Combining Technical and Human-Centered Strategies for Decision Support in Command and Control:

The ComPlan Approach

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ABSTRACT

ComPlan (A Combined, Collaborative Command and Control Planning tool) is an approach to providing knowledge-based decision support in the context of command and control. It combines technical research on automated planning tools with human-centered research on mission planning. At its core, ComPlan uses interconnected views of a planning situation to present and manipulate aspects of a scenario. By using domain knowledge flexibly, it presents immediate and directly visible feedback on constraint violations of a plan, facilitates mental simulation of events, and provides support for synchronization of concurrently working mission planners. The conceptual framework of ComPlan is grounded on three main principles from human-centered research on command and control: *transparency*, *graceful regulation*, and *event-based feedback*. As a result, ComPlan provides a model for applying a human-centered perspective on plan authoring tools for command and control, and a demonstration for how to apply that model in an integrated plan-authoring environment.

Keywords

Decision support, mixed-initiative planning, critiquing, cognitive systems engineering.

INTRODUCTION

This work presents the ComPlan approach to support plan authoring in command and control. ComPlan combines results from research on both technical as well as human-centered research on mission planning. Our approach is technically related to mixed-initiative planning systems and critiquing systems. Our specific contribution lies in using results from human-centered research on cognitive systems engineering and military decision theory to create a support tool that matches the work process and representation of plan elements of planners.

Designing knowledge-based support tools for planning in military staff and civilian emergency management teams is a challenging task. It can be cumbersome to model all aspects of command and control situations correctly and therefore, many researchers have explored mixed-initiative planning systems as well as critiquing systems to extend the capabilities and usefulness of classical AI systems in realistic planning situations. We can describe research in these areas as a *technical* approach to providing decision support for mission planners. An alternative approach is to study what mission planners actually spend their time on and what requirements their work situation puts on support systems. Such a *human-centered* approach is taken by cognitive systems researchers and researchers who study military decision making. Both approaches have strong merits, and they complement each other well in describing how we can move forward towards usable and capable decision support for command and control. To be successful in realistic settings, however, we argue that decision-support systems research needs to draw from both human-centered as well as technical approaches, and we describe three guiding principles that we maintain are important for plan authoring tools.

In the following sections, we present technical and human-centered research on decision support for mission planning and use these results to support the ComPlan concept.

BACKGROUND

Our work on ComPlan builds on research in both *mixed-initiative planning*, *critiquing systems*, *cognitive systems engineering*, and *military decision theory*. In this section, we present related work from these disciplines.

Mixed-initiative planning

Mixed-initiative planning systems have successfully been deployed for solving logistical problems (Ferguson, Allen, Miller, 1996), to plan space missions (see for example Cortellessa, Cesta, Oddi and Policella, 2004; Bresina, Jónsson, Morris and Rajan, 2004), to help mission commanders plan military operations (see for example Smith, Hildum and Crimm, 2005; Hayes, Larson and Ravinder, 2005), and to plan for large-scale fire fighting (Fdez-Olivares, Castillo, García-Pérez and Palao, 2006).

When using mixed-initiative planning systems, human planners and automated planning systems support each other's actions by producing different parts of the final plan. Some mixed-initiative planning tools allow the user to decide on an overall course of action and suggest methods for dividing a plan into smaller, more specific fragments (see for example, Myers, Tyson, Wolverton , Jarvis, Lee and desJardins, 2002; Fdez-Olivares et al. 2006).

Others involve users in modifying plan constraints, search heuristics or solution criteria (Anderson, Anderson, Lesh, Marks, Mirtich, Ratajczak and Ryall, 2000) to control the search for a solution. Most tools incorporate several of these techniques to allow continuous cooperation between users and an AI planner until a final plan is produced.

All of these support systems assume that the internal domain model of the tool is consistent with real situations, and that complete plan specifications can be produced using a human to fill in slots in a template. In ComPlan, we have taken a somewhat different approach. Although plan constraints can be used to maintain plan consistency, they also serve to highlight problems. The user can choose how to use constraints during planning, with the intention that planning should not be restricted by assumptions made in the internal model.

