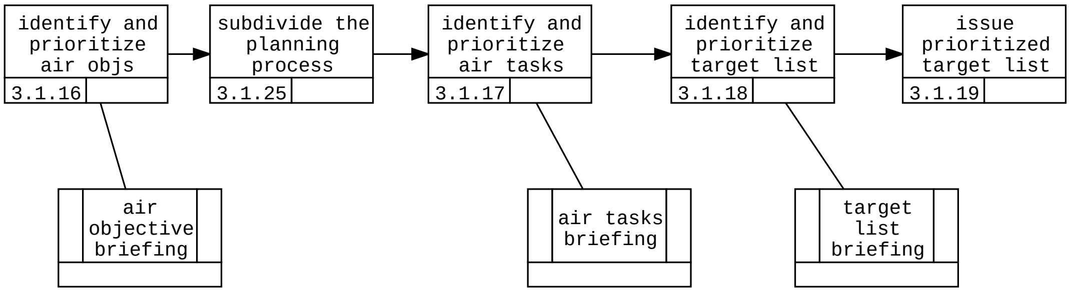

Figure 41: Planning an Air Campaign

B2: *Deny use of primary electrical sources to YOC population.* Rephrased[11] to:

DENY USE of `electricity` to YOC population

B3: NEUTRALIZE `YOC petroleum production` supporting warfighting effort

B4: DENY USE of `petroleum products` to YOC population

B5: NEUTRALIZE `production of chemical products`

B6: *Prevent chemical products from becoming weapons of mass destruction.* This has been rephrased to:

[11] The term "electrical production", which appears in the Air Objectives (e.g. B2.1), is more general than "primary electrical sources". However, "electricity" is a more general term still, which is at the same level as "petroleum products".

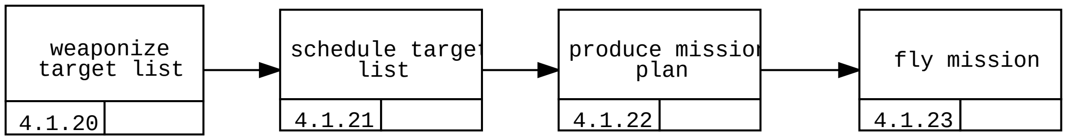

Figure 42: Executing an Air Campaign Plan

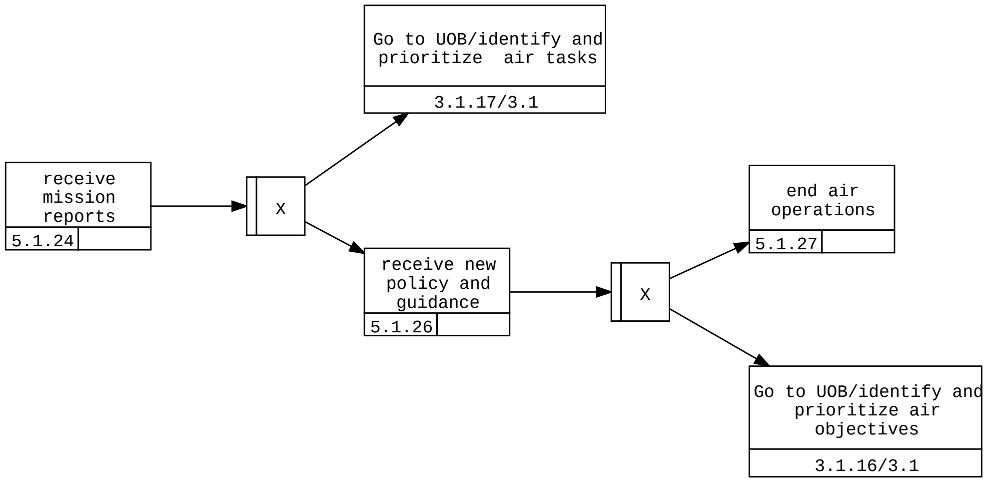

Figure 43: Evaluating an Air Campaign

DENY USE of `chemical products` for the manufacture of weapons of mass destruction.

B7: NEUTRALIZE `YOC special weapons capability` and `delivery means`

B8: *Defend against Weapons of Mass Destruction.* The current phrasing of this objective is identical to objective E7; it has therefore been removed from this section. Air objectives B8.1, B8.2 and B8.3 are renumbered to E7.1, E7.2 and E7.3.

C.2.3 National Infrastructure

C1: DENY USE of `national roadways` for transport of military equipment

C2: DENY USE of `national railways` for transport of military equipment

C3: DENY USE of `national waterways` for transport of military equipment

C4: DENY USE of `national communications nets` to transport military information

C5: INTERRUPT the flow of goods on `national roadways`

C6: INTERRUPT the flow of goods on `national railways`

C7: INTERRUPT the flow of goods on `national waterways`

C8: INTERRUPT the flow of information on `national communication networks`

C9: *Build sufficient combat power for future offensive operations.* This has been rephrased to:

OBTAIN sufficient `Blue Forces` for future offensive operations.

C10: *Ensure Freedom of Navigation.* This has been rephrased to:

PERMIT SAFE ACCESS to `national waterways` for Blue shipping.

C11: SUSTAIN `(Blue) Forces` for Minimum of 45 Days

C.2.4 National Population

D1: DENY USE of `national television systems` to transmit military information

D2: DENY USE of `national radio systems` to transmit military information

D3: DENY USE of `national computer systems` to transmit military information

D4: DENY USE of `national television systems` to influence YOC population

D5: DENY USE of `national radio systems` to influence YOC population

D6: DENY USE of `national computer systems` to influence YOC population

D7: CONDUCT NEO of `US personnel` and `other volunteer Foreign Nationals`

D8: NEUTRALIZE `YOC economic centers` to slow the flow of military resources

D9: *Deny access to YOC economic centers.* This has been rephrased to:

DENY USE of *national transportation networks* leading to YOC economic centers.

In this form, it can be seen that this is an infrastructure objective rather than a national population objective.

D10: *Employ C2W methodologies.*

USE C2W methodologies to influence `YOC population`.

This is a high level objective; in order to match the level of detail of the other objectives, individual C2W methods should be specified.

C.2.5 Fielded Forces

E1: DETER `YOC aggression` against B/G

E2: DETER `Yellowland aggression`

E3: *Conduct Land, Sea and Air operations to restore the sovereignty of B/G.* Like A3, this is a national or political objective which should really be considered at a higher level of command than the other CinC objectives. However, it has been rephrased to:

RESTORE THE SOVEREIGNTY of `B/G` by fielding military forces.

E4: STOP `YOC forces` north of Desired Area

E5: DEFEND `B/G` from YOC Attack

E6: DEFEND `Greyland` from YOC Attack

E7: *Defend Against Weapons of Mass Destruction.* Rephrased to:

DEFEND `Blue forces` Against Weapons of Mass Destruction

E8: DISRUPT `YOC Special Forces Capability`

C.3 Air Objectives

C.3.1 Leadership

A1.1: DISRUPT `YOC political control` of armed forces

A1.2: DESTROY `YOC political control` of armed forces

A1.3: DISRUPT and DEGRADE `YOC intelligence capability`

A1.4: ISOLATE `YOC National Command Authority`

A2.1: DISRUPT `YOC political control` of population

A2.5: DESTROY `YOC political control` of population

A6.1: DISRUPT `YOC military control` of armed forces

A6.2: DESTROY `YOC military control` of armed forces

A6.3: DISRUPT and DEGRADE `YOC intelligence capability`

A7.1: DISRUPT `YOC military control` of population

A7.2: DESTROY `YOC military control` of population

C.3.2 Key Production

B1.1: DISRUPT `key electrical facilities` providing power to YOC military

forces B1.2: DESTROY `electrical facilities` providing power to YOC military forces

B2.1: DISRUPT `electrical production` to YOC

B2.2: DESTROY `electrical production` to YOC

B3.1: DISRUPT `petroleum production` providing fuel to YOC military forces

B3.2: DESTROY `petroleum production` providing fuel to YOC military forces

B4.1: DISRUPT `petroleum production` throughout YOC

B4.2: DESTROY `petroleum production` throughout YOC

B5.1: DISRUPT `chemical production` facilities

B5.2: DESTROY `chemical production` facilities

B7.1: DESTROY strategic targets (`pol-mil C2` and `NBC/TBM capability`)

C.3.3 National Infrastructure

C1.1: DRIVE YOC into `desired chokepoints` and `restricted LOCs`

C1.2: DISRUPT MOVEMENT of `YOC forward corps` and `committed 2nd echelon forces`

C2.1: DRIVE YOC into `desired chokepoints` and `restricted LOCs`

C2.2: DISRUPT MOVEMENT of `YOC forward corps` and `committed 2nd echelon forces`

C3.1: DRIVE YOC into `desired chokepoints` and `restricted LOCs`

C3.2: DISRUPT MOVEMENT of `YOC forward corps` and `committed 2nd echelon forces`

C3.3: *Attack critical naval targets.* Given that this supports CinC objective C3 (Deny use of national waterways for transport of military equipment), this has been rephrased to:

ATTACK `naval transport ships` which are capable of transporting military equipment on national waterways.

C4.1: DISRUPT `command and control` of YOC Air/Land/Sea forces.

C4.2: DISRUPT and DEGRADE `YOC intelligence capability`

C8.1: DISRUPT `command and control` of YOC Air/Land/Sea forces

C8.2: DISRUPT and DEGRADE `YOC intelligence capability`

C9.1: DEPLOY `(Blue) forces` capable of deterring YOC aggression

C9.2: DEPLOY `(Blue) forces` capable of supporting NEO

C.3.4 Fielded Forces

E4: *Disrupt YOC Ground Scheme of Maneuver.* Rephrased to: DISRUPT Ground Scheme of Maneuver of `YOC mechanized land forces`

E7.1: DESTROY strategic targets (`pol-mil C2` and `NBC/TBM capability`)

E7.2: DISRUPT `YOC Weapons of Mass Destruction capability`

E7.3: DESTROY `YOC Weapons of Mass Destruction capability`

C.4 Air Tasks

These had not been sorted by Checkmate at the time of writing. Categorization has been performed by the author of this document. Where a air task falls into one category but services an air objective in another category, it is categorized under the former. For example, *Destroy known NBC logistics support* is categorized under **National Infrastructure**, even though it supports the air objective *Disrupt YOC Weapons of Mass Destruction Capability*, which is categorized under **Key Production**.

C.4.1 Leadership

YOC forces :

DESTROY `key national headquarters`
DISRUPT `YOC reconnaissance/surveillance capabilities`
DISABLE known `NBC C3 capability`

DISRUPT C3I to frontline offensive units

DISRUPT enemy control of air operations and (control of) air defenses

DESTROY key command centers

DESTROY air defense C3I

DISRUPT key command and control nodes

DISRUPT TBM C2

NEUTRALIZE airborne C3 capability

DISRUPT key C3 nodes

DESTROY key YOC LADS C2 facilities

DESTROY command centers & comm nodes to disrupt YOC political and military direction of armed forces

DESTROY army, corps, and division HQs or ISOLATE them from subordinate units

Sever LOCs in support of GCC ground scheme of maneuver. Rephrased to: SEVER local command centers in support of GCC ground scheme of maneuver. Rephrased to:

DESTROY coastal surface surveillance radar C2

DESTROY key YOC LADS C2 facilities

DISRUPT naval C3I

DISRUPT Political Leadership of YOC Forces

DESTROY Command and Control Facilities in the forward area

DESTROY key YOC LOC's supporting forward troops

RENDER INEFFECTIVE C2 from YOC leadership to ballistic missiles

Blue forces :

PROVIDE battle management/C3I capability

PROVIDE surveillance and reconnaissance of region

DESTROY YOC intelligence collection/dissemination capability

EXPLOIT CUWTF intel and targeting when tasked by the B/G C3

C.4.2 Key Production

DESTROY known NBC research facilities

DESTROY known NBC production facilities

ATTRIT military production capability

DISRUPT electrical power supply to LADS and pol-mil C3I

DISRUPT/DESTROY military vehicles, armor, and artillery assembly & repair facilities

DISRUPT/DESTROY remaining POL production and storage

DISRUPT/DESTROY remaining munitions and propellant production and storage

DISRUPT NBC production and storage capability

DISRUPT nuclear reactor & fuel/ore processing
DESTROY YOC mining capability
DISRUPT YOC Electrical Power Distribution
DESTROY Naval Production Capability

C.4.3 National Infrastructure

DISRUPT YOC naval port operations
DESTROY logistics/maintenance/supply areas
DISRUPT SATCOM capability
DESTROY known NBC logistics support
DESTROY known NBC stockpiles and storage facilities
DISRUPT electrical power grid
DESTROY key naval communications nodes and EW/GCI
DESTROY railroad transportation terminals and facilities
DESTROY key bridges & tunnels
DISRUPT operations along LOCS/chokepoints
DESTROY POL storage/distribution facilities

C.4.4 National Population

None given.

