An Interoperable Framework for Distributed Coalition Planning: the Collaborative Planning Model

Thomas Klapiscak, John Ibbotson, David Mott, Dave Braines

Emerging Technology Services
IBM UK Ltd, Hursley Park, Winchester SO21 2JN, UK
{klapitom, jbibbotson, mottd, dave_braines}@uk.ibm.com

Jitu Patel

Dstl
UK
jmpatel@mail.dstl.gov.uk

***Abstract*—Planning is a core military activity, which is carried out by a large, culturally diverse, hierarchical and geographically distributed teams each with different specializations. The assumption that a single planning tool is appropriate for all members of the distributed team is no longer appropriate. A representation of the plan together with its associated artefacts is needed so that a shared representation and understanding of the plan can be communicated. In this paper we describe on-going work into the development and evaluation of a collaborative planning model that not only describes the plans and their artefacts, but also provides a representation of the rationale or reasons that the plan is what it is. We describe a software infrastructure under development for managing the planning model and current work on using the model to represent NATO operational planning objects as an interoperable format for linking strategic planning systems to coalition partner specific tools.**

Keywords- Planning, Semantic Representation, Controlled Natural Language, Interoperability

I. INTRODUCTION

Planning is a core activity in any military operation. It typically commences months before the start of operation and continues during operation until it is complete and the warfighters are back from theatre. Over time, planning has moved from a co-located, concurrent, small team activity to an activity that involves a large, culturally diverse, hierarchical and globally distributed team.

Figure 1 shows a simplified model of activity within a planning cell. In response to the Command Intent and working within the given Rules of Engagement and national doctrine and tactics, a planning team within a headquarters would gather necessary data and generate a plan. This plan is then either executed or passed to the sub-headquarters for further detailed planning.

Figure 1: A simple model of activity within a planning cell

For a military operation there would be one coherent campaign plan consisting of a combat plan and a sub-plan for each of the combat support functions. Furthermore, each of the support functions may have their own plan for implementing their support to the combat plan. For example, an Engineer support plan will specify the provision of a bridge at a specified location and time to support the combat plan. The Engineers will also have a separate plan for resources and logistics to ensure the Combat Support plan is effectively and efficiently executed.

Figure 2 illustrates the flow of information between planning teams[1]. A campaign plan, in this example, would consist of PlanA and PlanB. Plans PlanA' and PlanB' are more detailed sub-plans of PlanA and PlanB, respectively. Though a number of different teams, each of which may be distributed, asynchronously develop each of the sub-plans, the overall plan has to be coherent for a successful outcome. Ensuring coherence involves continuous deconfliction of resource usage as well as coordination of where, when and the type of effects to be achieved.

---

[1] This is a simplified model presented to highlight issues in plan generation. In practice, the information flow is bi-directional – PlanA and Plan B, and even their sub-plans may be developed in parallel with constant communication between planning teams.

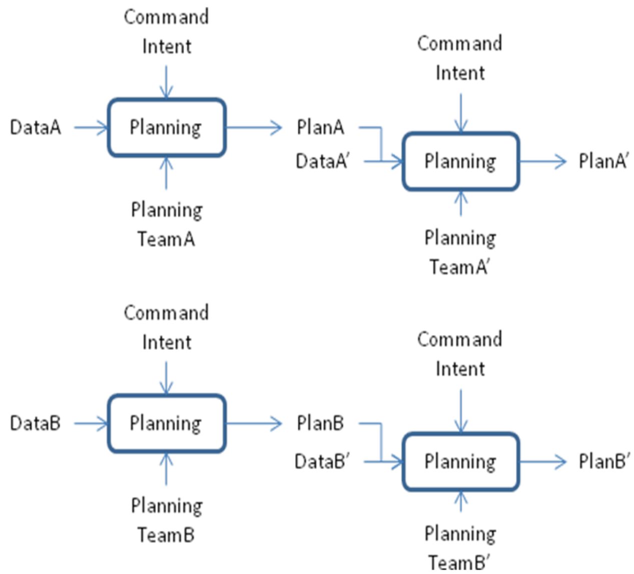

Figure 2: Example information flow during processing

Currently, different planning teams either plan manually or use bespoke planning support tools. So the Command Intent and PlanA fed into Planning TeamA' would be in the form of hard copies. The output of Planning TeamA' (PlanA') would also be issued as a hard copy document. A more significant issue is that PlanA does not contain all of the information generated by TeamA; it just contains concise information prescribed in the planning template. However, during the planning process the team would collect and generate a lot of information including assumptions, constraints, rationale and options.

Another inefficiency in the process is that there is limited re-use of data; for example, DataA' uses and builds upon DataA. However, in practice teamA' would often gather their data from scratch as they may not have easy access to DataA.

Overall, significant benefits of distributed planning can only come if the team is able to communicate and maintain a shared understanding of the commander's intent, objectives, resources and constraints, as well as decisions made and justifications for planning options chosen or alternatives rejected. Loss of shared understanding results in decisions that are inconsistent with the overall goals and constraints of the team [1]. This is particularly true in coalition planning, where work is distributed across different organizations, from different military traditions, and with different resources. Decision support tools, planning representations, and asynchronous communication networks now mediate the planning process. The focus of the work reported in this paper is how to build and support shared understanding between teams who are engaged in plan development supported by their own specialist planning support tools. As an example we describe our current work to demonstrate use of the Collaborative Planning Model (CPM) in facilitating interoperability between operational planning tools.