Critiquing Systems

Compared to mixed-initiative planning, critiquing systems (Silverman, 1992) present a different approach to using domain models for supporting mission planners. Instead of offering solutions, they compare computer-generated solutions to human ones and only present critical differences. Critiquing in military command and control has been studied in several projects (see for example, Valente, Gil and Swartout, 1996).

In a way, mixed-initiative planning systems compare to automated planners in much the same way critiquing systems compare to expert systems. Both can be considered to be relaxations of completely automated problem solvers and interact with the user much more closely than their automated counterparts to maintain trust in the system and to capitalize better on the joint capabilities of both human and computer when solving difficult, real-life problems.

In ComPlan, we demonstrate that a critiquing system for planning and a mixed-initiative planning system can complement each other well. Knowledge, which can be used for planning and simulation, can also be used to highlight constraint violations in the same framework.

Cognitive systems engineering

Cognitive system engineers study how to design efficient support systems for humans, considering how humans think and behave. As a result of such studies, cognitive systems engineers have devised models for intelligent support systems.

For command and control, cognitive systems researchers stress that intelligent support systems should neither *emulate an expert* nor *supply solutions* to problems (Woods, Johannesen and Potter, 1991, Hollnagel and Woods, 2005). Also, cognitive systems researchers have posited that any participant in a planning process, whether human or computer, needs to make its contribution conspicuous and intelligible (Dekker and Woods, 1999). A planning application should make it clear what actions it performs when modifying a plan and help human planners interpret both the reasoning as well as the results of a joint planning process. As a consequence of this, Dekker and Woods (2002) argue that *event-based information, simulation of predicted events* and pattern-based representations should make for effective support rather than automation of command and control.

In ComPlan, we visualize information, provide domain-dependent feedback and manage constraints using the same knowledge source and mechanisms.

Military decision theory

Planning military missions involves generating a plan on the one hand, but on the other, it is also very much about improving one's understanding of a situation (Shattuck and Woods, 2000). As an example of this, Ferguson, Allen, and Miller (1996) found in a study that only 23% of the utterances in problem-solving dialogues of human planners actually refer to suggesting courses of action. The rest of the communication pertained to establishing a common understanding of the situation and discussing strategy. Based on this analysis, one could argue that a planning support tool should be built to support *all* relevant activities that human planners actually spend their time on, and not only those that involve creating a plan.

However, it is not that easy to establish exactly which work to support in military planning. Traditional planning models established in military doctrine such as the NATO Guidelines for Operational Planning (GOP) (North Atlantic Treaty Organisation, 2000) or the US Field Manual 101-5 (Department for the Army, 1997) *pre*scribe how to plan military operations at various levels, but they may not accurately *de*scribe how planning is performed in practice.

One recently developed model of decision making, the Recognition Planning Model (RPM) (Ross, Klein, Thunholm, Schmitt, Baxter, 2004), describes the activities of military commanders when they plan military operations. The prescribed model for planning as stated by the GOP declares that the planner should gather information without committing to any particular course of action, then form at least three different courses of action, evaluate them in parallel and select the most appropriate one for execution. According to the RPM, this is not always the case. Rather, military commanders tend to commit to a single alternative early in the planning process and use various techniques to adapt the plan to the current situation. This means, generating many different options for complete plans may not be most useful to planners, which has also been noted in field studies on mission planning (Ross et al., 2004).

Guiding principles

One of the toughest challenges when devising intelligent decision support for mission planners may be to incorporate high-level knowledge-based reasoning in a manner that is acceptable for end-users and offers efficient and clear support. Dynamic situations, where goals and means to solve them can change frequently puts high demands on the design of support tools.

We have elicited three principles from research on command and control that have influenced our work on ComPlan: *transparency*, *graceful regulation* and *event-based feedback*.

Transparency

When faced with the challenge of creating a domain model for such a complex domain as mission planning for crisis situations, there are basically two options for researchers. The first option is to improve the knowledge elicitation process and support domain experts when describing a domain of interest (see for example Kim, 1999; Blythe, Kim, Ramachandran and Gil, 2001).

