Improving Shared Understanding in Multilevel Planning

Michael C. Dorneich
Honeywell, USA

David Mott
IBM, UK

Ali Bahrami
Boeing, USA

Jitu Patel
DSTL, UK

*Abstract***— Planning is a specific example of a problem solving activity that is undertaken across multiple (human) collaborative agents. In order to collaborate, these humans need to form a shared understanding of various aspects of the plan, mutual goals, the contexts of the other agents, and the rationale for others decisions and assumptions. Failure to reach this shared understanding can have serious implications to the success of the resulting plan. Currently plans are developed and shared with peer and subordinate units in a static format such as text, diagrams and spreadsheets which do not normally contain any of the reasoning, logic and interdependencies. As a result, the plans are not easy to update and planning tends to take a lot more time than is normally available. Over the last two years we have been developing a representational scheme, called the Collaborative Planning Model (CPM), for capturing plans from planners at different levels of command. In September 2008, the representational power of CPM to support multiple planners collaborating to create a plan, and detect resource conflicts as they arose was evaluated. This paper summarizes the results of the exercise, and discusses areas for further development to make CPM an effective framework for shared understanding in multi-level planning which is expected to improve timely generation of plans.**

I. INTRODUCTION

Military planning is a group activity that is distributed in space as well as along functional areas. While the main plan is developed by the "planners" sitting in HQ, elements of the plan are simultaneously developed by the supporting units (e.g., logistics, fires, communications). There is a constant rapport between planners and the supporting units, who feed in their estimates for the proposed mission plans generated by the HQ Planners. This estimate process can be quite intensive and complex, depending on the size of force deployed and expected duration of the operation. The output of the process is a plan, which states what needs to be done, when, by whom and allocates the required resources.

In order to generate timely and effective plans, there needs to be a shared understanding of the operational objectives and of the evolving plan between the HQ Planners and the functional units. Lessons from recent operations suggest that the process is largely manual and slow. For instance, during the Iraq war, plans were frequently received by the forward commanders after departure. Thus, the planning domain poses challenges related to "timely and correct information" (e.g., generating viable plans in timely fashion) and "rapid collaboration" (e.g., seamless and coherent working between groups of planners at multiple levels of command) that have been identified as ITA program Grand Challenges [1].

One of the possible reasons for less than optimal shared understanding between planners is the fact that plans are currently captured in static representation such as text or diagram [2]. Thus, what is shared between planners (and operators) are the outputs of the planning activity which does not typically contain any information about the rationale, constraints or assumptions for the decisions. Associated research on possible causes of miscommunication in coalition operations has demonstrated that context plays an important role in fostering shared understanding [3]. In the planning case, the contextual information is embedded in the rationale, constraints and assumptions underlying the decisions.

Over the last two years, we have been investigating how to foster shared understanding between planners in order to improve quality and timely generation of plans. The central thesis driving this research is an understanding that planning is a human activity which involves disparate groups working in tandem to generate a coherent plan. There is an enormous load on communication bearers due to the fact that these teams are often working at a distance. It is hypothesized that the communication load can be reduced if the plans (complete or partial) that are shared are much richer in content (i.e., they include the necessary contextual information). These "richer" plans would also improve shared understanding between the teams. Ultimately, this will lead to effective plans generated much more efficiently.

The research has focused on developing a representational scheme for encoding all necessary concepts for coalition campaign planning as well as the detailed tactical plans. This plan representation language is called the Collaborative Planning Model (CPM). The CPM ontology is implemented in a Web Ontology Language (OWL 1.1) and capable of representing planning concepts typically present in "static" documents (e.g., objectives, tasks, decision points, resources) as well as assumptions, constraints and human rationale associated with decisions made while creating plans [4].

In September 2008, an exercise was conducted to evaluate CPM's ability to support distributed multi-level military planning. This paper provides a summary of the evaluation exercise and discusses the key findings (for detailed description of the exercise see [4]). The paper then discusses the merit of fostering shared understanding versus just providing interoperability, which is the currently preferred solution for efficiently generating plans.

II. CPM Evaluation

A. Objectives

The evaluation hypothesis is that CPM could be used to import and export plans, merge sub-plans, and to support the detection of the reasons for conflicts. Thus the goal was to explore the representational power of CPM in handling multilevel collaborative planning.

The second evaluation goal was to demonstrate the integration of multiple planning tools via CPM. In order to facilitate an evaluation of the representational power of CPM, IBM and Honeywell each developed experimental tools to exchange, merge and display CPM-based plans and rationale. The tools, IBM Visualizer and Honeywell PlanEditor, were deliberately developed independently, based only on the formal definition of CPM, and so provide somewhat different functionality and visualization capabilities.