C.4.5 Fielded Forces

YOC forces ATTRIT follow on forces
ATTRIT front line forces
ATTRIT enemy fighter/bomber force
DESTROY key SAM sites
DESTROY SAM sites threatening air operations throughout YOC
DISRUPT maneuver and momentum of committed forces with CAS
NEUTRALIZE YOC 240/170mm artillery
DESTROY remaining mech & armor assets of 2nd echelon forces and strategic reserves
DISRUPT YOC SAM/AAA sites along coastal corridors
DESTROY Silkworm missile/sites and storage
DISRUPT/DESTROY SAM/AAA/GCI affecting insertion corridors and drop zones
RENDER INEFFECTIVE YOC target acquisition systems
DESTROY landmines
DESTROY key EW/GCI sites supporting YOC defense assets
Destroy coastal surface surveillance radar sites and C2. Divided into two: DESTROY coastal surface surveillance radar sites is categorized here; destroying the radar's C2 is categorized under Leadership

Neutralize YOC capability to utilize its aircraft and airfields. This is a higher level objective, since "capability to utilize" might encompass fuel, pilots, repair facilities, etc.

DESTROY major `YOC surface and sub-surface combatants` and `SOF insertion platforms`

DISRUPT `YOC Ground Forces` With CAS

DESTROY `Tactical SAMs` in YOC

DESTROY `Strategic SAMs` in YOC

DESTROY `EW/GCI radars` within 100 Km of the border

DISRUPT `YOC Fighter/Bomber Operations`

DESTROY `Coastal Surveillance/Fire Control Radars`

DESTROY `YOC SAM/AAA sites`

DESTROY Silkworm `missiles/sites` and `storage`

DESTROY `key EW/GCI sites` supporting YOC defense assets

DISRUPT `YOC fighter capability`

DISRUPT/DESTROY `SAMs` on border, `AAA` near drop zones, and `EW/GCI` threatening CUWTF insertions

DISRUPT `YOC SAM/AAA sites along coastal corridors`

DISRUPT `YOC bomber capability`

DISRUPT maneuver and momentum of `committed forces` with CAS

Disrupt movement & maneuver into M-K corridor. Rephrased to: DISRUPT movement & maneuver of `forces` into M-K corridor

ATTRIT `forces` in Wonchor corridor

DISRUPT/DESTROY `240mm/170mm artillery` beyond the FSCL

DISRUPT `240mm/170mm artillery` inside the FSCL

DISRUPT `mechanized and armored formations` between FLOT and FSCL

DESTROY `YOC SOF infiltration aircraft`

DESTROY `major YOC surface and sub-surface combatants` and `SOF insertion platforms`

DESTROY `SAMs` beyond 100km of the DMZ

Assist in holding defense north of capital city by DESTROYING `YOC non-hardened artillery and vehicles`

ATTRIT `Naval Bases` and their Employment Capability

DESTROY enemy `OCA assets`

YOC supply, storage & repair facilities DESTROY `TBM launchers, storage, and support`

DISRUPT `TBM shipment/transshipment`

DISRUPT `resupply` of naval POL, munitions, & spares

DESTROY `ammo storage`

DESTROY `naval ship repair` & `resupply facilities`

Disrupt naval surface craft bases, support facilities, and naval C3I. This objective has been divided into 3 objectives: DISRUPT `naval surface craft bases` and DISRUPT `support facilities` are categorized under **Fielded forces**, while disrupting naval C3I is categorized under **Leadership**.

DISRUPT `marshalling areas` and `sustainment capability` beyond the FSCL

DISRUPT `marshalling areas, supply, and corps C2 beyond FSCL`

Blue forces *Employ passive defensive measures.* Rephrased to: ASSIGN and PROVIDE `military equipment` which is capable of passive defense.

PROVIDE `ground/naval point defense` for protection of Blue COGs from air & TBM attacks

CONDUCT CAS in support of the `Rear Area Security Forces`

Support B/G ground scheme of maneuver and deception plan through AI. Rephrased to: PROVIDE `AI` to support B/G ground scheme of maneuver and deception plan.

High level objectives The following were listed as air tasks, but are more appropriately categorized as either CinC objectives or Air Objectives.

Disrupt YOC ability to employ weapons of mass destruction (WMD). This is almost identical to Air Objective B8.2, and it belongs at the Air Objectives level.

DISRUPT Employment of `Weapons of Mass Destruction` by YOC Forces

DISRUPT `military activity` in the area of the planned NEO

DESTROY `command centers and comm nodes` to disrupt YOC political direction of armed forces

Unclassified DESTROY `RADRELs` – unknown abbreviation

EMPLOY `SIGINT collection assets` – unknown abbreviation

EMPLOY `HVAA assets`/Provide adequate HVAA protection – unknown abbreviation

C.5 Centers of Gravity

The centers of gravity which have been elicited from the sets of objectives have been categorized into hierarchies. These hierarchies are shown below. The aim of producing these hierarchies is to permit a near-exhaustive approach to identification of centers of gravity. By working from the top of a hierarchy downwards, planners can easily identify if they have considered all relevant categories of centers of gravity.

The 5 top level centers of gravity in these hierarchies are `Leadership`, `Key Production`, `National Infrastructure`, `National Population` and `Fielded Forces`. These correspond to Col. Warden's "5 rings" approach to identification of centers of gravity. The approach which has been taken to developing these hierarchies is top-down extrapolation; that is, if there are several centers of gravity at the same level of a hierarchy, and one of them is decomposed in a certain way, then the others are assumed to be decomposable in the same way. An example of this can be found in Figure 47, which shows centers of gravity connected with transportation. Since road, rail, inland waterways, coastal shipping and civil air transport are all transportation *networks*, then the hierarchy assumes that the key centers of gravity for all these types of transportation can be categorized as *nodes*, *choke points* or *segments*.

A key component of the hierarchies which contributes to the goal of identifying all relevant centers of gravity is the identification of *intra-hierarchy links*. These show where a center of gravity in a different part of the hierarchy is relevant to the current center of gravity. The name of the related hierarchy is displayed in the bottom half of the CoG node. For example, one form of communication is by newspapers and printed media; the distribution of these requires transportation. A planner examining the **segments** of the newspaper communication network would therefore be directed to look at the centers of gravity for the appropriate type(s) of **transportation**.

Following these intra-hierarchy links may lead to the identification of unexpectedly relevant centers of gravity. To take an example based on real life, a planner who was attempting to prevent a large army of tanks from invading would examine the hierarchy for **Fielded Forces**, and would discover "Logistics" as a center of gravity. In this category, he would be invited to consider **Ammunition**, **Fuel**, **Spare Parts** and **General Munitions**. On examining Fuel, he might decide that fuel **storage** is a potential center of gravity; but not only is it difficult to attack, it is also an inadequate supply for a large army of tanks. This inadequacy suggests that the other possible source of fuel – a supply line – should be considered.[12] Here an intra-hierarchy link applies; the fuel is either supplied by transport vehicles (in which case a link must be made to **National Infrastructure: Transportation**) or, as in this case, it is supplied by pipeline, in which case the appropriate starting point is **National Infrastructure: Fuel**. Since fuel pipelines form a network, then **nodes**, **choke points** and **segments** must be considered. The segments in a fuel network are pipelines; it turns out that there are only 5 pipelines used for pumping fuel to these storage areas, which makes the pipelines a possible center of gravity. However, fuel pipelines are hard to attack and easy to repair. The nodes in the network are the input fuel plants and the storage areas, which are either too heavily defended or too far away to consider. The consideration of choke points, however, leads to the identification of three (undefended) pumping stations at a point where the gauges of the fuel pipes change, thus ensuring that all fuel is routed through these three stations.

[12] In fact, there are two other possible sources of fuel; direct access to a fuel production plant, and siphoning it from other vehicles. The former is unlikely to avoid notice, and the latter is infeasible for a large army, even if they were not using specialized fuel.

Observations

1. The centers of gravity which are identified in the different types of objectives correlate fairly closely with the different levels of the hierarchies. Most of the centers of gravity identified in the CinC objectives appear in the third level of the hierarchy (e.g. `national roadways`; most centers of gravity identified in the air objectives appear in the fourth level of the hierarchy (e.g `choke points`); and most centers of gravity identified in the air tasks appear in the fifth level of the hierarchy (e.g. `bridges`).

2. While the planners do identify Blue Centers of Gravity as well as hostile and adjoining Centers of Gravity, there is evidence that Blue Centers of Gravity are not considered in the same level of detail. The centers of gravity identified for Blue in the CinC objectives (e.g. "sustain `forces` for a minimum of 45 days") and in the air objectives (e.g. "deploy `forces`") belong to the first or second levels of the hierarchies of centers of gravity. In addition, the actions applied to these centers of gravity imply a higher level of abstraction; for example, sustaining a force implies supplying all the needs of that force, which implicitly requires a complete infrastructure to be established for that force (bringing in fuel, taking out casualties, etc). `Infrastructure` is one of Col. Warden's "5 rings", and can therefore be found at the top level of the hierarchy of centers of gravity. Similarly, deploying a force requires considerable attention to be paid to the transportation requirements of that force[13] including but not limited to military air transport; `transportation` is a 2nd level center of gravity.

   It would seem sensible (if time is available) for the planners to analyze Blue centers of gravity to the same level of detail as hostile and adjoining centers of gravity (if possible), to the level of identifying likely targets for any hostile and adjoining planners who might be conducting a similar exercise.

[13]This assumes that deploying a force refers to the movement of a force into the battleground, as opposed to allocating new units to the theatre.