The other option is to make the domain model open for inspection and modification by the end users. This approach has been used in, for example, the SIADEX system (Fdez-Olivares, Castillo, García-Pérez, and Palao, 2006). Creating an open knowledge base is also a prerequisite for the support system to act as a “good team player” as described by Dekker and Woods (1999). They claim that *transparency* in the reasoning process, and hence in the knowledge base underlying the reasoning, is necessary for intelligent support systems to be successful.

In the case of an automatic planner, the reasoning process is more or less by design obscured from the user's view although researchers have studied extensively how to use, for example, dialogue interfaces to support human-computer collaboration (see for example Myers, 2003; Ferguson, and Allen, 2005; Muñoz-Avila, Aha, Breslow, and Nau, 1999). Still, making formal reasoning comprehensible in partially automated planning systems presents a major challenge. In ComPlan, we have opted to use domain knowledge in applications we believe are easier to inspect than partially automated planning, such as maintaining constraints based on visually represented dependencies and presenting visual feedback (critique) on plan modifications. Also, domain knowledge in ComPlan can be inspected through the use of multiple views representing different aspects of a plan.

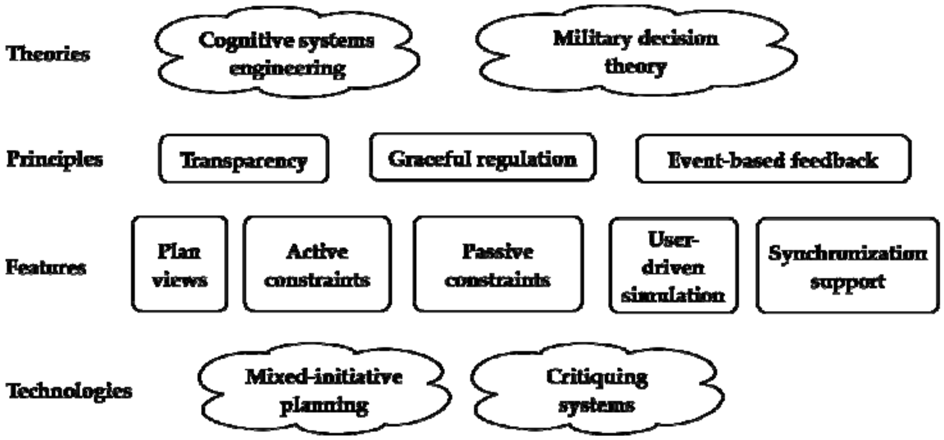

Figure 1. The main features of the ComPlan model are justified by three guiding principles elicited from human-centered research on Command and Control and based on research on mixed-initiative planning systems and critiquing systems.

Graceful regulation

The concept of graceful regulation alludes to graceful degradation: the ability of a system to function even in the absence of some components. In our case, the user may at one time restrict the use of a certain constraint and still benefit from other functionality in ComPlan. Some parts of the internal domain model may be known to hold most of the time, yet not always. In such a situation, the support tool must be prepared to accept plan modifications that conflict with its internal reasoning. Otherwise, it will be of little use in situations when its' model is invalid. An alternative to modeling a domain well enough so that these situations do not occur and not consider uncertain knowledge as part of the domain model is to offer *different strategies* when using the knowledge. ComPlan offers the option of switching between *active* and *passive* use of constraints as well as disabling them completely. By setting a constraint as passive, it only notifies the user of possible constraint violations instead of enforcing the declared or implied constraints of the plan. The user may also opt to make a passive constraint active again.

Event-based feedback

As Dekker and Woods (2002) argue, event-based feedback is an important mechanism for providing decision support in command and control. Researchers in the field of mixed-initiative planning have also noted that support for synchronizing the distributed work of multiple planners may in fact be more important to the success of a military staff compared to semi-automatic plan generation (Myers, Jarvis, Lee, 2001). Events that trigger feedback in ComPlan include all plan modifications made locally and also those made by other planners, so that feedback can be provided on all plan modification events in a staff environment. Events that trigger feedback could in principle correspond to any directly observable change in the plan or environment. In a mixed-initiative plan generation system, events that modify the plan come primarily from the plan engine itself, which makes event-based feedback more difficult to implement since the user interaction does not directly correspond to changes in the plan.