B. Protocol

Figure 1 illustrates one possible structure of a multi-level collaborative planning process, and forms the basis of the evaluation scenario. A Battalion commander (Planner 1) creates a Battalion level "main plan". Two sub-plans are needed, and so the Battalion commander exports the relevant portions of the main plan to two Company level planners (Planner 2A and Planner 2B). Each planner imports the plan into their (different) planning tools. After creating their sub-plans, the resulting sub-plans are exported to a simple resource allocation simulator to be checked for resource conflicts. The sub-plans are imported back into the Battalion Commander's planning tool, along with any identified resources conflicts, and are merged into the main plan.

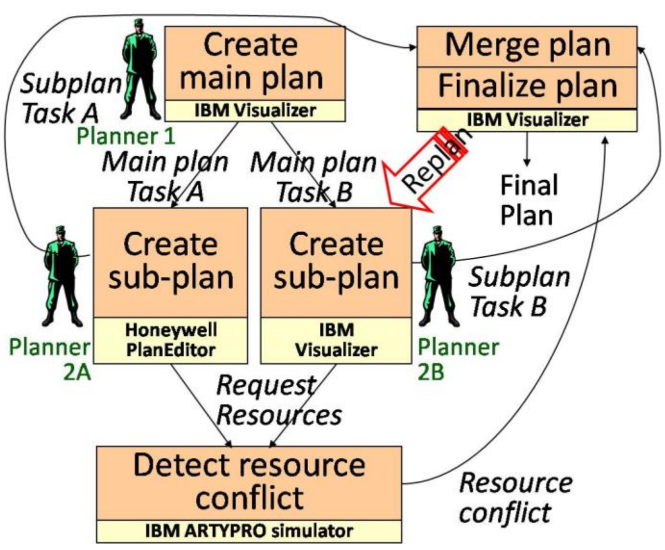

Figure 1. Multi-level collaborative planning facilitated by CPM.

C. Scenario

Planner 1 developed the overall evaluation scenario, which centered on an Armored Brigade whose mission was to defeat a hostile brigade (see Figure 2).

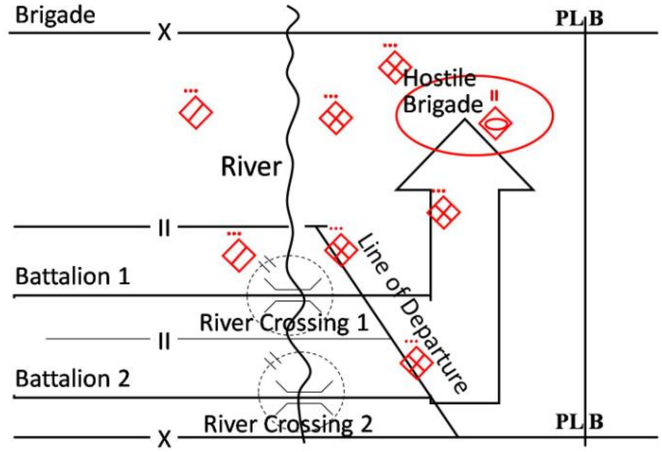

Figure 2. Brigade (X) and two Battalions (II) (hand drawn).

Battalion 1 and 2 were each tasked to build a bridge and to secure the area after the bridge. For this they needed Engineering resources and Artillery resources to handle a hostile force at the south. Once they are finished, Battalion 3 (not shown) will act as the attacking force. It will push through across the bridges towards the enemy, and thus will need Artillery Support to attack and fix (prevent movement) the hostile battalions. The plan also had a feint (move designed to deceive the enemy) to the north (not shown) to draw forces away from Battalion 1 and Battalion 2's activities. Combat support consisted of Close Support Artillery (owned by Brigade but "on loan" to each Battalion). It was hypothesized that Battalions 1 and 2 would both request the use of Artillery for targets in the North (at Brigade level) and targets in the south (at Battalion level), and that these might be conflicting as resources were limited.

The main plan was turned into two CPM "Collaborations", where a collaboration defines a problem to be solved by a planning agent and "plan" container into which the solution should be placed and returned to the problem setter. Here the problem setter is Planner 1, and there was a problem to be solved by each of Planner 2A and 2B. Each collaboration problem contained a set of tasks, with one main task being the "super task" of all of the others; this main task was created to meet an objective in the main plan. One collaboration was exported to Subplanner 2A and one to Subplanner 2B, in order that they may each generate a solution (a "subplan") that would eventually be merged into the main plan to form a complete solution to the main planning problem.