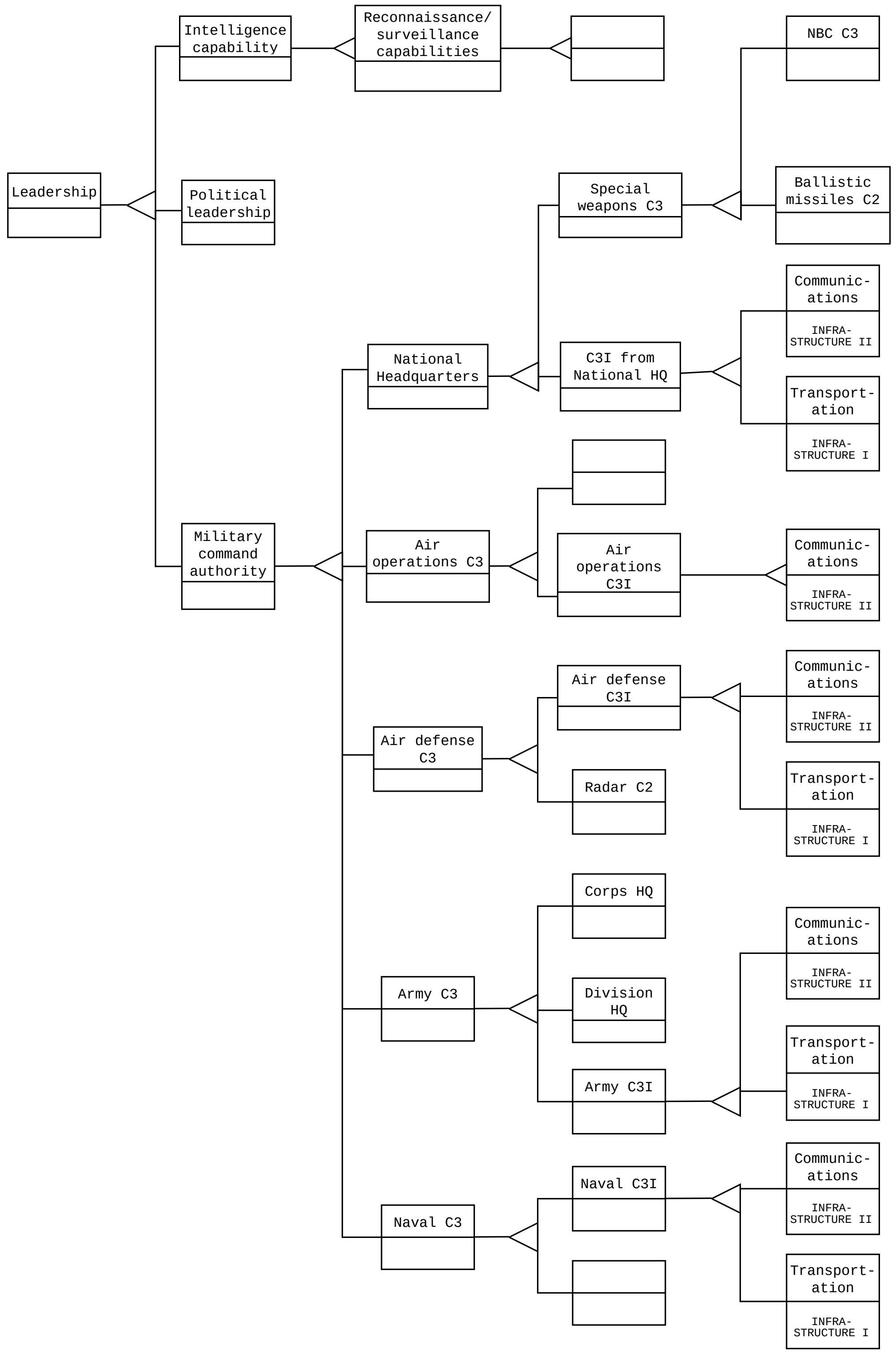

Figure 44: CoGS: Leadership

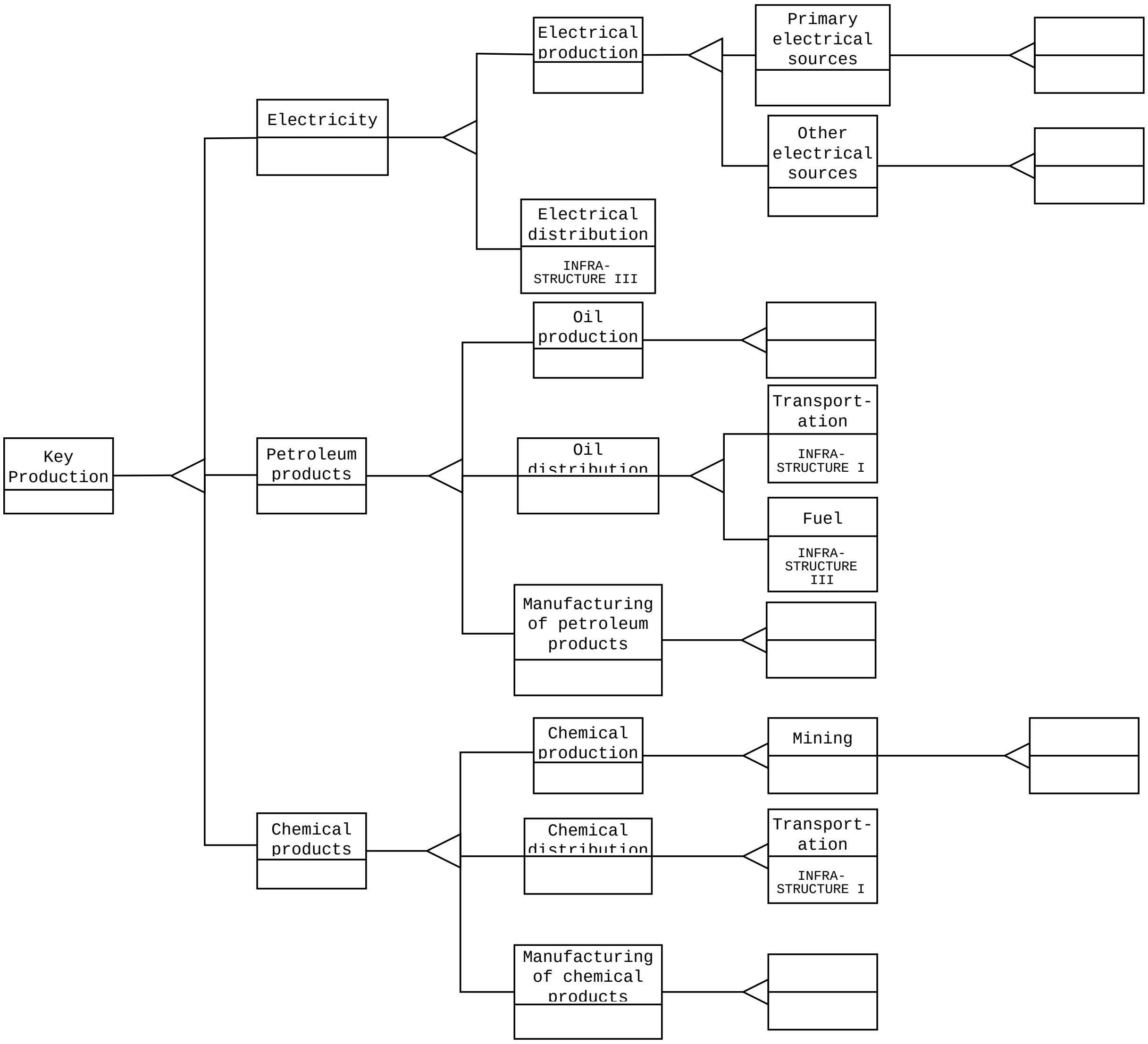

Figure 45: CoGS: Key Production 1: General

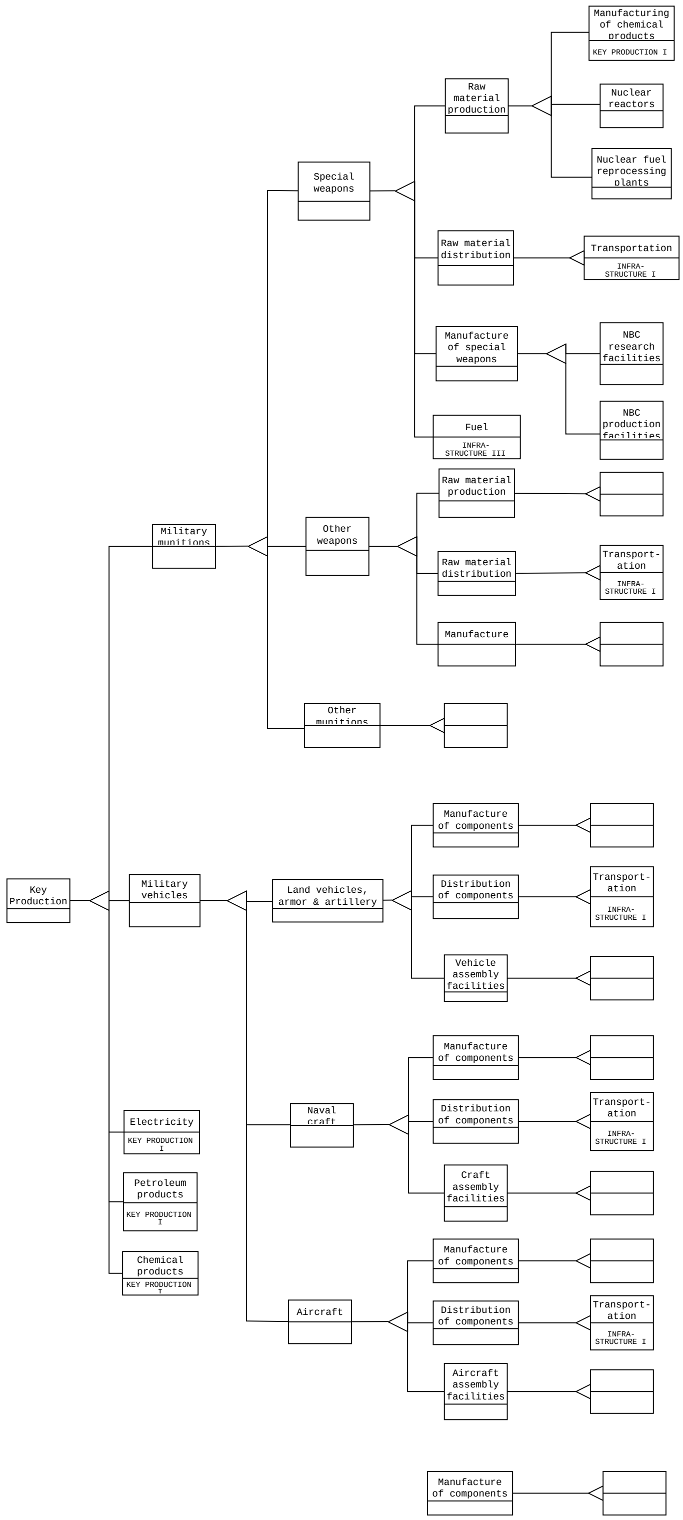

Figure 46: CoGS: Key Production 2: Military

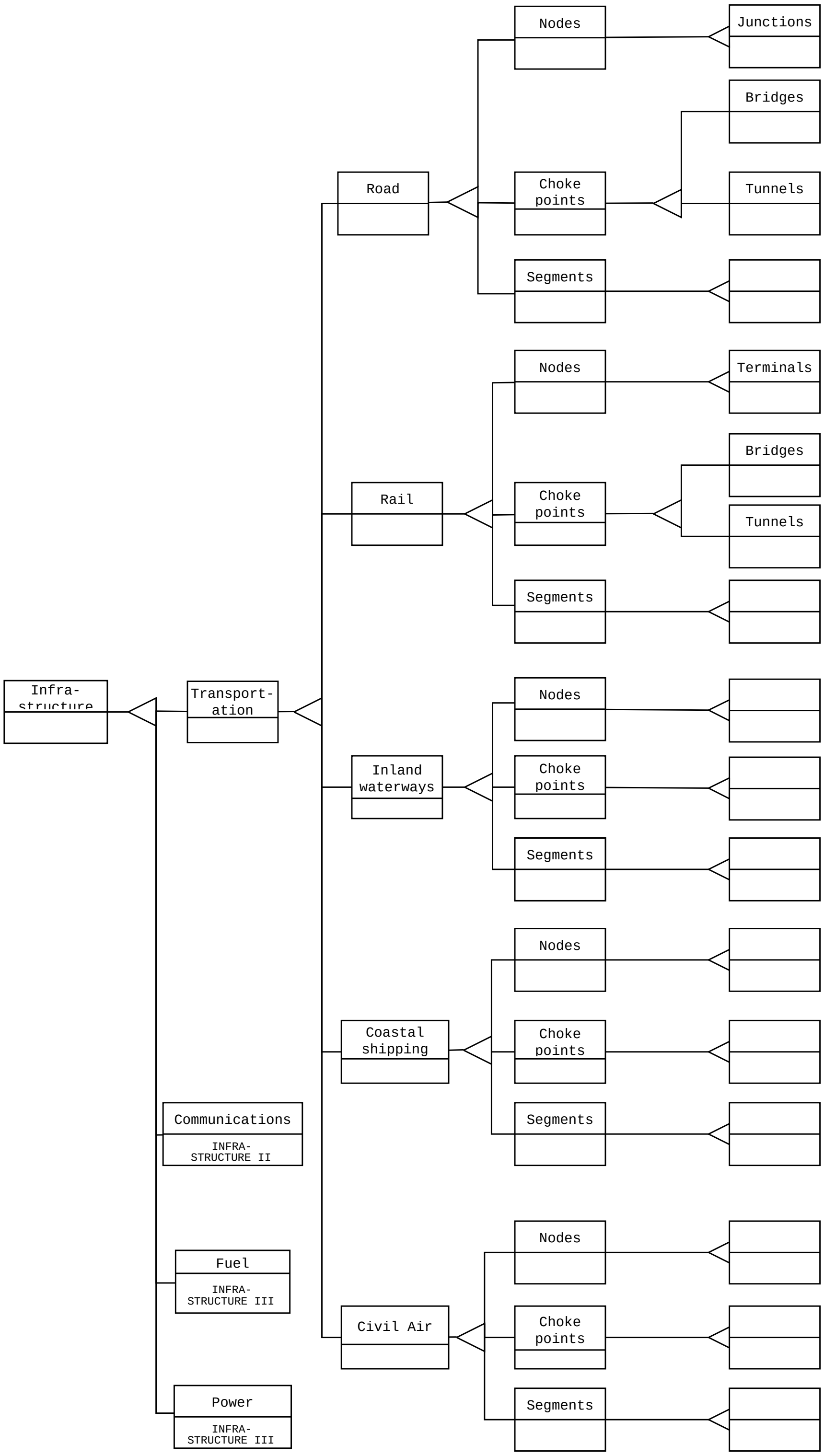

Figure 47: CoGS: National Infrastructure 1: Transportation

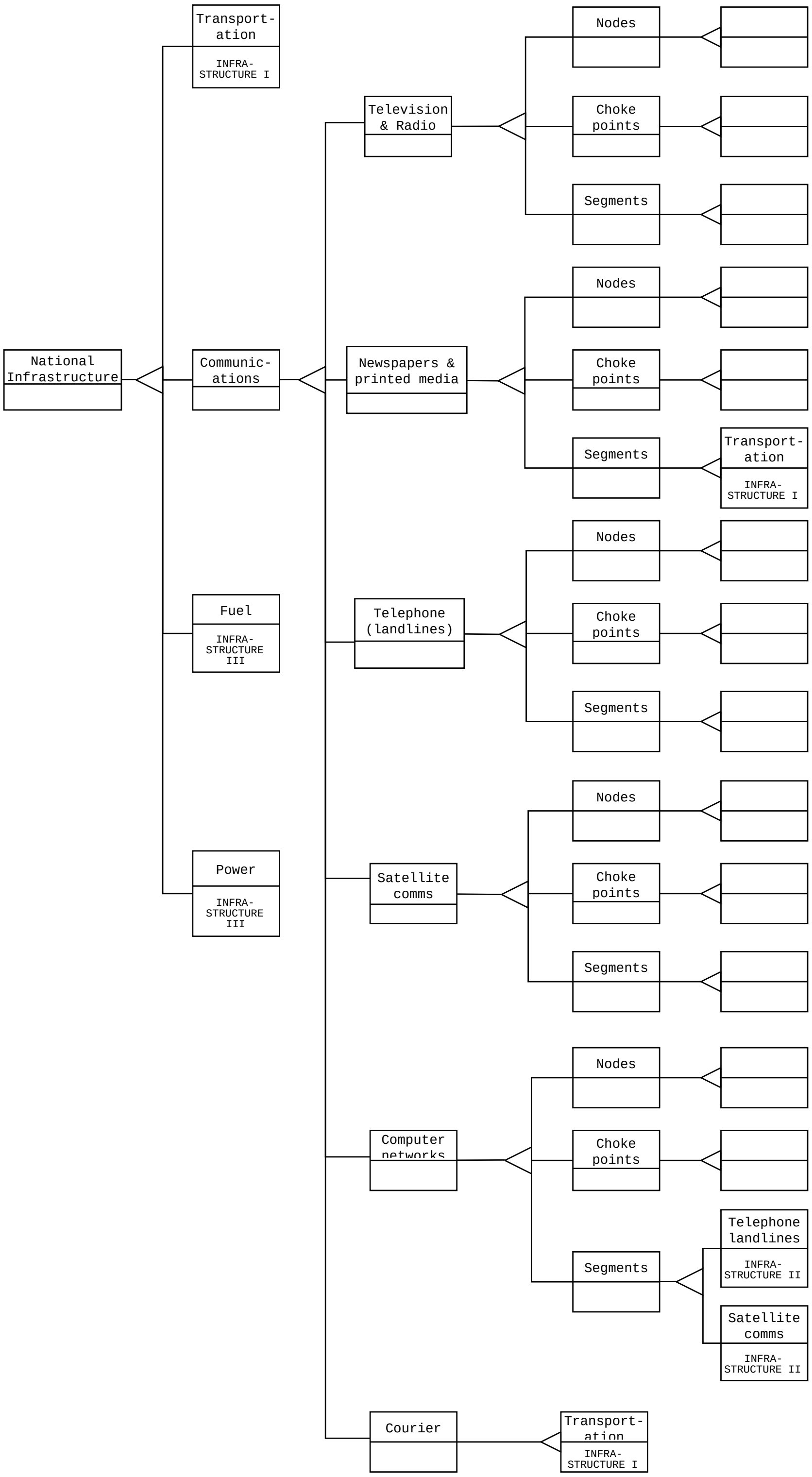

Figure 48: CoGS: National Infrastructure 2: Communications

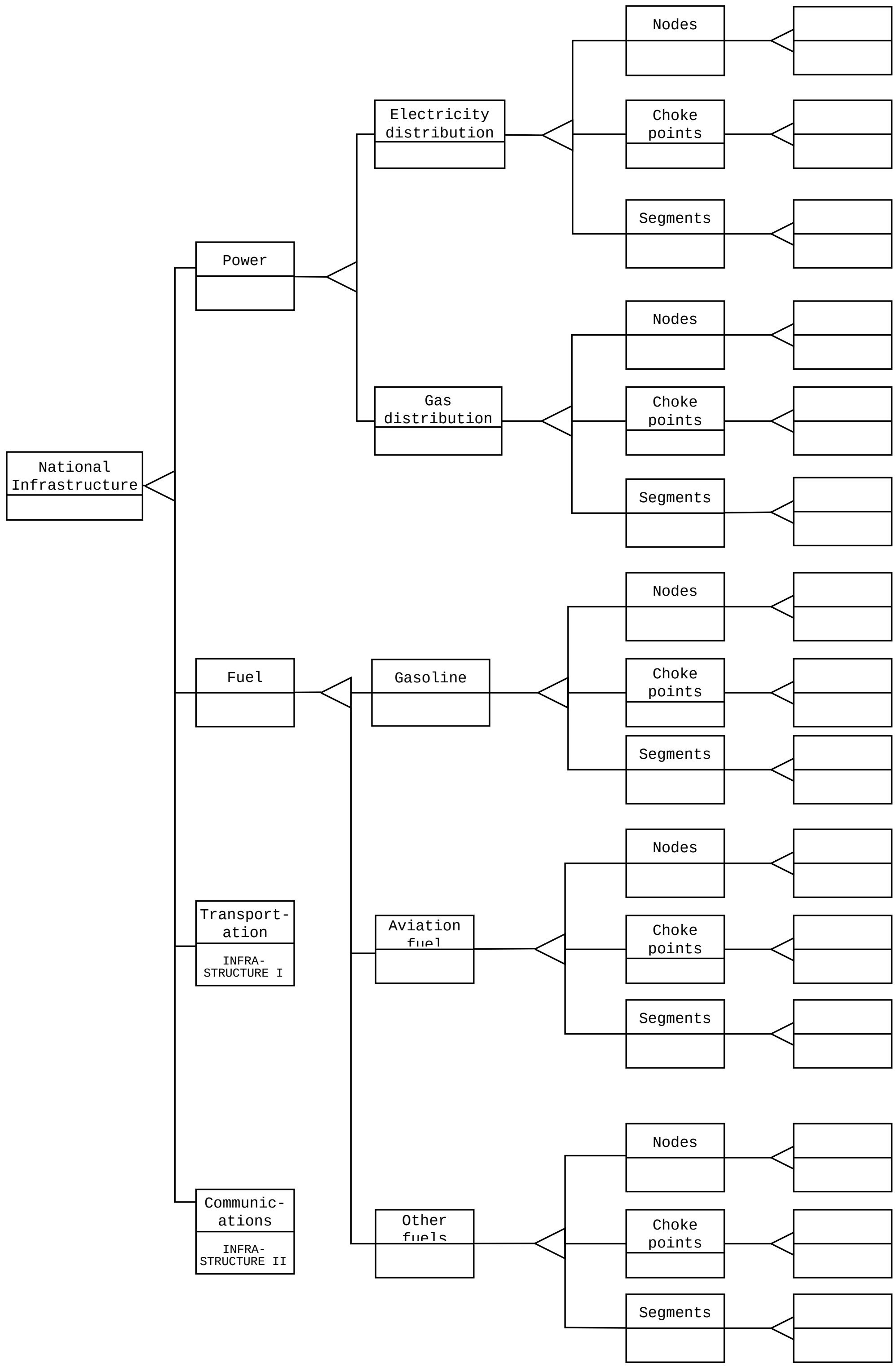

Figure 49: CoGS: National Infrastructure 3: Fuel & Power

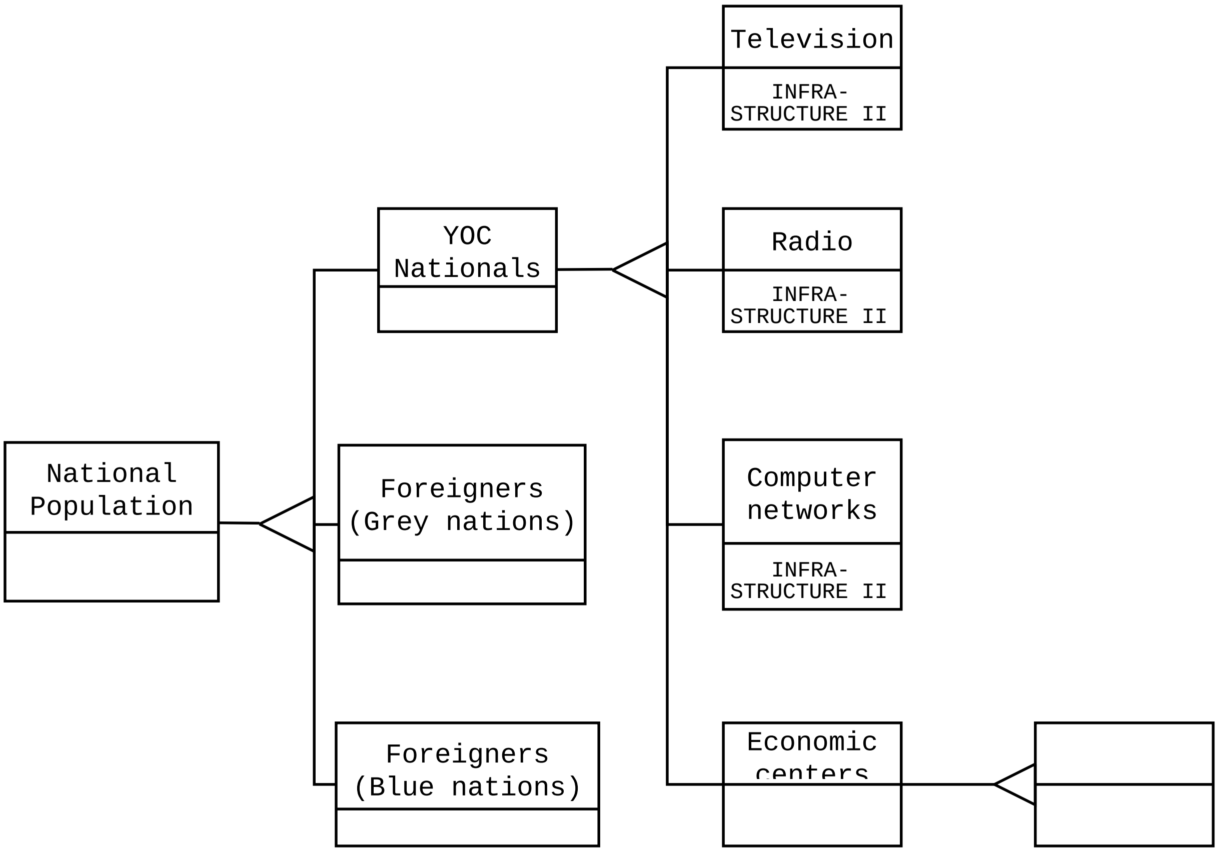

Figure 50: CoGS: National Population

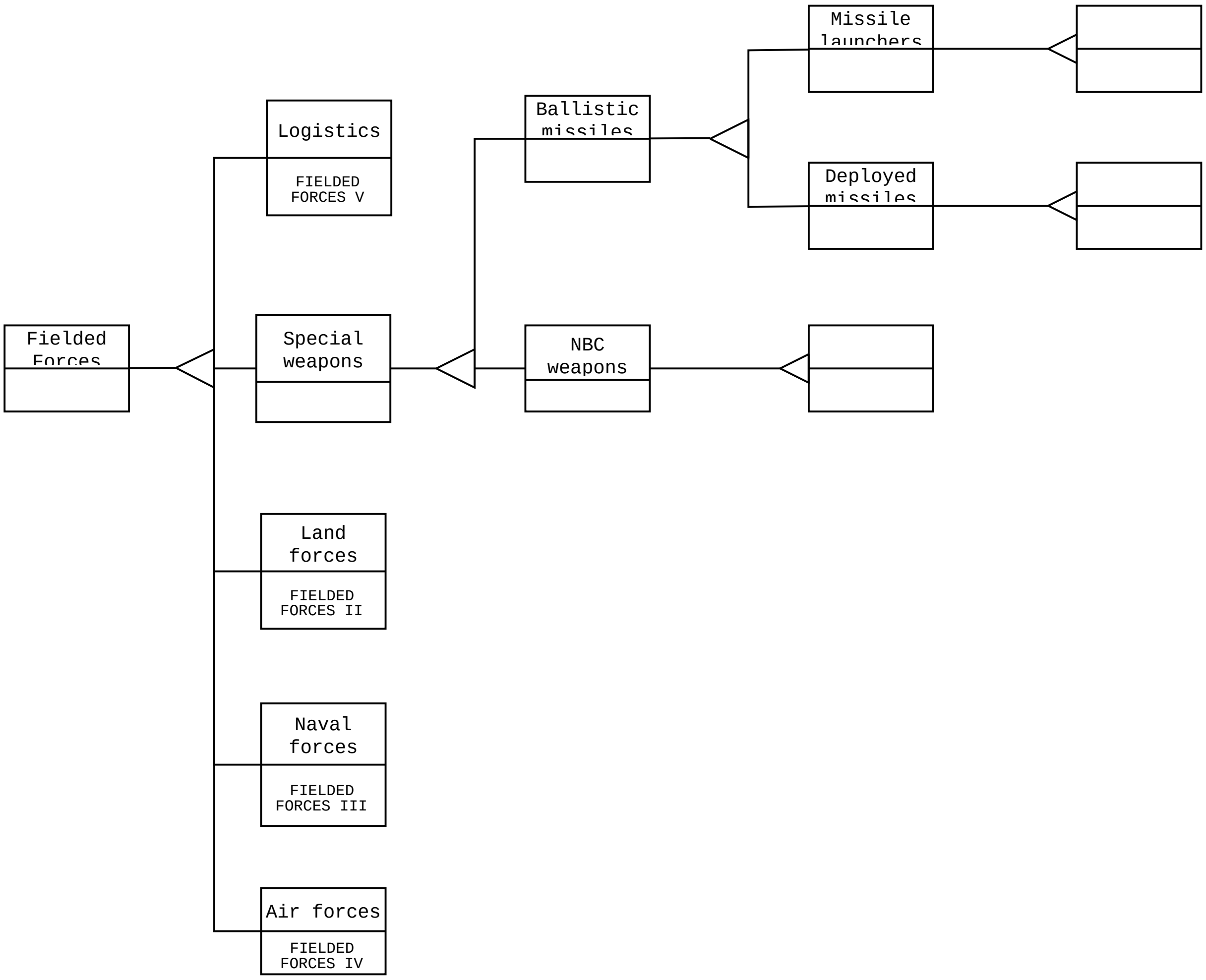

Figure 51: CoGS: Fielded Forces 1: Special Weapons

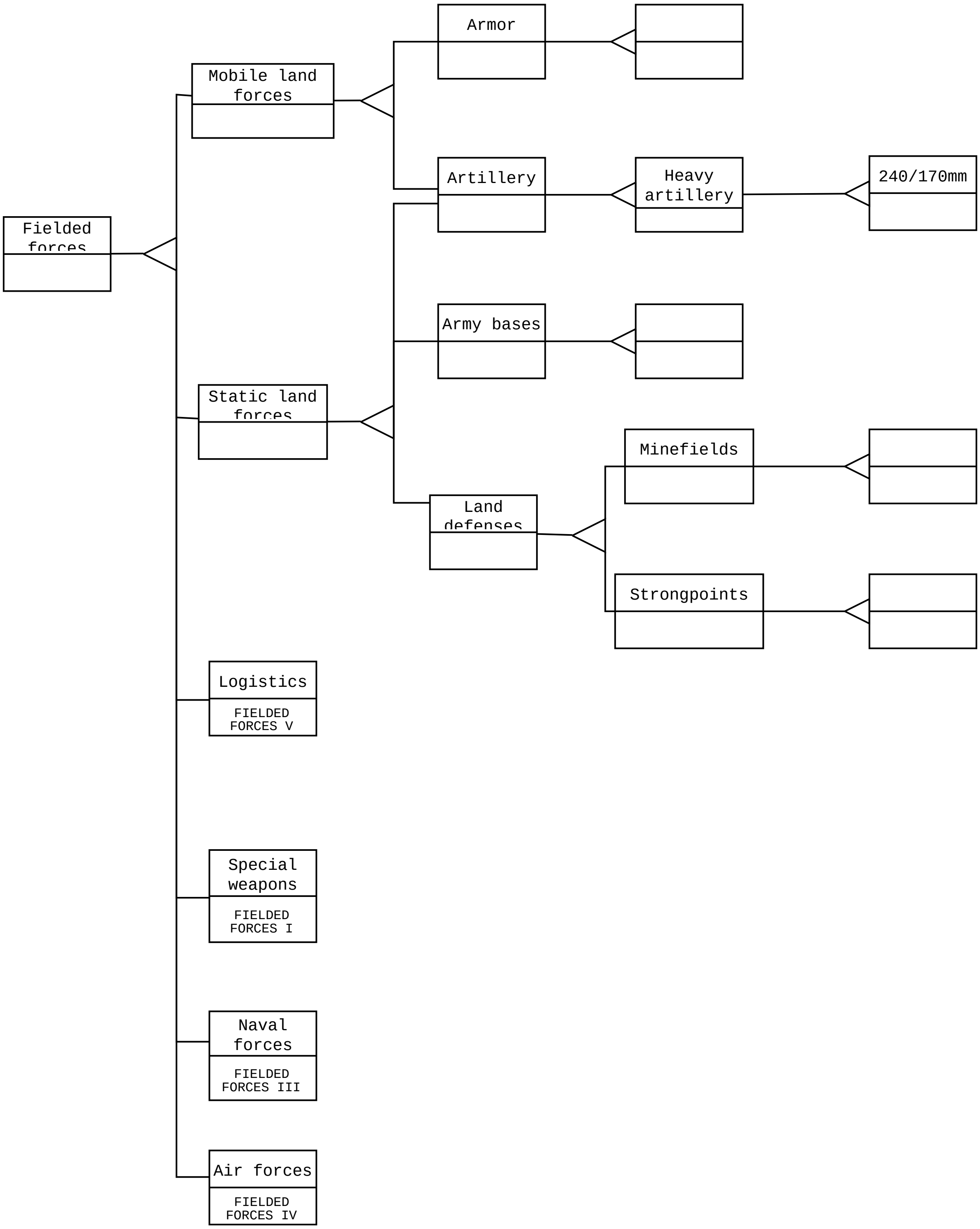

Figure 52: CoGS: Fielded Forces 2: Land forces

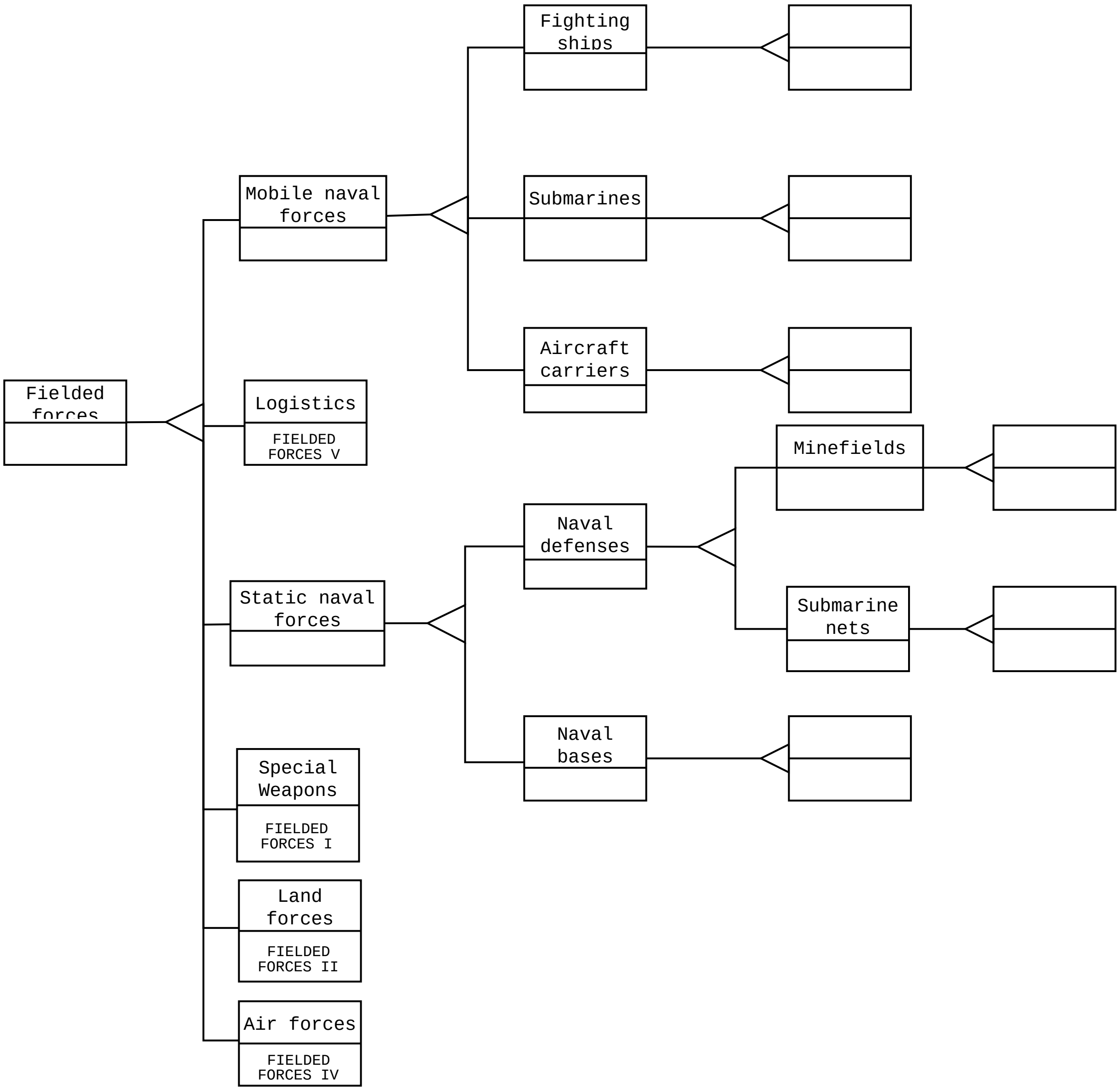

Figure 53: CoGS: Fielded Forces 3: Naval forces

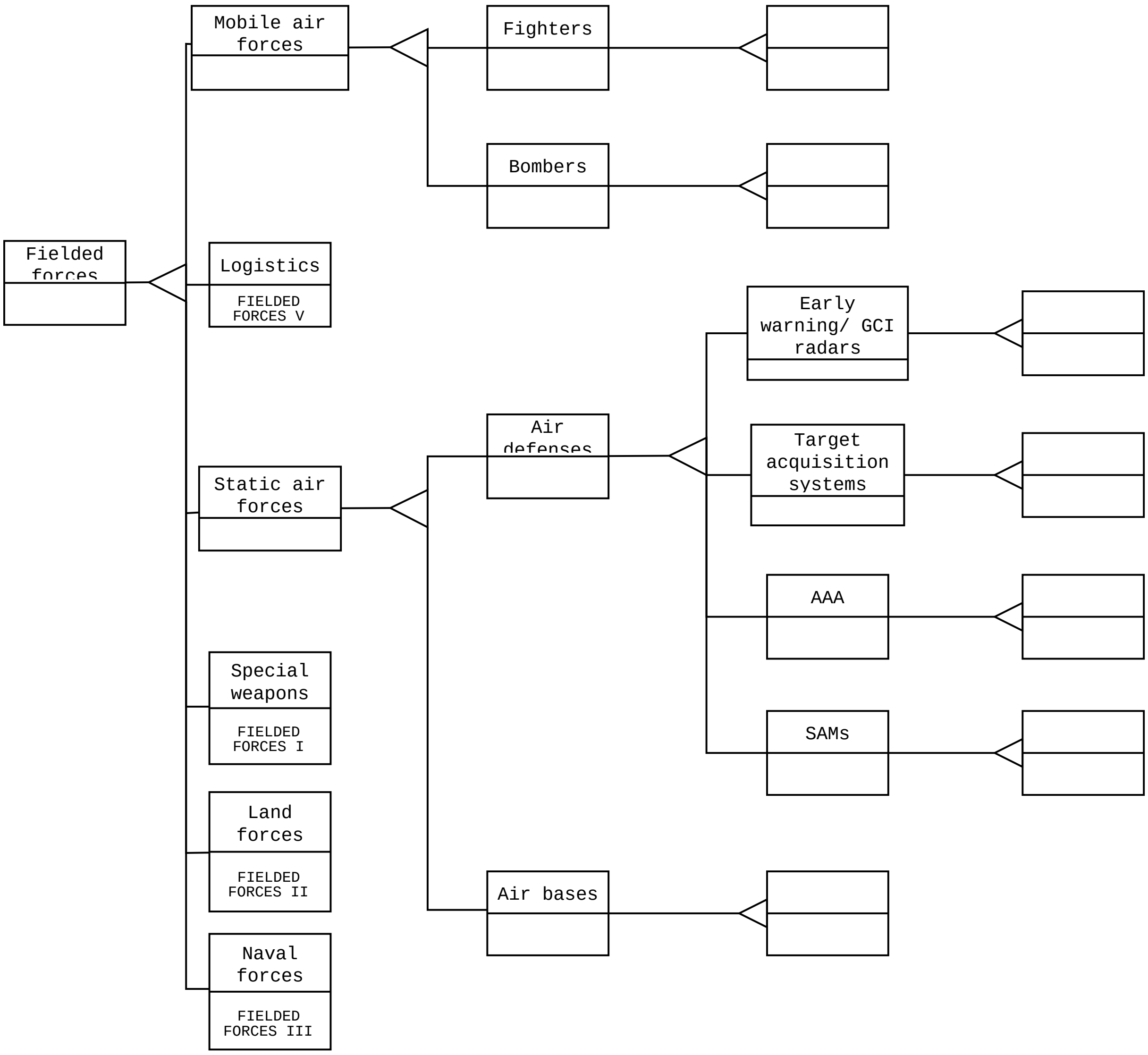

Figure 54: CoGS: Fielded Forces 4: Air forces