The outline of the paper is as follows. We start with a brief statement on the motivation for this research in Section II. Then, in Section III, we describe the Collaborative Planning Model (CPM) as a way to address plan modelling within a distributed environment. In Section IV, we present Controlled English (CE), which is a controlled natural language interface to the CPM that is both understandable by humans and processable by machines. In Section V we introduce current NATO planning doctrine and the TOPFAS tooling that has been developed to support it. We also give a simple TOPFAS plan for an example scenario devised to illustrate our work. In Section VI, we detail our initial steps towards developing a semantics-preserving mapping between TOPFAS and the CPM, and illustrate these with a preliminary CPM encoding of the aforementioned TOPFAS plan. Finally, we discuss on-going work on evaluating CPM with existing NATO planning tools in Section VII.

II. Motivation

Many researchers have perceived planning to be a single process or a homogenous set of problems to be solved, with automated solutions designed on the basis of such assumptions. Instead, military planning should be viewed as a set of interrelated activities that are carried out by different sets of planners working at different times, in different locations, and with different perspectives [3]. These activities may be conceptually quite different. It is therefore argued that military planning is more appropriately viewed as a capability that consists of a collection of different activities jointly aimed at producing a set of coordinated plans to achieve a given set of high-level mission objectives. This perspective, while essentially human-centred, can be used to help identify the key areas where automated support may be most beneficial. It preserves the human contribution to the planning process that allows for maximum utilization of human knowledge, creativity, experience, and situation awareness while offering automated support to increase planning effectiveness.

Given this view of the military planning process, a representation of the plan and its artefacts must be capable of addressing the following issues:

Collaboration - Military planning is a collaborative activity involving a large number of military staff working in distributed teams on different aspects of a plan. Management and shared understanding presents a challenge.

Specialization - The plans generated by a strategic planning team and the supporting specialized operational planning teams needs to be coherent and synchronized. Therefore, there must be a close link between plans generated at different command levels and across the specialized functional areas.

Communication – During the handover of the plan from strategic planners to the operations staff, a detailed and comprehensive brief should be conducted. Unfortunately, due to frequent pressure on time, this is often not possible.

Changing Situation - Any representation of a plan must be supportive of re-planning within the constraints identified above: collaboration, specialization and communication amongst geographically distributed planning teams.

We now discuss the Collaborative Planning Model and how it can be used to address these issues.

III. THE COLLABORATIVE PLANNING MODEL

The Collaborative Planning Model (CPM) is a representational framework for plans and planning processes, which aims to provide a formal specification of the semantics of planning and collaboration. [4,6,7] It is an ontology developed to support military planning by representing goals, plans, constraints, and human rationale associated with decisions made while creating the plan [5]. As well as standard planning concepts such as task, objective, resource, and constraint, it also contains concepts relating to multilevel collaborative planning and shared understanding. For example, a "collaboration" represents the setting of a planning problem to be solved by other, lower level, planners and a "synchronization" represents a collection of constraints that must be satisfied as a group across a specific level of planning. Results of evaluating the CPM to support multi-level manoeuvre and fire support planning are given in [8].

The CPM is not at this stage intended to be a complete model of collaborative planning in all military domains. However it has been designed in a layered fashion, from general abstract concepts through to detailed military concepts, in order to allow extension into further military domains as they are explored. Indeed the more generic concepts have been applied to other areas such as intelligence analysis. Concepts are derived from various sources including PLANET [9] and I-N-O-V-A [10], as well as through a detailed evaluation of military doctrine and extensive consultation with military domain experts.

The CPM is represented in a Web Ontology Language (OWL 1.1). While a useful machine understandable representation, raw OWL is not a human friendly representation. Two approaches have been taken to improve the human readability: to develop a human-readable Controlled Natural Language (ITA Controlled English [11], based upon work by John Sowa [14]) that can be mapped to and from OWL; to explore plan-specific visualization by creating different independently-developed research-grade tools with the ability to create, edit, visualize and exchange plans in CPM: the IBM Visualiser, the Boeing Graphical Plan Authoring Language (GPAL) Tool, and the Honeywell PlanEditor [2]. The tools provide a graphical representation of the spatial and non spatial aspects of the plan, including a display of the plan on a map and the relationships between entities such as objectives and tasks; facilities for editing the plan including objectives, tasks, resource requests, and assignments; capabilities to import and export plans in CPM/OWL, and the display and capture of the rationale for properties of plan entities.

The CPM also permits the representation of the rationale for information about entities in the plan, in terms of the reasoning steps that led to the information, together with the assumptions and decisions that were used [5]. For example a constraint on the start time of a task may have been created as a result of decisions at a high level of planning, together with contextual information about the world state, and temporal reasoning about the sequencing of the related tasks. This is illustrated in Figure 3 where an assumption made by a planner leads, through logical inference, to a timing constraint on an action.