The exported collaboration also included the entire main plan as context. Some experiments have been done on attempting to filter the amount of detail of exported plans, for example by using the rationale. Filtering may also be important in heterogeneous settings (e.g. planning involving both the military and NGOs) where policies may prevent some aspects of the plan from being shared. However to date no better way has been found than exporting the entire plan (i.e. no filtering). However the collaboration for the (corresponding) other sub-planner was not exported. Further work may be necessary in the area of designing good filters. Thus a visualization of the sub-plans (as shown in Figure 3) actually contains the entire main plan, but in order to simplify the diagrams, only the specific subcomponents have been shown, by manually cutting out the relevant components. This is why the diagrams below also have links to "higher-up" components.

Planner 2A controlled Battalion 1. Planner 2A imported the main plan with the sub-plan identified as the empty plan (the collaboration solution) that needs to be filled (see Figure 3). There were four sub-tasks assigned under the main task of "secure Nth LD for Armd Regt": 1) Clear up to the river, 2) Seize the River Crossing Site, 3) Defeat the Enemy north of the LD (line of departure), and 4) Secure the north LD for the armed regiment. Similarly and concurrently, Planner 2B received a collaboration for the sub-plan for Battalion 2.

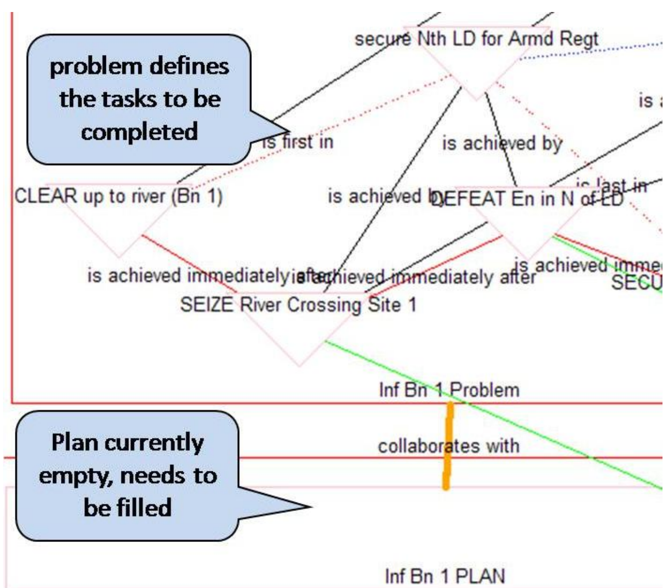

Figure 3. CPM representation of Planner 2A 's sub-plan.

III. Evaluation Findings

A. Initial Plan Creation (Session I)

In Session I, the Battalion planner (Planner 1) created a main plan. For several of the planning stages (scenario, order of battle, plan), the planner drew a rough diagram on paper first, although this did not include much detail. For the plan, he referred to a document defining the "effect" schematic verbs (SEIZE etc.), which he used to name tasks.

Much of the subsequent working out of the detailed tasks and how they were to be packaged into collaborations was then done by the planner using the Visualizer. The collaborations for Battalion 1 and 2 (including the sub-plans to be filled out by Planner 2A and 2B) were worked out in some detail. In reality such details are deferred until the situation is clearer (where sub-planners would be told "detailed orders to follow")

Limited human rationale was captured, due to experimental time constraints, and this was augmented by the automated reasoning of the Visualizer in respect of propagation of timing constraints. However this is probably insufficient to support full replanning, and the limitation caused an issue in the subplanning of Planner 2B (to be discussed in Section III.B.1).

B. Sub-plan Creation (Session II)

Each subplanner received the exported main plan, containing their collaboration (including the tasks to be planned) and entire main plan as context. Planner 2A imported the CPM plan into the PlanEditor, and Planner 2B imported it into another instantiation of the Visualizer. Both planners were able to use their respective tools (via the experimenter) to capture the tasks in the plan, although the tasks were defined at a fairly high (and hence abstract) level. The planners augmented the use of the tool with the use of pencil and paper to view the problem from a different planning perspective, although it seemed (as an informal observation) that neither of these methods was dominant. However, it is clear that for a tool to effectively support the planning process, multiple planning perspectives need to be supported (see discussion in Section IV for more detail). The resulting plan by Planner 2B is shown in Figure 4.

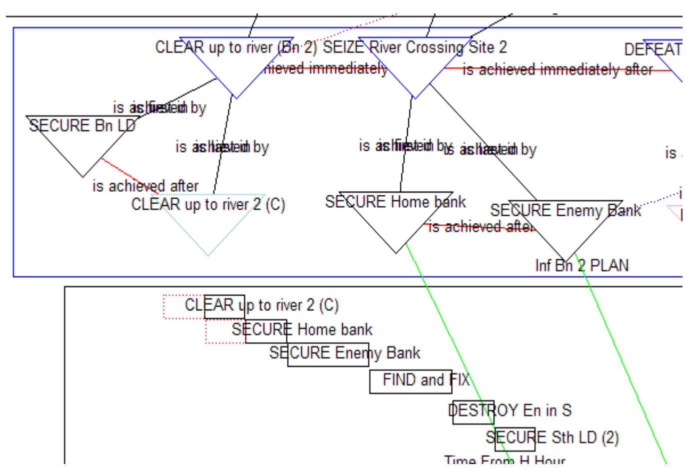

Figure 4. The CPM representation of Planner 2B's sub-plan.