THE COMPLAN MODEL

With ComPlan, we believe we have created a model for plan support systems that creates an intersection between the cognitive needs as stated by researchers on cognitive systems engineering and military decision theory on the one hand, and the technical opportunities exploited for support exploited previously in mixed-initiative planning and critiquing systems.

Figure 1 illustrates the concepts introduced by ComPlan and their relation to research on cognitive systems engineering and military decision theory. In the following sections, we present each of them in turn.

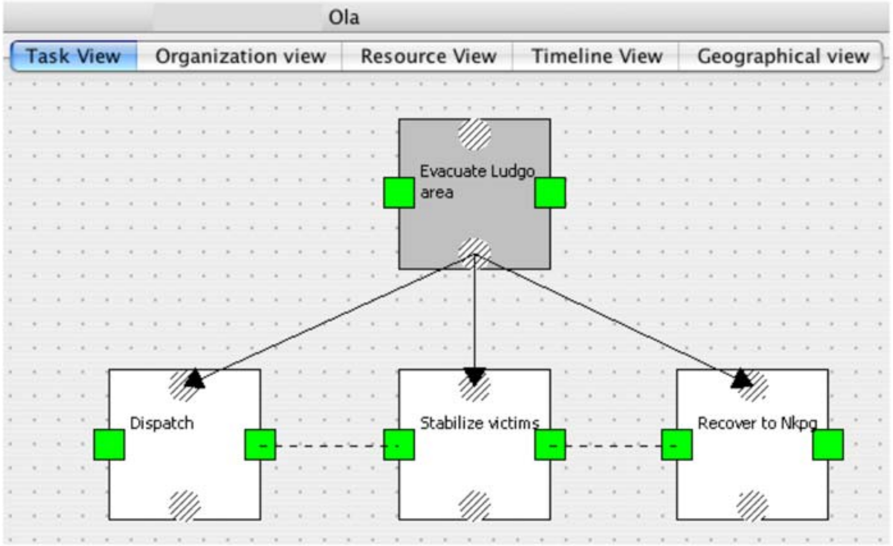

Figure 2. The *task view* describing a set of tasks to be carried out during a mission, with dependencies marked with lines between them.

Plan views

Plan views present plan information to human planners in a way that is conceptually natural to them. In

ComPlan, views are accessible and editable in parallel, and use direct, graphical representations close to the ones used in traditional military planning. In our current implementation of the ComPlan model, they include

- the *task view*: a visual, *graph-based representation* of the relationships between tasks in a plan (see Figure 2),
- the *organizational view* which presents the domain knowledge of resources available for the current planning situation,
- *timelines* for tasks and resources that provide an overview of the timing of the plan (see Figure 5), and
- a *map* which presents spatial information and geographical constraints.

In these views, we present users with the option of using feedback mechanisms (passive constraints) that are specific to each view. Each critic presents information either graphically as overlays on the ComPlan interface or in natural language. These *passive constraints* are based on the same technique used to enforce *active constraints*, which help a planner maintain certain aspects of a plan automatically.

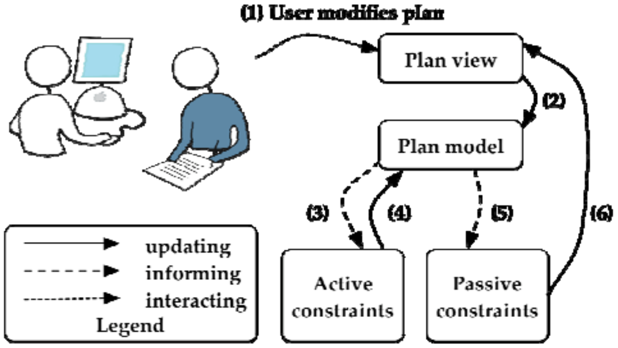

Figure 3. Ilustration of user interaction with ComPlan during planning. As the user modifies the plan, ComPlan manages active constraints to keep the plan in a consistent state and thereafter notifies passive constraints of the current state