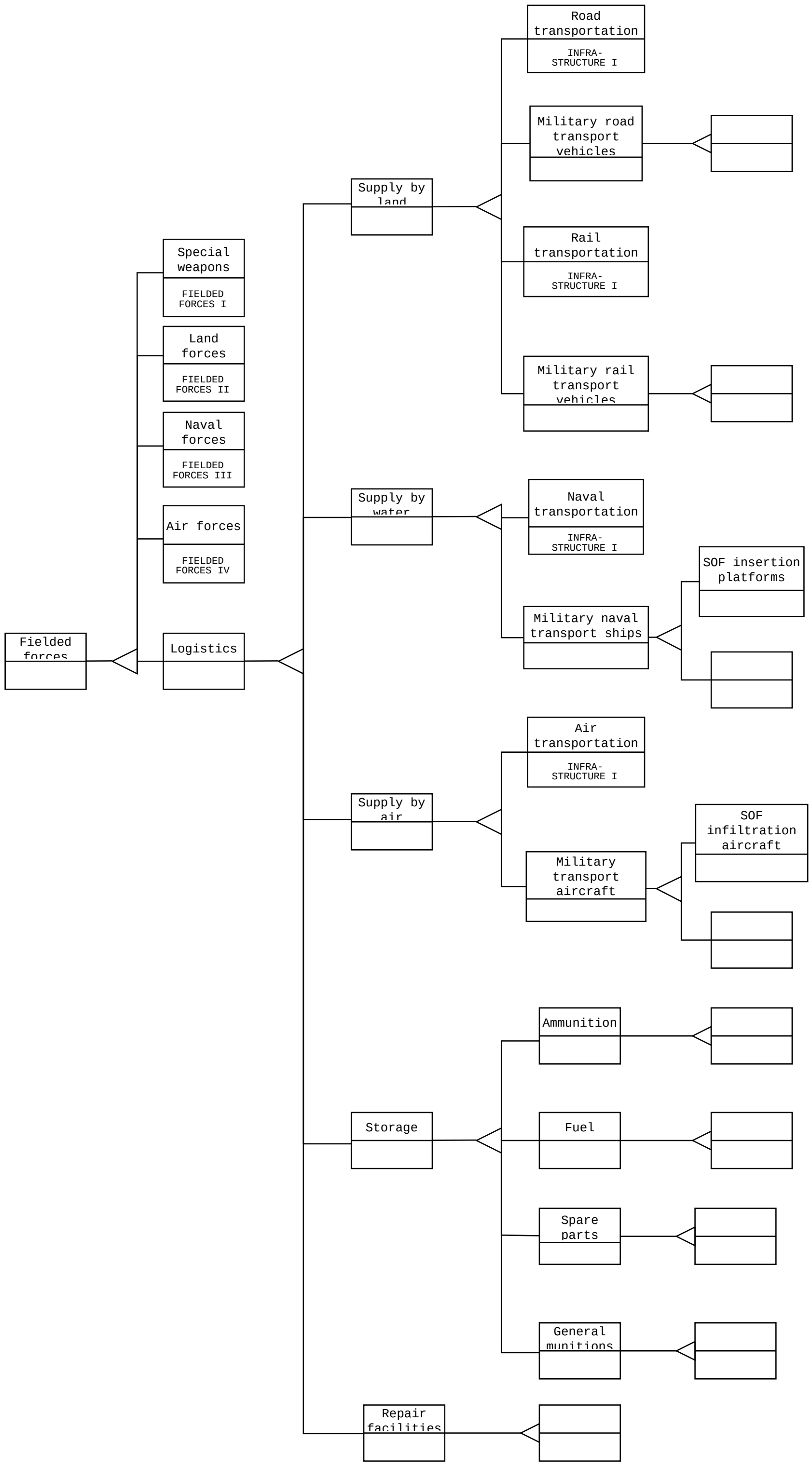

Figure 55: CoGS: Fielded Forces 5: Logistics

C.6 Actions

The actions listed here are those found in air objectives (whose format is "Perform ACTION on *center of gravity* with `modifier`"). The actions identified are listed below. The observations which were made on actions are likely to be superseded by current discussions, so have not been included in this document.

The actions identified are as follows:

- CinC Objectives
  - Leadership
    - Isolate;
    - Neutralize;
    - Protect
  - Key Production
    - Deny use;
    - Neutralize
  - National Infrastructure
    - Deny use;
    - Interrupt;
    - Obtain;
    - Permit use;
    - Sustain
  - National Population
    - Deny use;
    - Conduct NEO;
    - Neutralize;
    - Use
  - Fielded forces
    - Deter;
    - Defend;
    - Disrupt;
    - Stop
- Air Objectives
  - Leadership
    - Isolate;

    * Disrupt;
    * Degrade;
    * Destroy
  - Key production:
    * Disrupt;
    * Destroy
  - National Infrastructure