1) Planning Strategies

Informal observation of the planning process produced some insights into the strategies used by the planners. While not an exhaustive task analysis, some of the more germane observations are presented here.

The main plan imposed some timing constraints on the sub-planners, which Planner 2A wanted to violate as he was constantly looking to "steal time". His stated focus on planning subtasks was "speed, speed, speed". Normally he would talk to the commander to see if violating the timing constraints was OK. This is an example of where having access to some of Planner's 1 rationale within the plan might have been useful.

Planner 2A also spent considerable time planning how to specify and load the reserve forces. A reserve force is a combat unit held in reserve to deal with any contingencies or unforeseen events that affects the attacking force’s ability to complete its task. The designation of which units are the reserve or attacking force is part of the planning, and can change on a task by task basis within the plan. Some rules of thumb he tried to follow included assigning a reserve to each task, keeping the plan simple, and avoiding rapid switching between assignments of attack and reserve.

He mentioned several times that there were caveats to his resource allocation, depending on how badly he thought a force might be depleted. For instance, he was unsure of whether to assign a force as a reserve given the fact that it may have been depleted after performing an attack to "destroy enemy". Thus aspects of the plan depend on variables that are unknown at the outset. Key force attributes (e.g. health) may need to be modeled in CPM to allow for later decision points.

Another goal of his initial plan is to build up a "time reserve" and maintain the ability to maneuver resources. In this case a “time reserve” means that he was trying to look for times when his scheduled start and end times for tasks had some “extra” time to be used when the execution of the plan results in unforeseen contingencies. He therefore wanted to be able to communicate to reserves: "you are the reserves, and this is why" (i.e. give them enough operational situation awareness). This supports the notion that communicating his planning decisions alone was not enough, but rather he wanted to communicate some rationale for the plan (see Section IV for more discussion).

Planner 2B felt there was too much detail in some parts of the initial problem, e.g. that he was forced to plan a "clear up to river" task. He would not have expected that this detail would be mandated (and would in any case be "obvious"). This may relate to a lack of clarity in CPM (at the time) between the task and objective issue leading to how the initial main plan was constructed; the Planner 2B was given “tasks” where he expected “objectives”.

Planner 2B felt that there was information missing from the initial problem, that of the rationale for the start time of one of the tasks (the clear river task), which initially seemed to be counter-intuitive. There was indeed no rationale given as it was not captured in the initial main plan. Since this was significant to Planner 2B, he "rationalised" the counter-intuitive information (i.e. calculated his own plausible rationale), using his understanding of the rest of the plan (in particular because of the unstated need to run a deception task prior to the clear river task). The intuition happens to be correct (demonstrating the experience and human rationality of Planner 2B) but it is possible that in a more complex problem such "rationalisation" might turn out to be incorrect. This is strong evidence that rationale is important to the planners.

2) Timing inconsistencies

There were two timing inconsistencies in each of the sub-plans. At the time, neither tool was able to indicate these inconsistencies in a way that was easy to understand. For example, Planner 2A planned principally by specifying earliest start time and latest end times to tasks. While he had in mind what typical (likely) durations of a task might be, he did not formally specify minimum durations. This later caused issues when it came time to merge the two sub-plans and look for resource conflicts, since a task with zero duration can always be fitted into a plan without conflict. It seems clear that he did not intend to specify minimum durations of zero, so some specification of minimum durations was required.

C. Merging of the Sub-plans

The import and merge of the sub-plan 2A back into the main plan is shown in Figure 5. This demonstrates that the sub-plan created in the PlanEditor could be imported into the Visualizer and amended even though the tools (and their respective displays) are completely different.

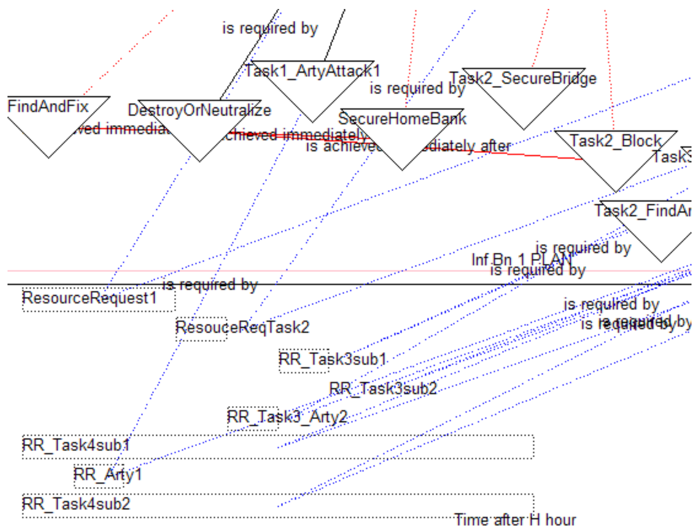

Figure 5. Merging and visualization of the PlanEditor sub-plan 2A in the Visualizer.