Active constraints

Active constraints are provided for planners to facilitate plan consistency when making changes. This functionality comes from the active use of constraints in some mixed-initiative planning systems and provides useful help for planners to check the consistency of the plan. As part of planning with a mixed-initiative planning system, users can modify or add constraints in a plan. These constraints may affect the timing of a task, its use of resources or relation to other tasks. In other systems, they can be used to restrict an automated planner when it searches for new plans, or to enforce constraints in the face of plan manipulations initiated by the user. Bresina et al. (2005) call constraints that enforce relationships during user interaction *active constraints* when describing the MAPGEN mixed-initiative system, which is also our intended meaning of the term. By analogy, passive constraints denote constraints that do not enforce relations but rather notifies the user in case of perceived inconsistencies.

Figure 3 shows how ComPlan responds to user interactions and in particular, the relation between active and passive constraints. Active constraints keep the plan in a consistent state as users make changes. Following the updates by both the user and the active constraints, passive constraints can immediately update the current plan view with visual feedback.

Passive constraints

All user interactions trigger an evaluation of the plan with respect to both active and passive constraints. Passive constraints, or *feedback mechanisms*, are evaluated after active constraints are processed (see Figure 2) and may, at the user's consent, present information on specific problems related to plan structure, timing or resource allocation. Passive constraints can change *policy* and become active, and active constraints can become passive. The reason for this is to achieve *graceful regulation* of the level of support our tool provides in case the knowledge base is not correct with respect to the current domain.

The analysis performed by our constraints is based on a straightforward model of a planning situation, where much of the underlying assumptions used by the system are exposed to the user and can be modified at run-time. We do not use an extensive knowledge base but have instead opted for a solution where as much of the domain knowledge as practically possible can be inspected and modified through the tool. We base this decision on the principle of *transparency*, which has been stressed as important by both Hollnagel (2005) and Dekker and Woods (2002) in the context of intelligent decision support systems. In ComPlan, all numerical settings on values such as the range and fuel consumption of vehicles, the distances between locations that the timing of missions can be set explicitly through the plan authoring interface.

Apart from using policies for constraint use, we promote transparency by using domain knowledge in user-driven interactive *simulations*.

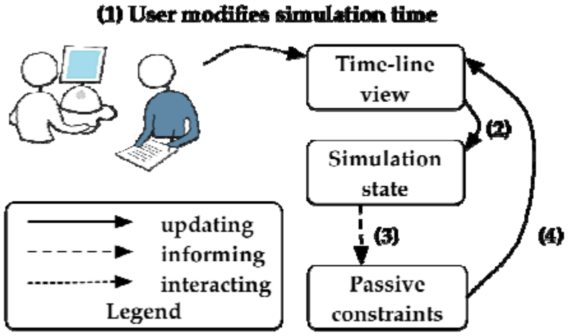

Figure 4. Illustration of the workflow during simulation in Complan. The simulation is directed by the user through a slider that represents the current time in the simulation.

Simulation

Our concept of interactive simulation uses a set of deterministic constraints in a user-controlled[1] simulation that provides immediate access to plan consequences and also feedback based on those consequences. Figure 4 provides an overview of this process. Whenever the user modifies the current time in the simulation, the simulation engine updates the simulation state and notifies constraints and visualization components accordingly. As a result, the user receives notification of potential problems if there are any and also receives a visual presentation of the projected state at the selected point in time.