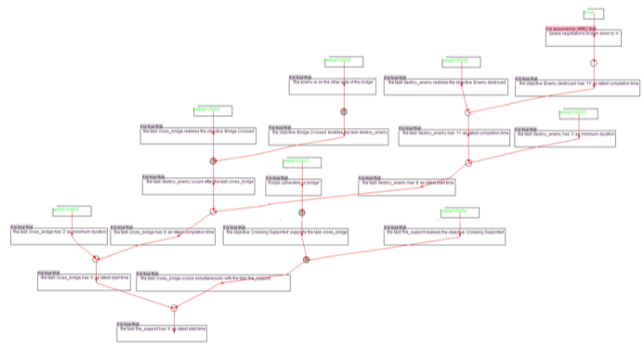

Figure 3: A representation of rationale

All of this rationale is explicitly encoded in the CPM, and may therefore be passed across between different tools that may use, analyse and add to the plan and its rationale. Such analysis may include calculating dependencies and knock on effects. Thus the CPM aims to be a representation of the problem solving state of the planners rather than just a plan interchange format. This facilitates the sharing of more complex reasoning across different levels of planning, such as assumption based reasoning that seeks to use the assumption and decision-based support of plan entities to determine the effects of changes in the external situation and planning requirements.

IV. ITA CONTROLLED ENGLISH

An important practical consideration for the construction and subsequent adoption of the CPM or any similar shared and centralized artefact is the degree to which it can be used by human users and machine agents within the overall knowledge processing community. As mentioned in the previous section, ITA Controlled English (herein referred to simply as CE) is an ITA variant of a controlled natural language originally developed by John Sowa [14].

Briefly, a key motivation behind the use of CE is its inherent amenability to consumption by both human and machine. Humans with no specialised training can read and understand CE since it is a subset of full natural English. Machines can parse and interpret CE owing to its formal grammar and underlying formal semantic model. Details of CE, along with a definition of its syntax and semantics can be found in [11], but for illustration, the following examples are shown:

CE Type	Example
New Concepts	conceptualise the task T ~ is achieved after ~ the task T1 .
Logical Relations	if (the task T has the value X as earliest completion time and the task T1 is achieved after the task T) then (the task T1 has the value X as earliest start time) .
Propositions	the division '3 UK DIV' has command of the brigade '12 (MECH) BDE'. there is a task named destroy_enemy that realises the goal 'Enemy destroyed by 11'. the task destroy_enemy is achieved after the task cross_bridge and has 8 as earliest start time. it is false that the hostile unit IAB has the bridge BR1 as location.
Attributed statements	it is stated by the commander CO40 that the task destroy_enemy has 3 as minimum duration.
Rationale (structured)	the task 'Build Bridge' has 18 as the earliest start time because the task 'Build Bridge' is achieved after the task 'Clear Road A' and the task 'Clear Road A' has 18 as earliest completion time.
Rationale (unstructured)	"the troops must be protected when crossing the bridge" because "the enemy is on the other side of the bridge"
Assumptions	it is assumed by the commander CO40 that the task 'Build Bridge' has 30 as earliest completion time.

Table 1: Examples of ITA Controlled English

With this in mind we have been developing a generic capability for the consumption and processing of CE sentences known as the "CE Store". The CE Store, designed to process any valid CE sentence, is a combination of a highly indexed persistent data store, a sentence parser, and a query and inference engine. The CE Store will accept all types of CE sentence (model, rule, fact, query, command, annotation) and is built on a relational database and implemented in Java.

From a data storage perspective there are similarities to a typical triple store implementation, but there are some key differences to better position the underlying data for integration into more traditional relational database oriented environments or data processing software. For example, the concepts created within the CE conceptual model (in the case of the CPM these are entities such as plans, tasks, activities, units, etc.) are manifest as distinct tables, with columns either located directly within these tables or in associated lookup tables. The schema for the database is dynamically generated based on the CE sentences used to define the conceptual model, and the tables are populated with data extracted from any CE sentences used to describe the various entities and their properties within this conceptual model. Inheritance of concepts and properties are implemented in a highly efficient manner using database views, enabling the data to be stored once within the database but retrieved from many different contexts.

A key factor in the design of the CE store component is consumability both from a machine agent and human user perspective so the CE store is delivered as a core java component with well-defined public code-level APIs that are designed specifically for machine level interaction. All of these APIs are built around the CE specification and either accept or produce CE sentences in order to communicate information. In addition to this core layer the CE store is also deployed with a standard web-based client implementation that wraps the core APIs in a set of JSON based web services and an HTML/JavaScript browser-based user interface to allow construction and subsequent navigation of the model and associated data defined within the CE sentences.

The CE store also supports the concept of "CE agents" which are simply units of specialized java code which can be developed to carry out particular functions relevant to the domain of interest, and which are configured via CE sentences and accept CE sentences as input and/or output. In the domain of the CPM such agents may include map co-ordinate conversion, complex resource allocation algorithms, confidence/certainty calculations etc. These agents can either be new implementations of such functions or calls out to existing software capabilities as required. Future versions of the CE store will include full rationale processing, assumption support and a focus on performance and scalability tuning.

V. The COPD and Planning in TOPFAS

Current NATO planning doctrine is embodied in the Comprehensive Operations Planning Directive (COPD) [12]. COPD establishes the processes that NATO should action in the case of an emergency and recognizes that a military response should be part of a comprehensive approach that also includes political, civil and economic effects. To support COPD, the TOPFAS suite of planning tools [13] has been developed. This provides a common environment for analysts and planners to assemble plans and supporting information for an on-going campaign. The information is intended to support the processes and reporting structures defined within the COPD. TOPFAS may be run as a stand-alone tool or in a collaborative environment with planners and analysts accessing a server. Outputs from TOPFAS are intended to support briefings to commanders so take the form of Microsoft Office documents; in particular Word, PowerPoint and Excel. There is no export facility where the structured plan may be extracted and distributed to other more specialized planning tools.