    * Drive (i.e. compel to move);
    * Disrupt;
    * Attack;
    * Deploy.
  - National Population
    * *Disrupt*[14]
  - Fielded forces
    * Disrupt;
    * Destroy

- Air Tasks
  - Leadership
    * Sever;
    * Disrupt;
    * Disable;
    * Neutralize;
    * Render ineffective;
    * Destroy;
    * Exploit;
    * Provide.
  - Key production:
    * Disrupt;
    * Attrit;
    * Destroy
  - National Infrastructure

[14] No air objectives are specified for national population. This action is specified because NEUTRALIZE appears in the CinC objectives, and so an analogy can be drawn with the Leadership and Key Production objectives.

    * Disrupt;
    * Destroy
- National Population No air tasks specified.
- Fielded forces
    * Disrupt;
    * Attrit;
    * Neutralize;
    * Destroy;
    * Provide;
    * Conduct CAS.

C.7 Modifiers

Many CinC objectives and Air objectives, and some air tasks, have associated modifiers. These modifiers may be:

- geographical (e.g. "Destroy SAMs **beyond 100km of the DMZ**");
- temporal (e.g. "Sustain (Blue) forces **for a minimum of 45 days**");
- categorical (e.g. "Deny use of national roadways for the transport of **military equipment**");

Lists of identified modifiers can be seen in table C.7 and table 4.

Observations

The modifiers are diverse, but a few patterns can be seen:

- The distinction between **military** and **civilian** is frequently drawn. Typically, the actions specified will have stronger effects on the military than on the civilian population. For example, objectives exist to DENY USE of national roadways, railways and waterways for transporting military equipment, but only to DISRUPT the flow of goods. However, in some cases (e.g. disrupting communication networks), it is necessary to cause equal disruption to both the military and the civilian populations. It is common for the planners to avoid deliberately targetting the civilian population, since past experience suggests that it does more harm than good.