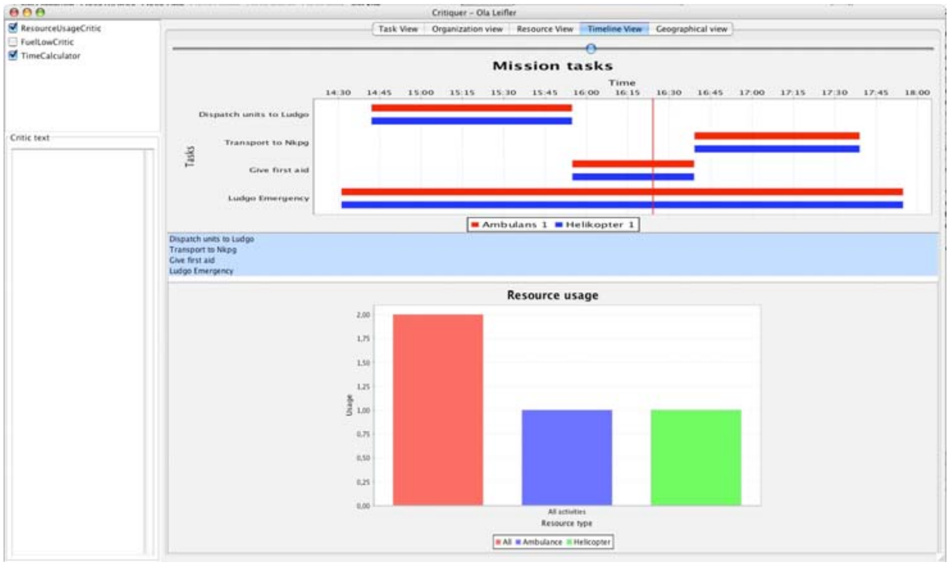

Figure 5. Screenshot of a simulation performed by the user in the time-line view. The user controls the simulation directly by moving a slider, and receives information immediately on some specific properties of plan at that point in time.

In Figure 5, we see an example of such a simulation in ComPlan. As a consequence of the user pulling a slider, the simulation engine advances the simulation to the corresponding point in time, indicated by a vertical bar in the time line. The user has requested information on resource usage, thus a bar chart with this information is displayed below the time line.

Interactive simulation can be useful when a large number of tasks and resources are planned for. Trying out and simulating many different approaches helps the user evaluate scheduling options and mentally simulating events. It

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[1] The simulation is *manually* driven forwards or backwards by the user.

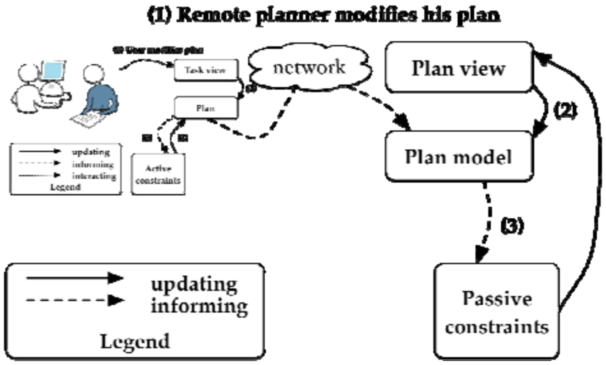


Figure 6. An illustration of using the actions of remote planners as input to the constraint engine.