The Operational Planning Tool (OPT) forms one part of the TOPFAS suite of tools. It allows causal, spatial, temporal and resource views of an operation to be developed using an underlying model. The model consists of linked objects represented graphically by the tool. Our current work is to conceptualise these objects within CPM thereby enhancing the functions of the TOPFAS model through CPM logical processing. We will also work with coalition partner specific tools to demonstrate CPM as a common plan representation model that can be exported from TOPFAS and shared amongst different planning systems in coalition partner countries.

TOPFAS objects from the Operational Planning Tool (OPT) and their relationships are illustrated in Figure 4.

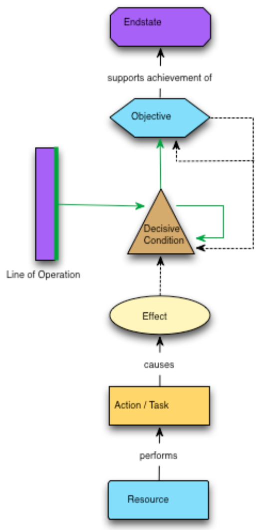

Figure 4: TOPFAS objects and their relationships

The COPD defines a line of operation as follows [12]:

In a campaign or operation, a logical line(s) linking effects and decisive points to an objective.

In the figure, a line of operation (LOO) identifies an ordered set of decisive conditions that must be achieved in order to realize an objective. Decisive conditions are themselves achieved by employing resources to execute actions (or tactical-level tasks) that cause effects. A decisive condition may also be achieved by realizing a set of objectives. Finally, an objective may be split into a set of sub-objectives.

Our understanding of these planning concepts and their interrelationships is based on informal definitions given in the COPD (such as the definition of a LOO given above) and TOPFAS documentation. We have also informally validated the consistency of our interpretations against example TOPFAS plans that we have had access to.

To illustrate the relationships between TOPFAS OPT objects, we have constructed a simplified scenario from the aforementioned example material. This is illustrated in Figure 5 below.

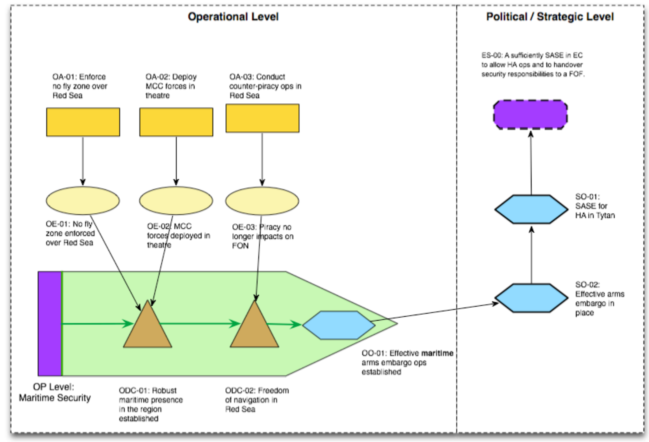

Figure 5: An example TOPFAS plan

The context of the scenario is that NATO has been requested by the UN to provide a safe and secure environment for humanitarian operations to take place in the fictional country of Tytan in the Horn of Africa. It is believed that in order to achieve this, a high degree of maritime safety is required to prevent piracy, stop the shipment of arms to insurgents and allow NATO resources to be deployed by sea to the area of operations. The illustration shows the maritime component of the overall campaign plan.

To achieve the desired political end state, actions must take place at the operational level. To achieve the political end state (ES-00), the objective of a secure and safe environment for humanitarian actions in Tytan (SO-01) must be achieved. To this end, a strategic objective must be achieved (SO-02) such that there is an effective arms embargo in place. Activities planned at the operational level support the achievement of this objective.

The operational level LOO is to establish maritime security and thereby achieve the objective of enforcing an effective maritime arms embargo (OO-01). To achieve this, two decisive conditions must occur; there must be a robust maritime presence in the area (ODC-01) and there must be freedom of navigation in the Red Sea (ODC-02). To support ODC-01, tasks to enforce a no fly zone over the Red Sea (OA-01) and deploy maritime forces in theatre (OA-02) must be performed in order to cause effects OE-01 (no fly zone enforced) and OE-02 (maritime forces deployed). Similarly, a task to conduct counter-piracy operations in the Red Sea (OA-03) must be performed in order to cause the effect of piracy no longer impacting on freedom of navigation (OE-03), which supports the achievement of the decisive condition ODC-02. Achieving the decisive condition ODC-02 supports the achievement of the operational objective OO-01. It should also be noted that in a full plan, resources would be identified/allocated to perform tasks. We do not cover resources in this paper so none are shown here.

VI. A MAPPING FROM TOPFAS TO CPM

For the CPM to enable inter-operability between TOPFAS and other planning tools, a mapping procedure must be developed to transform TOPFAS plans into a semantically-equivalent CPM representation. To support the feasibility of this work, we have devised an incomplete and preliminary mapping based on our initial interpretation of the informal descriptions and examples of TOPFAS vocabulary that we have had access to.

Figure 10 (page 9) shows a visualisation of the CPM output of our preliminary mapping procedure when applied to the above TOPFAS plan. We note there are considerably more objects and relationships in the CPM plan relative to the TOPFAS plan shown in Figure 5. The detail shown in Figure 10 is necessary due to the formal data model that underpins the CPM; the implicit meaning attributed to some TOPFAS relationships must be captured explicitly as logical predicates in the CPM. Throughout this section we refer to excerpts from this figure to exemplify particular aspects of the mapping.