- Another distinction which appears to be important is the distinction between **weapons of mass destruction** and other weapons. This is reflected in the hierarchies of centers of gravity, where "special weapons" (i.e. nuclear/ biological/ chemical weapons and ballistic missiles) are treated separately from other weapons.

- In the higher level objectives, the majority of geographical modifiers are concerned with fielded forces, and their locations in relation to battlegrounds and demilitarized zones. However, there are also some concerns related to the whole region, typically connected with evacuation of U.S. civilians and other non-combatants.

Geographical	
`US citizens`	in the region
`US forces`	in the region
`YOC aggression`	against B/G
`YOC forces`	north of Desired Area
`B/G`	(a geographical modifier is implicit in the CoG)
Temporal	
`YOC economic centers`	to slow the flow of military resources i.e. until the flow of military resources is sufficiently slow
Categorical	
`YOC political control` `YOC military control`	YOC armed forces

`YOC political control`
`YOC military control`
`primary electrical sources`
`petroleum products`
`national television systems`
`national radio systems`
`national computer systems`
	YOC population

`national roadways`
`national railways`
`national waterways`
	Transport of military equipment

`national roadways`
`national railways`
`national waterways`
	Transport of goods

`national communications networks`
`national television systems`
`national radio systems`
`national computer systems`
	Transmit military information

`YOC petroleum production`	supporting warfighting effort
`chemical products`	for the manufacture of weapons of mass destruction.
`national waterways`	for Blue shipping.
`national transportation networks`	leading to YOC economic centers.
`Blue forces`	Against Weapons of Mass Destruction

Geographical	
Temporal	
Categorical	
YOC political control YOC military control electrical facilities petroleum production chemical production?	YOC armed forces
YOC political control YOC military control electrical production petroleum production chemical production	YOC population
naval transport ships	which are capable of transporting military equipment on national waterways.
command and control	YOC Air/Land/Sea forces
Capability	
(Blue) forces	capable of deterring YOC aggression
(Blue) forces	capable of supporting NEO

Table 4: Modifiers: Air Objectives Level

D The CommonKADS methodology

D.1 Organizational Model

The CommonKADS organizational model recommends examination of an organization from five major perspectives:

- the **activities** of the organization;
- the **structure** of the organization;
- the **processes** in the organization;
- the **power/authority** in the organization;
- the **resources** in the organization.

Each perspective is represented by a single diagram, or by text. These five perspectives can be combined into cross-products which provide the most useful information. For example, the CommonKADS Organizational Model was used to model a Social Security department; a cross-product of activities and structure was produced which highlighted an area of inefficiency, because one of the activities (archiving) was being performed by three different divisions of the department [deHoog *et al*, 1993].

D.1.1 Enriching the CommonKADS Organizational Model for the ACP domain

The process of domain familiarization also suggested that some aspects of the organization surrounding ACP – in particular, power/authority relationships – would benefit from being represented in more detail than the CommonKADS Organizational Model currently supports. It was decided that the multi-perspective approach to organizational modelling would be maintained, but that the perspectives would be altered to permit the representation of rights of access to resources and information, and the representation of who was responsible for performing which activities. This distinction was derived from the ORDIT project which is intended to support organizational requirements definition [Dobson & Strens, 1994]. The result was that a set of perspectives were developed based on three basic entities: *activities*, *agents* and *resources*. Figure 1 shows the perspectives which were used, and how they were combined.

D.2 Task model

The Task model shows the tasks carried out in the course of a particular process. If the organizational model indicates a particular function which might usefully be automated, a task model can be produced which provides a detailed description of the tasks which carry out that function. The task model may also identify the inputs and outputs of each process (or task), and the decomposition of tasks into more specific sub-tasks. Its purpose is to allow identification of tasks which could usefully be performed by an automated system, or by a program and a user working in conjunction.

A typical task model is shown in Figure 56, using the graphical format which was originally specified in [deGreef & Breuker, 1992]. The model represents the tasks involved in the preparation of a meal; such a model might be used by a large restaurant or a hotel which was considering a reorganization of its business.

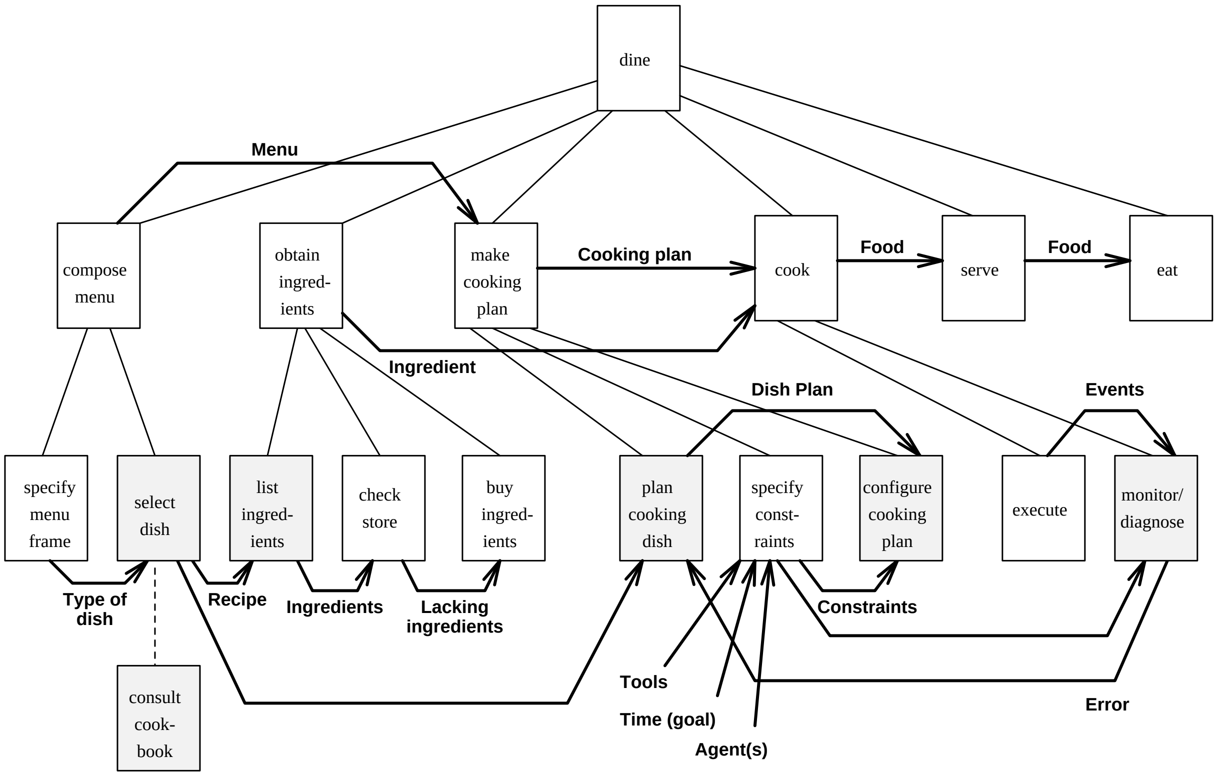

Figure 56: Task model: preparing a meal

In this diagram, the boxes represent tasks; the arrows represent inputs and outputs of tasks; the lighter lines show the decomposition hierarchy of tasks; and the shading indicates those tasks which are worth considering for implementation using a computer system.

D.3 Agent Model

The Agent model represents the capabilities required of the agents who perform a process, and constraints on their performance. The agent model represents all the agents which participate in a problem solving process. It is often useful to develop two agent models: one which is based on the task model, showing which agents are currently involved in performing particular tasks, and one which predicts the agents and capabilities required to carry out future tasks.

An example of an agent model, using the graphical format suggested by the CommonKADS Workbench, is shown in Figure 57.

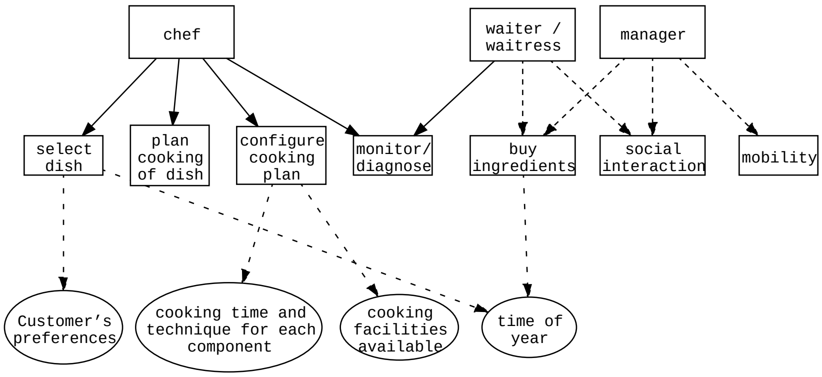

Figure 57: Agent model: Preparing a Meal

D.4 Communication Model

The Communication model shows the communication required between agents during a process; it may also specify the form of messages, and specify who takes the initiative in a transaction. The communication model indicates all the transactions which take place between different agents. Normally, this will comprise transactions between a knowledge based system and other agents. It is therefore often convenient to combine the Communication model with the Agent model.

An example of an communication model, using the graphical format suggested in the KADS-II report on the CommonKADS Communication Model ([Waern *et al*, 1994]) is shown in Figure 58.

D.5 Expertise Model

The Expertise model is a model of the expertise required to perform a particular task. This model is divided into three components:

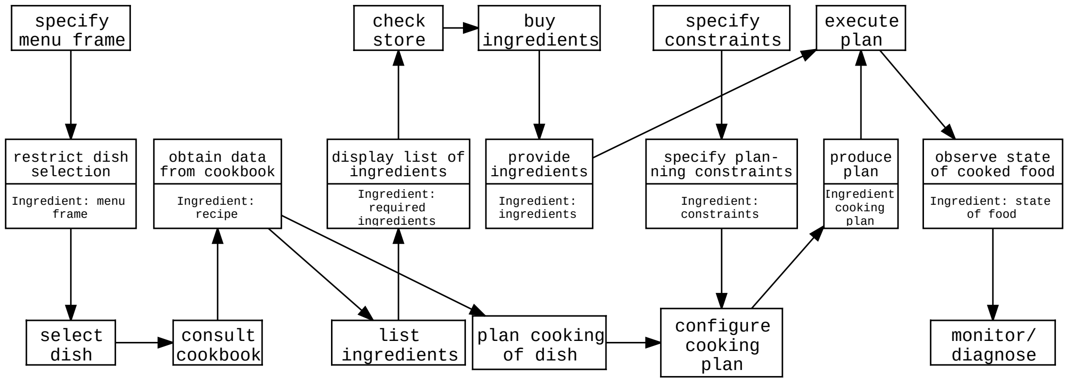

Figure 58: Communication model: Preparing a Meal

- declarative knowledge about the domain;
- the inference processes required during problem solving;
- a task structure specifying the hierarchical decomposition and ordering of the inference processes.

D.5.1 Expertise Model: Domain Level

The domain knowledge in the model of expertise represents the declarative knowledge which has been acquired. CommonKADS suggests that each item of declarative knowledge is classified into one of the four categories outlined below:

- **Concepts**: classes of objects in the real or mental world of the domain studied, representing physical objects or states;
- **Properties**: attributes of concepts e.g. *colour*.[15]
- **Expressions**: statements of the form "the *property* of *concept* is *value*";
- **Relations**: links between any two items of domain knowledge.

Once items of domain knowledge have been classified, they can be used in *domain models*, which show relations between different items of knowledge. For example, a domain model might show all acquired examples of one concept **causing** another; or it might show a taxonomic hierarchy of concepts, connected to each

[15]CommonKADS also supports *attributes*, which are properties which can belong to multiple concepts, and which are defined independently from concepts for convenience. *Weight* might be an example of a CommonKADS attribute.

other by **is-a** relations. Figure 59 shows an example of a domain model; this model represents indicative relationships between certain symptoms of a manufacturing machine, and possible faults with that machine.