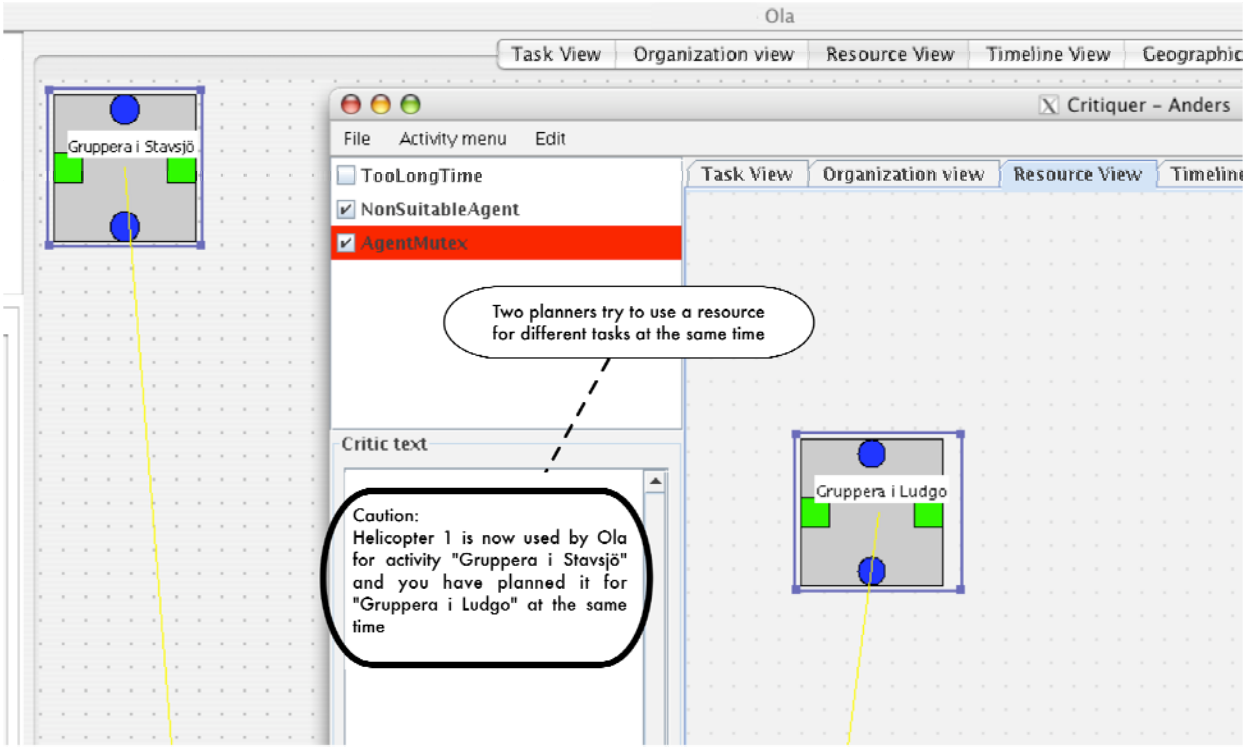
can also be useful when a mission that has already begun needs to be re-planned and the consequences of small modifications to an existing plan need to be evaluated quickly.

Although it is important to provide simulation of future events and supporting efficient exploration of options for a *single planner*, this form of support is not sufficient in a scenario where many different people collaborate on planning an operation. Therefore, we have devised a mechanism for informing one instance of ComPlan of the actions taken by other instances on the same network, so that several planners can work jointly on planning an operation.

Synchronization support

A joint staff needs to make sure resources are not oversubscribed and that there are no conflicting intentions among planners. To support the synchronization of work performed by several concurrently working planners, we use the same model for constraint propagation and feedback as described in Figure 3 extended with support for remote planners.

Figure 6 illustrates how planning actions performed in one instance of ComPlan on a network can propagate to other instances. Actions from a remote ComPlan instance do not lead to updates of a local plan, since this would violate the principle of *transparency*, but rather, only passive constraints are fired so that the local view can reflect conflicts between the locally developed plan and plans made by others.



☐ TooLongTime
☑ NonSuitableAgent
☑ AgentMutex

Two planners try to use a resource for different tasks at the same time

Caution:
Helicopter 1 is now used by Ola for activity "Gruppera i Stavsjö" and you have planned it for "Gruppera i Ludgo" at the same time

Figure 7. Illustration of how a critic notifies the user of a conflict in resource usage between two planners.

Figure 7 illustrates how two instances of ComPlan operate together when on a local network. Once aware of each other, plan modifications performed in one instance of ComPlan are forwarded to remote instances where they are treated as if a local user performed them. In the figure, there is a conflict of resource usage that is signaled as a text message to the local user.

DISCUSSION

Plan views

Cognitive systems researchers have long stressed the importance of embedding support systems in the context of work, so as to make use of naturally occurring cognitive artifacts and *enhance* existing practice, not *replace* it (Woods, 1986; Hollnagel and Woods, 2005). In a sense, automated planning systems *replace* some activities during planning by suggesting courses of action based on an initial set of parameters. In experiments with the Recognition-Primed Decision Model, researchers found that commanders were much more interested in visualization support than tools for generating plans (Ross et al., 2004).

ComPlan allows manual planning with the option of maintaining constraints determined by the user. This simplifies the existing practice of calculating the time requirements of different plan options but does not automate any of the cognitive activities during planning. Although ComPlan makes extensive use of multiple, concurrent, directly editable views, the concept has been discussed and implemented partially by other researchers on mixed-initiative systems.