The sub-plans were imported into a prototype resource management tool to (manually) detect resource request conflicts. A final merge took place in the Visualizer of sub-plan 2A (as received from Honeywell) and sub-plan 2B (as modified to remove the timing inconsistencies). The entities were repositioned by hand to avoid overlap, and some timelines were added to show the various tasks in the two sub-plans and the timing relations between the tasks. There was an inconsistency in the sub-plan 2A that was not resolved during the experiment.

IV. DISCUSSION

The evaluation has shown that plans may be shared across multiple planners and combined back into a single plan, including the merging of rationale, using the CPM. We recognize that there are a number of challenges that must be met when achieving shared understanding in more complex multi-level collaborative planning:

A. how the same entities are viewed at different levels
B. how rationale may be captured and visualized
C. how the context of the planner is taken into account
D. how the amount of information to be transmitted across the network between planners is reduced
E. how different version of the plans may be managed
F. how conflicts across different plans are managed

A. Multiple-Level Representation

Each planner must have a particular view of the plan and its rationale. In collaborative planning, even though the plan that is being worked on may be logically the "same", different planners in the collaboration may have different views of the shared plan. For multiple-level planning, the planners are likely to have views of the plan entities at different levels of representation, relating to the differing levels of planning. For example, when planning a fire support task, the battalion planner may be concerned about the number of rounds of ammunition that is needed for the field artillery, whereas the logistics planner (who is to support the supply of ammunition to the entire division) may be concerned about the delivery of ammunition at the general level of "crate".

For the plans at different levels to mesh together, the levels of representation must also be compatible, so that the same plan entity (in this case, ammunition) is simultaneously viewed in different ways. There are several ways that different levels of representation of the same plan entity may be related:

- *addition of constraints*: by the retention of the exact same entity at the different levels, but with the lower level entity having more constraints added, to provide a more detailed description.
- *aggregation*: by having different higher and lower entities, the lower level entity being part of a higher level "collection" entity
- *mapping*: by having different higher and lower entities, with a logical semantic mapping between them

The ammunition is an example of the aggregation approach, where the lower level "round" is part of a high level collection "crate". Each different type of multilevel relationship will have its own applicability, challenges and ease of shared understandability. For example the addition of constraints is simple to define and understand and can easily be represented in CPM, whereas mapping may require arbitrarily complex logical inference defined in a logical language and needing sophisticated visualization to achieve shared understanding.

B. Rationale

Shared understanding of related plans is required to ensure synchronization and consistency of plans across multiple levels of planning. To achieve this it is necessary for the collaborating agents to be able to understand the logical aspects of other plans at different levels, and to relate these to their own plans. Logical understanding of others' plans requires: an ability to communicate the logic of a plan, an ability to visualize the logic and its implications, and an ability to express and communicate the rationale for plan entities, including relevant assumptions, decisions and reasoning steps.

During the exercise there were several instances when the availability of rationale would have been useful. Examples include the puzzlement of Planner 2B at the existence of the clear river task, Planner 2A's question of whether the timing constraints could be violated, and Planner 2B's desire to communicate to the reserves.

Whilst planning, Planner 2B articulated a constant stream of rationale, explaining what he was doing and why. This suggests that planners are capable of expressing rationale, This was not captured in the Visualizer, partly due to the main focus of the experiment on capturing the plans, partly due to the nature of the Visualizer tool and partly because of the limited time and high volume of the rationale information. However some was captured on paper, and further work has been done to encode this in the Visualizer, and to link up the formal rationale to conflicts in resource requirements [6]. Further work is required to determine if all of the information could be so encoded. However it is possible that the stream of rationale from Planner 2B was an artefact of the experimental protocol, in that there was an experimenter "in between" the planner and the tool, requiring some higher degree of communication. and further work is also needed to consider this issue. Table 1 shows some examples of Planner 2B's rationale.

Table 1. Rationale, and its context.

Context	Rationale
Choosing an agent for the task SECURE home bank (on the left of the river, the same side of the home forces)	Given that this is line of sight, Armour can be used. Armour is the strongest available resource. We need strongest as the enemy MUST be removed. Therefore use Armd Sqn 4
Choosing an agent for the task SECURE enemy bank (on the right of the river, the opposite side of the home forces)	There is currently no bridge across the river; a bridge is needed; and I assume that the bridge will not be built in time, so can't use Armour. Best remaining is Infantry. Therefore use Inf Coy 2/1. Since the reconnaissance unit is there, we can use them too.