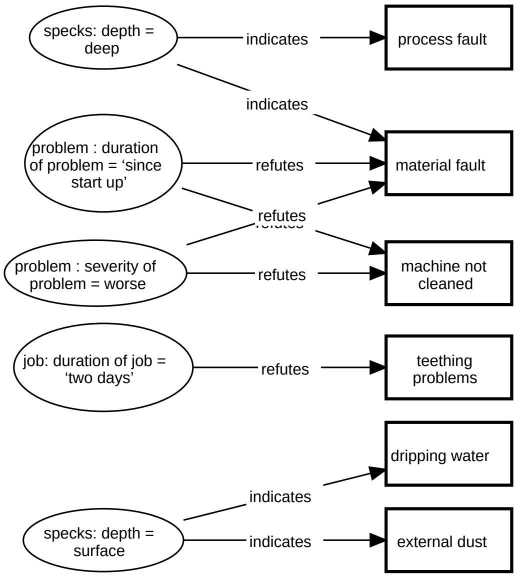

Figure 59: A domain model which links expressions with concepts

CommonKADS also recommends that the domain knowledge is represented at a more abstract level, at which generic statements about the structure and contents of domain models are expressed. The terms used at this abstract level are stored in a *model ontology*, and the statements at this abstract level are known as *model schemata*. This abstraction is intended to form a basis for re-using domain models in different problem solving situations.

The domain knowledge in the CommonKADS Expertise model therefore consists of a *domain ontology* (i.e. a collection of classified terms) and a number of *domain models* which represent relations between items from the domain ontology. In addition, it is recommended that an abstract view on the domain knowledge is created.

D.5.2 Expertise Model: Inference Knowledge

The second subdivision of the Expertise Model records knowledge about inference which may be performed in order to solve a problem. This information is represented in *inference structures*, which are diagrams showing how various **inferences** and **knowledge roles** link together to perform problem solving.

Both KADS-I and CommonKADS provide a library of generic inference structures, indexed by the type of task which is being performed (classification, diagnosis, configuration, etc.). These generic inference structures can be used as a starting point for developing an inference structure for a particular application.

An example of an inference structure can be seen in Figure 60.

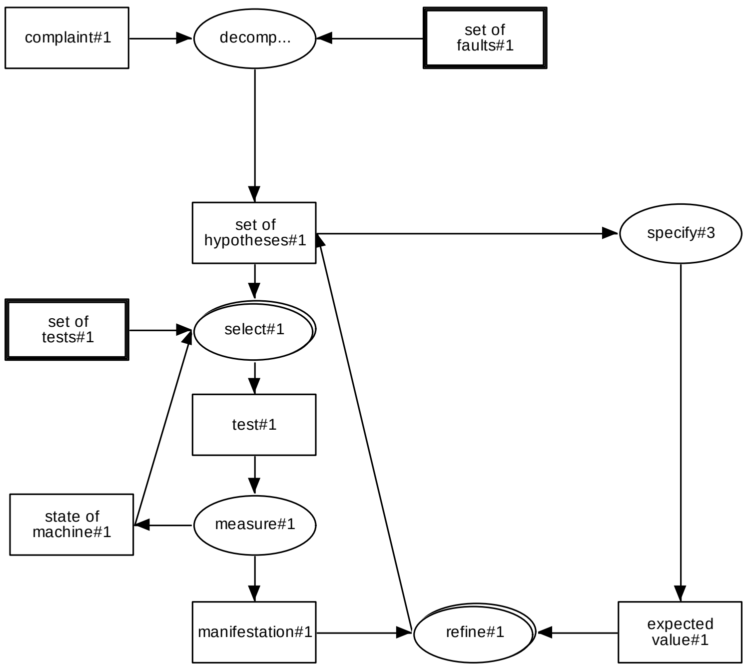

Figure 60: Inference structure: Machine Fault Diagnosis

In this inference structure, machine fault diagnosis is seen as a process of:

1. decomposing a set of possible faults, on the basis of some symptoms, to produce a set of hypotheses about the current fault;
2. selecting a suitable test to narrow down the set of hypotheses;
3. deciding what the expected result of this test would be if any of the hypotheses were correct;
4. performing the test and observing or measuring the result;
5. updating the set of hypotheses, by removing any which do not conform with the result of the test.

The last four steps are performed iteratively until only one hypothesis remains, or until no further tests are available. This inference structure therefore represents the "Sherlock Holmes" approach to diagnosis: by eliminating the impossible, whatever remains must be the truth.

It can be seen that knowledge roles are represented as boxes, and inference steps as ovals; arrows link knowledge roles with inference steps. Variations on the basic graphics include inference steps with a "double oval" (indicating that this inference step is expanded into more detail in a lower level inference structure) and bold outlines on knowledge roles (which indicate that a knowledge role is *static*; that is, the knowledge it represents is not changed in any way during problem solving.

D.5.3 Expertise Model: Task Level

The task level of the model of expertise is normally represented as a graphical hierarchy. However, textual representation is also possible, and can be more informative; see [Kingston, 1993b] for an example.

Task knowledge differs slightly between KADS-I and CommonKADS, because KADS-I has an explicit *strategy* level of knowledge, whereas CommonKADS considers strategic knowledge (now known as *problem solving knowledge*) to be orthogonal to the domain-inference-task decomposition of the Expertise Model. In both cases, however, the task knowledge which needs to be modelled consists of various tasks which have to be performed and actions which have to be achieved, and breakdowns of these tasks into subtasks. In addition, CommonKADS has an explicit category for tasks which pass information to or from the problem solving process (known as *transfer tasks*); a selection of *problem solving methods* (pre-defined generic task structures); and a detailed specification of how tasks should be defined.

An example of a task structure can be seen in figure 61.

This diagram represents a decomposition hierarchy, showing the tasks which must be performed in order to diagnose faults in a machine.

CommonKADS also provides definitions for a library of *problem solving methods* i.e. pre-defined task structures for certain tasks. However, this "library" currently contains very few problem solving methods (cf. [Kingston, 1993a]).

D.6 Design Model

The Design model culminates in the design of a knowledge based system to perform all or part of the process under consideration. The design process in CommonKADS is broken down into three stages:

- **Application design**: decomposing the Expertise Model into a number of components. Decomposition can be functional, object-oriented, or specific to a particular AI paradigm (e.g. blackboard systems).

- **Architectural design**: deciding on the AI techniques and representations which would be most appropriate for implementing the different decomposed items.

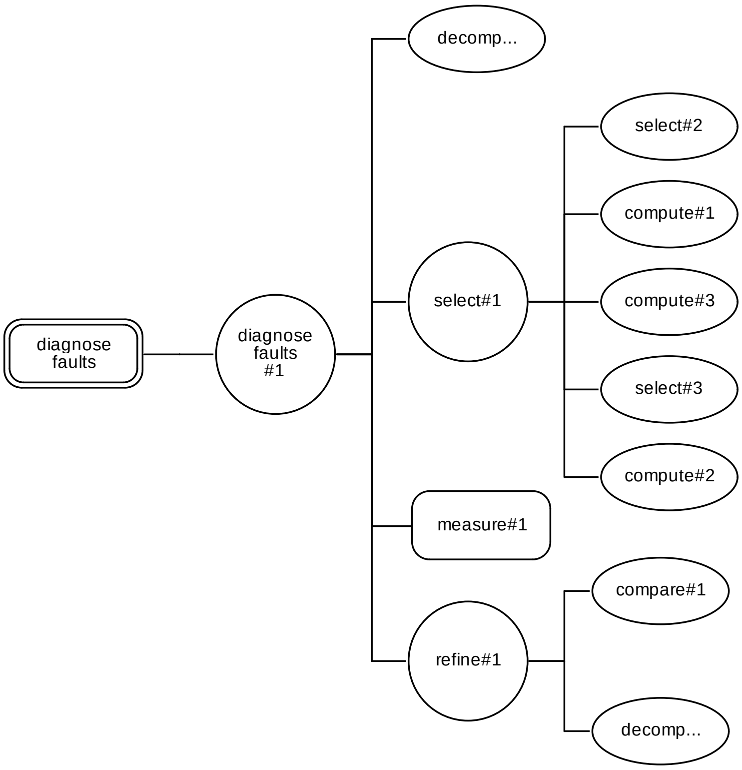

Figure 61: Task structure: Machine Fault Diagnosis

- **Platform design**: deciding how to implement these AI techniques and representations in the chosen programming tool on the chosen hardware.

While it is possible to represent the Application Design (at least) in diagrams, CommonKADS does not recommend any graphical format for the Design Model; instead, it is expected that the different stages of this model will be represented using text. However, during the course of a recent project, a graphical representation for the Design Model was used (see figure 62); the four columns of nodes represent:

- tasks (from the Task Structure of the Expertise Model);
- functional units (the Application Design);
- knowledge representation techniques (the Architectural Design);
- particular knowledge representations and inference techniques (the Platform Design).

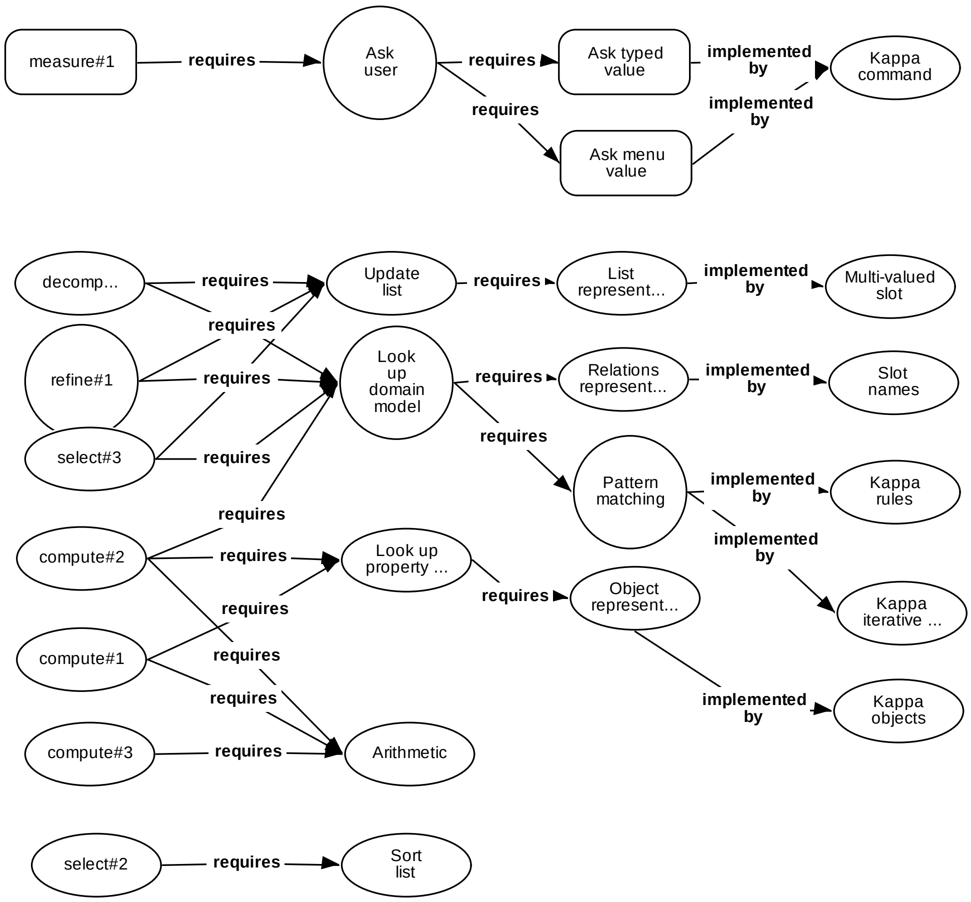

Figure 62: Design model: Diagnosing faults in machinery