When describing opportunities for future research in mixed-initiative planning, Burstein and McDermott (1996) name specifically “different perspectives of conveying information” as an important area. In research closely related to the agenda for mixed-initiative planning systems, Jones (1993) describes views as important means of enhancing collaboration in mission planning contexts. There are different interpretations of this concept in plan authoring tools. Levine, Tate and Dalton (2000) use views to present human planners with information related to the planning process in the O-Plan plan authoring system and Kim and Blythe (2003) use the concept of views to present time-related information of process models in the KANAL critiquing tool.

Even in the absence of multiple concurrently available views that a planner can switch between, several mixed-initiative tools allow hierarchical specifications of plans using one interface, and some manner of seeing the consequences of the plan as it unfolds using another (see for example Smith, Hildum and Crimm, 2005; Fdez-Olivarez et al., 2006; Myers et al., 2003; Foor and Asson, 2001).

Simulation

Burstein and McDermott (1996) argue in their research agenda for mixed-initiative planning that simulation should be an integral component for visualizing plans, and that simulation should resemble a movie showing the unfolding of the plan. Using simulations in such ways suggest that simulation results should be *graphical* and used primarily to *emphasize information* relevant to a human planner, not to achieve optimal solutions by iteratively simulating different plans. Modeling and simulation play a central part in military planning as a human process described by the Recognition Planning Model (RPM) (Ross et al., 2004), which characterizes military planning as a process where commanders initially choose a template plan as their preferred option. This template is often based on earlier experiences and is adapted as more information arrives. An important step in the development of a plan is *war gaming*, whereby a plan is subjected to "what if" scenarios and tested iteratively. War-gaming is often performed, individually or in groups, as a mental *simulation* of hypothetical future events to allow better understanding of the possible outcomes of a plan. This is also the intended use of simulations in ComPlan.

In emergency response applications, modeling and simulation have been used for many different purposes, although for the most part, such simulations have been isolated from other information systems. Recently, however, researchers have begun to argue for the integration of simulation as part of larger frameworks for decision support (Jain and McLean, 2003), much as simulation is integrated in ComPlan.

Collaboration support

Myers, Jarvis and Lee claim that for many military planning situations, collaboration tools could turn out to be more useful than automated plan generation systems due in part to the difficulty of modeling the domain (Myers, Jarvis and Lee, 2001). Myers et al. presented a tool, CODA, where planners subscribe to certain types of changes made by others to a common plan. By subscribing to such information, CODA helps planners collaborate through their planning tools between joint meetings. For example, two planners who decide to use the same exclusive resources for a period of time during a mission can be notified of this inconsistency through CODA. In comparison to CODA however, ComPlan can analyze *all* remote plan modifications and not only specific types of changes.

RELATED WORK

Related work on creating models for plan-authoring tools has mostly been based on technical research on automated planning (mixed-initiative planning) and critiquing.

System	Plan views	Passive constraints	Active constraints	User-driven simulation	Synchronization support
PASSAT		●	●		
ComiRem			●		
INSPECT		●	●		
ComPlan	●	●	●	●	●

Table 1 . A Comparison of Planning Systems

System	Plan views	Passive constraints	Active constraints	User-driven simulation	Synchronization support
PASSAT		●	●		
ComiRem			●		
INSPECT		●	●		
ComPlan	●	●	●	●	●

Table 1 . A Comparison of Planning Systems

presents an overview of previous projects in the area of plan authoring support. Most other related tools are similar in the sense that automatic constraint management or text-based feedback based on complete plan specifications has been the principal concern.

CONCLUSIONS

ComPlan demonstrates how to combine results from human-centered research with concepts from mixed-initiative planning systems and critiquing systems when supporting mission planners in crisis situations. The concepts in ComPlan are based on three important principles elicited from research on command and control, and the selection and implementation of support techniques in ComPlan have been chosen based on how they support these principles. In doing so, we provide a model for more user-centric application of decision support technologies, which can be used to verify claims by command and control researchers regarding how to design decision support systems. By paying attention to human-centered research in the design of ComPlan, we demonstrate how to design support systems that may better reflect human needs and human thinking as described in previous research on human behaviour in crisis management.

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