In the CPM, the rationale supports entities in the plan such as objectives or tasks, rather than directly supporting decisions taken by the planners. This is because CPM sees a decision as being something that has an "intuitive" component, more in the nature of an "assumption". However Planner 2B seemed to be justifying "decisions", and further analysis has been undertaken to tease out the exact semantics of decisions and justifications [6].

At the current state of the project, the CPM provides a means of defining the plan and the rationale, Controlled English and higher levels of Controlled Natural Language provides a textual medium for communication of this information [6] and graphical diagrams provides some basic visualization of the rationale [7]. However significant work is required to establish the most suitable means of communication and visualization, and this work must be based on studies of human cognition and the graspability of logic and its implications, together with experiments in the human aspects of communication of rationale. One particular problem is the capturing of rationale. At least one of the planners (2B) articulated a constant stream of rationale, however this is not usually the case in high pressure operational environments. In real situations, planners typically work under severe time constraints and so the focus is on generating the core plan without recording the underlying reasoning behind the decisions.

C. Enhanced Plan Representation with Context Aware Information

In a multi-level planning environment, many planners are working on a plan independently throughout the planning process. Given the complexity of coalition plans, it is difficult, if not impossible, for every planner to understand all details of the entire plan. In fact, each plan participant has its own role in planning process, and therefore may only need to understand a small portion of the plan, along with additional contextual (including situational) information that is not necessarily included in the plan itself.

In our approach, the same planning element will be used for every situation or context [8]. What changes from context to context is not the representation of specific planning elements but what attributes, features, or relationships should be represented (this may be seen as an example of the first type of multiple representation above). Context aware representation speaks directly to the task-specific concerns and interests of specific group of users and, as such, it will selectively represent aspects of the plan and feature representations in which the user operates. Thus shared understanding may not require an understanding of the total plan, only those parts relevant to the planners task in hand.

Since context is situation specific, it is essential that the plan representation scheme can be easily extended to incorporate new concepts as need arises. As a result of the exercise, CPM ontology was updated and functionality enhanced to meet the requirements of the Planners, such as the need to represent decision points and to better view timing constraints.

Planner 2A expressed a desire to schedule concurrent tasks (i.e. those starting and ending at the same time). Although CPM permits the representation of such tasks, neither of the tools permits their input, and this would be a useful addition to the visualization. Planner 2B was able to express the tasks for the subplan, with the exception of a conditional task (i.e. one that would only be executed if certain conditions were met).

At the time of the evaluation, there was still some confusion within CPM (Version 2.7) between the semantics of tasks and objectives, and this surfaced briefly in the discussions with Planner 1 and also with Planner 2B. For example, Planner 2B felt there was too much detail in some parts of the initial problem, in that he was forced to plan a "clear up to river" task. He would not have expected that this detail would be mandated. Thus the planner was given tasks where he expected objectives. The distinction between objective and task has been clarified in the next version of CPM (2.8), where an objective is defined as a predicate to be achieved and a task is defined as a time-based activity that has effects.

The concept of "subtask" was thought of in two different ways by Planner 2B: as something into which a higher task is broken (i.e. the intended meaning); as something that is a prerequisite for another task. (These are not the same concepts, since a prerequisite task may already be present due to another part of the planning process).

Planner 2B was not able to represent conditional tasks. Neither the version of CPM (2.7) nor the tool used by Planner 2B could represent conditional execution of tasks or plans. Planner 2B initially desired to represent such a condition, specifically that if he were to meet more enemy forces than expected on the right side of the river, then he would wish to call in reserve forces to assist. When it was noted that the tool could not represent this concept, Planner 2B decided that this was not really necessary and that he would make the “simplifying assumption” that the location of the enemy was as stated in the original main plan geography.

Subsequent to the evaluation, discussions were held with Planner 1 and the military concept of "decision point" was added to CPM (2.8). A decision point, as defined in CPM, is a three part structure: an observation area, a time window in which a decision needs to be made and an alternative sub-plan typically containing a task in an intent area; the semantics being that if some key event happens in the observation area, a decision is made to execute the task in the sub-plan.

Due to the difficulty that Planner 2B had in adding a decision point, subsequent work was done to add decision points to CPM and associated decision point visualizations were added to the Visualizer. In our case, Planner 2B wished to move reserve forces if there was significant enemy in the east bank of the river, and the subsequent work allowed a decision point to be visualized, attached to an observation of the enemy strength in the relevant area, leading to an alternate plan to be executed if required.