A. Objective

Objectives are used in a CPM plan to identify some world state that some owner (a deliberative agent) wishes to hold (i.e. 'be the case') for some interval of time [7]. This desired world state can be defined in terms of an informal natural language proposition and/or a formal logical proposition (perhaps expressed in CE). Flexibility in the permissible interval of time can be achieved by specification of some combination of earliest/latest start/end times and minimum/maximum durations. Objectives can also be decomposed into hierarchies of objectives/sub-objectives; the (transitive closure of the) set of sub-objectives of an objective specify necessary (but not sufficient) preconditions for it to hold. An example of such a hierarchy is illustrated in Figure 6 (an excerpt taken from Figure 10), in which OO-01 is related over *'has as subgoal'* to ODC-01 and ODC-02. Note that the names of CPM relationships such as *'has as subgoal'* are actually CE fragments deliberately chosen to permit direct construction of meaningful CE sentences (e.g. *"the objective SO-02 has as subgoal the objective OO-01.")*.

Based on informal TOPFAS vocabulary definitions, these semantics appear to largely match those of a TOPFAS objective. To illustrate, the generalised definition of CPM objectives given above can be *specialised* to apply to the military domain (e.g. *'world'* is a generalisation of '*engagement space', 'owner'* is a generalisation of *'military commander'* and *'desired world state'* is a generalisation of *'goal essential to a military plan'*). TOPFAS objectives can also be hierarchically decomposed using the TOPFAS hierarchical link, and we assume that this link is likely to imply identical logical constraints to (the inverse of) the aforementioned *'has as subgoal'* CPM relationship.

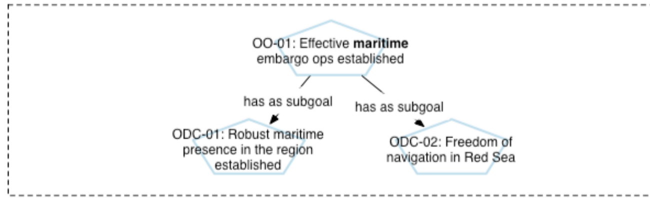

Figure 6: A CPM Objective hierarchy

One notable difference is the models' treatment of the temporal properties associated with objectives. In contrast to the aforementioned flexibility offered by the CPM, TOPFAS appears to only permit the specification of a single *'end date'* value. In order to define a meaningful mapping of this to CPM vocabulary, we must first discover the precise implied meaning of this value (e.g. *can objectives be completed before this date without violating the plan? For how long after this date should an objective be maintained?*). To elaborate on this, we note that the CPM defines a set of rules that induce and propagate conclusions about temporal values and relationships from (and thus constrain) asserted premises [7]. For any CPM-TOPFAS mapping to be meaningful, we must ensure that equivalent conclusions are drawn by both vocabularies from the same premises.

Other, less challenging differences relate to various military-specific attributes applied to TOPFAS objectives, such as whether or not they are *attainable*, *plan-essential* and so on. Future work will establish the necessity of these attributes *(are all objectives not, by definition, attainable and plan-essential?)* and identify (or develop) candidate CPM analogues as required.

B. Desired End state

TOPFAS also introduces an object type for the description of *end states*. The desired end state of a campaign should describe an acceptable military and/or political world state that must exist before the campaign can be considered complete. Objectives are derived from this end state and it thus forms the basis of operations planning. [12]

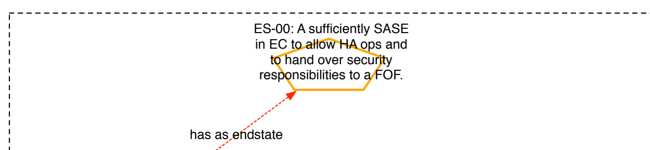

Figure 7: A CPM objective used to represent end state

As shown in Figure 7, a CPM plan uses the *'has as endstate'* relationship to identify a particular CPM objective that defines the desired end state of the plan. Note that this relationship originates from a CPM container object (not shown in Figure 7) used to identify the *intent* of a commander to achieve an assigned *mission* (these CPM planning artefacts are detailed later in this section). We believe that the CPM sub-structure described above is sufficient to express the meaning of a TOPFAS end state object, but a more in-depth investigation is required to tease out any subtle semantic differences and necessary CPM extensions.

C. Task and Effect

Tasks are used in a CPM plan to express that an agent is required to execute an activity in order to meet an objective by causing a change in world state [7]. Planned tasks are assigned by a superior agent to a subordinate, are given permissible timings (its temporal properties are equivalent to those of objectives), and an available pool of resources. That a task is performed in order to meet an objective is captured using the *realises* relationship. Generally speaking, an objective is realised by a single task (the CPM semantics of alternative tasks realising a single objective are currently undefined). However, tasks can be decomposed into hierarchies of sub-tasks, necessary (but not sufficient) for their completion, using the *has as subtask* relationship. The above definitions are illustrated in Figure 8; the tasks OA-01 and OA-02 are subtasks of a single, shared parent and so are necessary for the completion of this parent task. Once complete, the parent task realises the objective ODC-01.