D. Selection and transmission of relevant Subplans

In a multi-level planning environment, yet another challenge is how to reduce the amount of plan relevant information across the network, hence reducing bandwidth and also to increase security. Providing a method for managing the flood of information not only reduces planner information overload that makes it difficult for a planner/executor to find what they need (and burdens them with the laborious task of separating the relevant from the irrelevant), but also reduces network traffic and improves security. We propose to employ context aware information processing as stated in section *C* to transmit the right subsets of the plan (sub-plans) for each planner based on the context, e.g. user task, role, situation awareness, etc..

E. Plan Configuration Management

Configuration management involves identifying plan revisions at given points in time, systematically controlling changes to the plan, and maintaining the integrity and traceability of the plan throughout the lifecycle. Configuration management poses a challenge in multi-level planning environments. When dealing with hundreds of subplans, keeping track of revisions and various dependency constraints imposed on the system, throughout its planning life cycle is very challenging. For example, a plan might depend on one or more subplans for its operation. There are various constraints on plan dependencies, for instance, plan p might require both subplans s1 version 1 and s2 version 3, while another plan might require subplans s1 and s2 both version 2. It is clear that these conditions become very complicated and hard to document, in a large planning system. As the plan evolves and different versions of plans are generated, the problems worsen. We propose formalization for configuration management, based on the approaches developed in [10] for software configuration management and applying it to planning system. Planning constraints and version restrictions can be encoded in CPM/OWL that can facilitate the sharing of knowledge about configurations, across various systems. We hypothesize that these restrictions may be derived, at least in part, from the plan-level rationale that already exists in the CPM. Detection and analysis of plan inconsistencies, by human, is a time consuming process. The machine readability of the OWL language potentially enables the application of reasoning on the specification, to automatically deduce the validity of test configurations, for example by querying the versions that are affected by a change to sub-plan p.

Shared understanding of shared plans requires the planners to keep track of different versions of the plan. By providing a mechanism for configuration management, potentially based upon the rationale of the individual plans, shared understanding may be improved.

F. Conflict detection

The evaluation focused on multi-level collaborative planning. As described earlier, multi-level planning is a process where a top-level planner will develop a plan to a certain level of specificity and then "hand-off" portions of the plan multiple subordinate planners. The resulting sub-plans are developed until the plan is fully specified in terms of standard operating procedures. Once the plan is fully specified, it is rolled up with each higher level incorporating the lower level plans. While this process results in an efficient distribution of work that manages the combinatory of planning, there are several limitations. The principal difficulty is the interaction of independently-generated sub-plans [11]. Interactions between sub-plans can result in two plans utilizing the same resources, be it a physical resource (e.g. a UAV or an artillery capability), a physical location (e.g. two different squads trying to maneuver through the same choke point), or a timing constraint. Often these conflicts can only be detected and resolved at a higher level view of the plan. We hypothesize that by including the rationale in the CPM, when a conflict is detected, the rationale will assist the understanding of why the conflicts arose, what higher level requirements they were derived from, what assumptions and decisions were made, and by whom. This information in turn, we hypothesize, will help the reasoning process that must be undertaken to resolve them.

V. Plan Sharing Vs Plan Interoperability

One of the main challenges in distributed multi-level planning is the fact that there will be different planning tools used by different functional areas and command levels. These planning tools will probably use bespoke semantics related to the functional area. However, there is an emerging NATO standard for command and control (C2) data called Joint Consultation, Command and Control Information Exchange Data Model (JC3IEDM). The purpose of JC3IEDM is to improve interoperability of C2 systems across a combined joint force [11]. It seeks to define "only the information that is to be exchanged rather than all of the information that would be needed by a national system" ([11] page 1) and therefore JC3IEDM is "first and foremost" an information data exchange model. The definition of JC3IEDM is focused on covering the essential information in reports that are exchanged for different purposes, such as an Airspace Control Order or an Operation Order.

While interoperability is necessary requirement for collaborative working, it does not improve shared understanding which is critical for generating effective (and timely) plans. Thus, CPM seeks to define more than just the information to be exchanged, since it seeks to model and support planning as a complete problem solving process as might be executed across collaborating agents. The information needed in problem solving may be more that just the immediate interchange requirements, and may include such information as the rationale for entities in the plan and the intermediate problem solving state (information on choices that have been made, choices that have been rejected, reasons for their rejection and restrictions on choices that have not yet been made).

If problem solving is to be achieved collaboratively, such problem solving information also needs to be represented as part of the data exchanged between problem solving agents. Therefore we are developing the CPM to represent such information, and the current version has a means of representing and rationale in terms of assumptions, decisions, reasoning steps and the consequent information about the plan entities themselves. We do not believe that it is possible to represent such information within JC3IEDM, and therefore systems combined with JC3IEDM will not, we believe, be able to be composed into joint problem solving systems without an additional connection path (e.g. human to human speech) to explain these problem solving aspects, such as what assumptions a particular component of the plan depends upon.

Both the CPM and the JC3IEDM have a conceptual model that underpins the detailed entities, and both have a set of core concepts that are diversified into a set of increasingly detailed concepts. This hierarchy of concepts permits the creation of new high level concepts that may address different situations and organizational structures that may not have been considered when the ontology was created, and also permits the mapping onto other external ontologies by matching across the high level definitions. Indeed a greater degree of generality of the highest level concepts leads to greater ease with which new concepts may be so defined. The CPM has been based upon high level concepts that were developed within the AI planning community with the intention of a high degree of generality and flexibility, such as I-N-O-VA [12] and PLANET [13]. We believe that the highest level JC3IEDM concepts are comparatively more specific to military planning. For example, the CPM defines, as a high level concept, a "constraint" that may represent any restriction on a plan; however the JC3IEDM does not contain the high level concept of constraint in its list of "Independent Entities" [11], although the concept of constraint is embedded into the more specific military concept of "Rule of Engagement". As another example, the CPM has the high level concept of "collaboration", this defining the passing of a problem to be solved from one agent to another. We do not believe that an equivalent concept is explicitly present in the JC3IEDM.

This grounding of the JC3IEDM in more specific military concepts may, we believe, impair the ease by which totally new planning organizational and representational structures may be created using the JC3IEDM, but it is such novel structures that may be key to the future operations of the military in a Network Centric environment. For this reason we are developing the CPM to model higher level, more generic concepts, based on the idea of collaborative problem solving.

In summary, we believe that JC3IEDM focuses on the interoperability of the planning results whereas the CPM focuses also on representing the problem solving process itself in order to facilitate better shared understanding of the plan.

VI. Conclusion

In the evaluation of the CPM, a single planner was able to develop a main plan and delegate the planning of sub-plans to two additional planners. The two sub-planners were able, in parallel, to develop sub-plans that were subsequently merged with the final plan to provide a holistic solution to the main problem. The evaluation was able to successfully demonstrate the integration possibilities of CPM in support of distributed, multi-level military planning. The two sub-planners developed their plans in isolation, on two different (and independently developed) planning tools, and the resulting sub-plans were successfully merged and imported into the original tool.

The study highlighted potential challenges that must be met when achieving shared understanding in more complex multi-level collaborative planning, including issues of representational semantics, rationale, configuration management, context and filtering, and plan interoperability.

The current work has looked at single nation planning involving different levels of command. In the next phase, this research will focus on multi-level planning for coalition operations to explore differences among planners and planning procedures. The research will address some of the issues identified above, including enhancing the representation of rationale and using it to improve planning between levels of command as well as between coalition partners. This is done with the understanding that shared understanding between planners is critical to the generation of timely and effective plans; and for this to happen one needs more than data interoperability.

Acknowledgment

The views and conclusions contained in this document are those of the authors 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.

The authors wish to thank Maj Edward Gentle, Lt Col Richard Sawtell, Lt Col Ian Buchanan, Dr Mike Strub and Dr Jun Yuan for contributions to the research in this paper.

References

[1] NIS ITA Biennial Program Plan 2009 (BPP09)

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

[3] Poteet, S. et al (2009) "Miscommunications and Context Awareness". paper submitted to the 3rd Annual Conference of the International Technology Alliance (ACITA), Maryland, USA, 2009

[4] 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.

[5] Dorneich, M.C., Mott, D., Patel, J. & Gentle, E. (2009). "Using a Structured Plan Representation to Support Multi-level Planning". *Proceedings of the Knowledge Systems for Coalition Operations*, Southampton, United Kingdom, March

[6] D. Mott and J. Hendler, "Layered Controlled Natural Languages", paper submitted to the 3rd Annual Conference of the International Technology Alliance (ACITA), Maryland, USA, 2009

[7] D. Mott, "Visualising rationale in the CPM", paper submitted to the 3rd Annual Conference of the International Technology Alliance (ACITA), Maryland, USA, 2009

[8] A. Bahrami, J. Yuan, D. Emele, D. Masato, T. J. Norman And D. Mott, "Collaborative And Context-Aware Planning," Proc, Military Communication Conference, November 17-19 2008, San Diego California.

[9] A. Bahrami, J. Yuan, P. R. Smart and N. R. Shadbolt, "Context Aware Information Retrieval For Enhanced Situation Awareness", Proc, Military Communication Conference, Orlando FL, 2007.

[10] Hamid Haidarian Shahri, James A. Hendler, Adam A. Porter, "Software Configuration Management Using Ontologies" 2nd International Workshop on Semantic Web Enabled Software Engineering (SWESE 2006), Athens, GA, USA, 2006.

[11] JC3IEDM Overview – DMWG, 24th April 2008, edition 3.1.c.

[12] 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

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