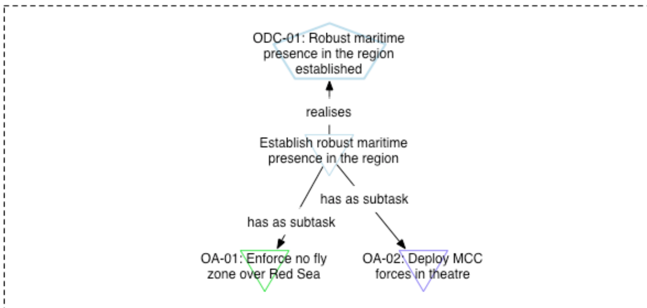

Figure 8: A CPM task hierarchy that realises an objective

The definition of the *'change in world state'* that results from the achievement of a task can be captured in the CPM by associating the task over the *has as effect* relationship to an *effect.* Effects have temporal properties (equivalent in nature to those of objectives and tasks), and can also be *preconditions* for tasks [7]. Figure 9 shows how effect and precondition specifications have been used to enrich the model shown previously in Figure 8 with this information. The CPM does not yet formally define the implications of task preconditioning, including (1) the implications of a task having multiple preconditions, and (2) a specification of the temporal constraints a precondition imposes on a task (and visa versa). Our initial (partial) intuitive specification (which we will assume is relevant to military planning for now) with respect to the above is: *the set of effects that are preconditions to a task must (1)* ***all*** *hold for an interval of time that (2)* ***contains*** *the interval of time during which the task is executed.* This statement, in conjunction with the CPM constraint stating that a*n effect can only hold after the completion of task that causes it*, permits us to infer that (as shown in Figure 9) initiating execution of OA-03 must *occur after* the completion of (the parent task of) OA-01 and OA-02.

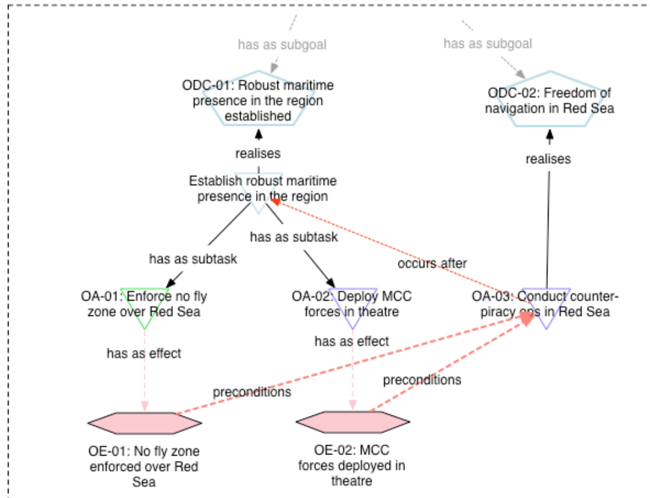

Figure 9: CPM effects as consequences of, and preconditions to, task execution

Based on our interpretation of informal TOPFAS vocabulary definitions, we believe that three TOPFAS entities closely match the semantics of CPM task and effect described above, namely the TOPFAS definitions of action/task[2] and effect. In examples we have seen, both CPM tasks and TOPFAS actions are typically associated with an *imperative* statement starting with a verb (e.g. “seize ...”, “destroy...”, “defeat...”), and associated effects are typically *declarative* statements that describe the (expected) resulting world state (in much the same way as objectives). Moreover, like CPM tasks, TOPFAS actions can be hierarchically decomposed, and we believe that the meaning of the *hierarchical* link used is equivalent to that of (the inverse of) the *has as subtask* CPM relationship.

As with objectives, there is an evident distinction in the way the models capture the temporal extents of actions and effects; in contrast to the CPM, TOPFAS actions do not permit the specification of multiple permissible intervals of time, and TOPFAS effects are associated with two distinct time intervals indicating that they are either 'building-up' or 'being maintained'. Additionally, we have not yet identified (or devised) CPM analogues for various TOPFAS action/effect attributes, including action metrics such as *willingness, risk level*, and *efficiency*, or those that distinguish between *implied* and *assigned* actions. Finally, in the CPM, a task is related directly to the objective it *realises,* and an effect is related to the objective(s) it supports indirectly via a chained *effect* → *preconditions* → *task* → *realises* → *objective* relationship. TOPFAS adopts the opposite approach; effects are directly asserted to *support* objectives (although this is not included in the example TOPFAS plan shown earlier in Figure 5), and actions provide support via effects. We believe that these both effectively capture the same essential meaning, but a formal investigation of this issue will nevertheless be necessary.

[2] We believe that a TOPFAS task is a specialised form of action, where the individual or organisation it is assigned can only exist at the tactical level [12]. There appears to be little semantic distinction here relevant to our work at this stage, so we deal only with TOPFAS actions in this paper.

D. Decisive Condition and Line of Operation

So far, we have covered *objectives, end states*, *actions* and *effects*. A missing (but fundamental) component of any military plan is a definition of several lines of operation that specify how an unacceptable situation in the world can be sequentially transformed into an acceptable one (i.e. the desired end state). In basic terms, this situational transformation occurs through the execution of actions to create effects. These effects provide the *concrete* support for a hierarchy of objectives (operational, to military strategic to NATO strategic) which culminates in the realisation of the overall desired end state [12]. An important component of a plan at the operational level is the 'operational design'. One of the purposes of this artefact is to establish *decisive conditions* along lines of operation.

Our current understanding is that a decisive condition, since it describes a desired *world* state (ultimately) necessary for the attainment of an overall desired *end* state, is similar in meaning to an objective. The primary distinction, we believe, is that a decisive condition describes a world state identified by a military commander as essential to containing or neutralising an opponent's centres of gravity and protecting one's own. As shown earlier in Figure 4, decisive conditions in a TOPFAS plan are typically related to one another over a line of operation. We believe that, together, these are used in TOPFAS primarily for operational *sequencing:* to specify the causal (and thus temporal) constraints between decisive conditions, and describe the ordered dependencies between actions, effects, decisive conditions and objectives.

To capture decisive conditions and lines of operation in the CPM we make use of the mapping exemplified in Figure 9 above. Decisive conditions are mapped directly to CPM objectives (as with ODC-01 and ODC-02). To capture the sequencing (we believe) is implied by a line of operation, we make use of the aforementioned *effect → precondition → task* relationship. In Figure 9, the tasks OA-01 and OA-02 realise (via a parent task) the 'decisive condition' ODC-01. The effects of these tasks (OE-01 and OE-02) are both asserted to be preconditions of the task OA-03, which realises the decisive condition ODC-02 that is subsequent to ODC-01 in the line of operation. Precisely how this captures operational sequencing is illustrated by the temporal constraint induced by these relationships: namely that OA-03 must *occur after* the completion of (the parent task of) tasks OA-01 and OA-02.

Further investigation is required to prove that this mapping fully captures the intended meaning of decisive conditions and lines of operation. It may well be the case that extensions built on top of existing CPM vocabulary are necessary for a full mapping of these concepts to be possible. For instance, the COPD emphasises the relationship between decisive conditions and centres of gravity [12], thus a CPM extension may be necessary to properly capture this emphasis.

E. Mission and Intent

The CPM defines a number of *containers,* which are used to assemble planning artefacts into groupings that share some characteristic(s). In this paper, we cover two: *mission* and *intent*. In brief, the contents of a CPM mission represent a direct order given by a superior commander to a subordinate commander. The contents of a CPM intent describe a subordinate's understanding of an assigned mission and the plan that they have devised to achieve it. [7]

Our experience with the TOPFAS tool suggests that one of its primary purposes is to facilitate collaborative planning between multiple levels of a military organisation. This capability is also a basic requirement of the CPM, and the CPM mission and intent containers form (at least part of) its mechanism for achieving this [2, 8]. To illustrate, we now provide a brief overview of the CPM plan shown in Figure 10. We have already outlined the CPM-TOPFAS mappings employed here, and we have also given a description of the example scenario to which this plan applies. Together these should be sufficient to provide an understanding of most of Figure 10; in the interests of brevity we do not give an exhaustive narrative of the mapping procedure employed here.

In Figure 10, colours[3] denote 'ownership' of a planning artefact (as specified in the key). Missions are shown as filled containers with an outline colour denoting the superior commander responsible for assigning the mission, and a fill colour indicating the subordinate commander the mission is assigned to. Intents are shown as unfilled containers with an outline colour denoting the 'owner' of the intent.

Here, the mission assigned to SACEUR is the political end state (ES-01) desired by the NAC. Based on this mission, the SACEUR commander has devised a strategic intent to achieve an overall strategic objective (SO-01), consisting of various sub-objectives (SO-02 is the only one shown here). Based on this intent, SACEUR assigns a mission to JFCNP that delegates responsibility for the maritime component of SO-02. Based on this mission, JFCNP devises an operational intent, and in turn specifies missions that delegate air and maritime responsibilities to ACC and MCC respectively.

F. Future Work

Our work thus far has not yet covered many important aspects of the COPD planning vocabulary. Notable examples include ORBAT specifications and logistics (resource allocation) (i.e. *"who"*), the prominent spatial dimension of planning (i.e. *"where"*), and so on. However, we have employed only a small subset of the CPM vocabulary in our mappings thus far, and we believe that the CPM has the potential to offer a far more comprehensive coverage than that detailed in this paper (indeed, the CPM does have specialised vocabulary for capturing the three examples given above) [7]. Moreover, where vocabulary is lacking (as may be the case for e.g. decisive conditions and lines of operation), we believe the underlying CPM modelling language is sufficiently flexible and expressive to accommodate future extensions.

[3] If required, the authors will provide a colour version of this paper on request.

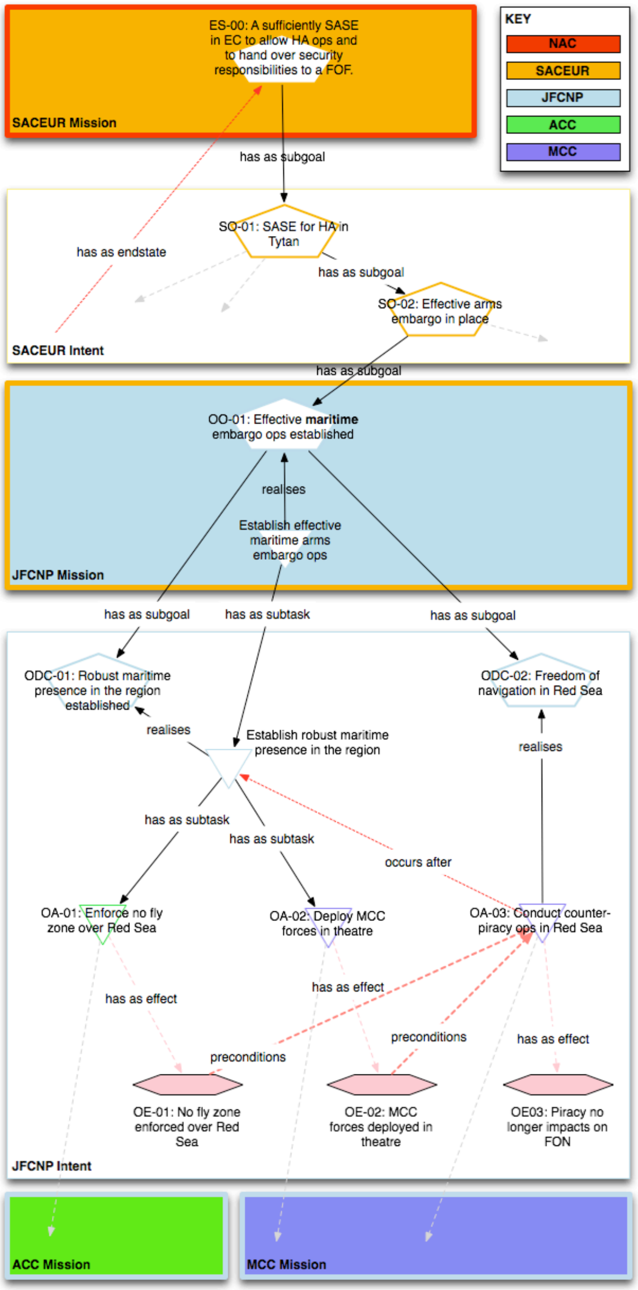

Figure 10: Example scenario visualised as CPM

VII. CONCLUSIONS

The fundamental research work of the ITA has led to the development and initial evaluations of a collaborative planning model. Subject matter experts within the UK and US have performed the evaluations. We have now embarked on a further development project to link CPM to existing NATO strategic planning tools. The richness of the CPM model will allow the TOPFAS planning representation to be exported into CPM for further processing and provide an interoperability format suitable for linking to other specialized planning tools within coalition partner organisations.

VIII. ACKNOWLEDGMENT

This research was sponsored by the U.S. Army Research Laboratory and the U.K. Ministry of Defence and was accomplished under Agreement Number W911NF-06-3-0001. The views and conclusions contained in this document are those of the author(s) and should not be interpreted as representing the official policies, either expressed or implied, of the U.S. Army Research Laboratory, the U.S. Government, the U.K. Ministry of Defence or the U.K. Government. The U.S. and U.K. Governments are authorized to reproduce and distribute reprints for Government purposes notwithstanding any copyright notation hereon.

IX. REFERENCES

[1] Allen, J.A., Mott, D., Bahrami, A., Yuan, J., Giammanco, C., and Patel, J. "A Framework for Supporting Human Military Planning," Proceedings of the Second Annual Conference of the International Technology Alliance, London UK, September 2008.

[2] Dorneich, M.C., Mott, D., Bahrami, A., Yuan, J., Smart, A. "Evaluation of a Shared Representation to Support Collaborative Multilevel Planning", Technical Report, See http://www.usukita.org.

[3] A Aitken, T. Humiston & J Patel "Dynamic Planning and Execution". In *Proceedings of the Fifth Knowledge Systems for Coalition Operations.* 2007 P. 37 – 42.

[4] Dorneich, M.C., Mott, D., Bahrami, A., & Patel, J. "Improving Shared Understanding in Multilevel Planning", Third Annual Conference of the International Technology Alliance, Maryland, September 23-24, 2009

[5] Mott, D., Giammanco, C., Dorneich, M.C., & Braines, D. "Hybrid Rationale for Shared Understanding", The 4th Annual Conference of the International Technology Alliance. London, England, September 2010

[6] Patel, J., Dorneich, M.C., Mott, D., & Bahrami, A. "Making Plans Alive", The 4th Annual Conference of the International Technology Alliance. London, England, September 2010

[7] Mott, D. "CPM: Visual Guide to the CPM v3", https://www.usukitacs.com/node/1712, 2011

[8] Dorneich, M.C., Mott, D., Bahrami, A., Patel, J., and Giammanco, C. "Evaluation of a Shared Representation to Support Collaborative, Distributed, Coalition, Multilevel Planning", The 5th Annual Conference of the International Technology Alliance, Maryland, US, August 2011.

[9] Gil, Y. and Blythe, J, "PLANET: A Shareable and Reusable ontology for Representing Plans", 2000 http://citeseer.ist.psu.edu/421975.html

[10] Tate, A. "Representing Plans as a set of constraints – the <I-N-O-V-A> model". In the proceedings of the 3rd International Conference on Artificial Intelligence Planning Systems, May 1996

[11] Mott, D., Summary of Controlled English, ITACS, https://www.usukitacs.com/?q=node/5424, May 2010.

[12] "Allied Command Operations Planning Directive COPD Interim V1.0", 17 December 2010.

[13] Thuve, H., "TOPFAS (Tool for Planning, Force Activation and Simulation)", Proceedings of 6th ICCRTS, http://www.dodccrp.org/events/6th_ICCRTS/Tracks/Papers/Track4/127_tr4.pdf

[14] Sowa, J., Common Logic Controlled English, March 2007, http://www.jfsowa.com/clce/clce07.htm