Using AI Planning Technology for Army Small Unit Operations

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Abstract

In this paper, we outline the requirements of a planning and decision aid to support US Army small unit operations in urban terrain and show how AI planning technologies can be exploited in that context. The work is a rare example of a comprehensive use of AI technologies across the whole planning lifecycle, set in a realistic application in which the actual user community set the requirements. The phases involved include:

- Domain knowledge elicitation
- Rich plan representation and use
- Hierarchical Task Network Planning
- Detailed constraint management
- Goal structure-based plan monitoring
- Dynamic issue handling
- Plan repair in low and high tempo situations
- Interfaces for users with different roles
- Management of planning and execution workflow

Introduction

In this paper, we outline the requirements of a planning and decision aid to support small US Army units operating in urban terrain and describe the prototype system we have built that demonstrates how AI planning technologies can be exploited in this context. The post cold war environment poses new challenges for the US Army. It is anticipated that in future it will operate more extensively in small conflicts within urban terrain (cities and towns). This is termed Military Operations in Urban Terrain (MOUT). The US Defense Advanced Projects Agency (DARPA) Small Unit Operations (SUO) Situation Awareness System (SAS) Program is developing the technological aids that will help provide the Army with operational superiority in this new context. The main role of the situational awareness component is to provide the soldier with richer information about the environment or battlespace in which he or she is operating through improved communication and electronic sensing capabilities. The Planning and Decision Aid (PDA) component is to assist the soldier in using this new wealth of information to make planning and acting decisions. In this paper we report on our work to identify the requirements of a PDA and describe the prototype system with have built to support the soldier.

This work was performed as part of the DARPA SUO/SAS Program and the DARPA/Air Force Research Laboratory Planning Initiative (ARPI) (Tate, 1996b). The Planning and Decision Aid (PDA) element is a joint project with SRI International. To complement AIAI's work on MOUT, SRI International is exploring the use of, SIPE (Wilkins 1988), PRS (Georgeff & Lansky, 1987), and MPA (Wilkins and Myers 1998) in Army operations down from battalion level and in open terrain with mechanized forces.

The remainder of this paper is structured as follows. We first introduce the planning requirements of US Army small units and detail how they vary depending upon the phase of an operation and the tempo of combat. We then discuss how these requirements can be supported with AI Planning technology, emphasizing the techniques relevant at each operation phase and combat tempo. The challenges posed for designing interfaces to AI planning systems in this environment are introduced and solutions proposed. The work is a rare example of a comprehensive use of AI technologies across the whole planning lifecycle, set in a realistic application in which the actual user community set the requirements.

Army Small Unit Planning Requirements

Small Unit Operations (SUOs) are typically company sized. In the US Army, companies are led by a company commander and consist of around four platoons. Each platoon is lead by a platoon leader who commands two or more sections, with each section composed of two or more squads. Squads are lead by a squad leader who controls two or more fire teams, with each fire team made up of approximately four soldiers.

The primary question we sought to answer during the requirements gathering was what kind of planning and decision aid a small army unit operating in urban terrain could utilize. Operations involve close combat situations in which it would appear that little time would be available for deliberative planning, generating options, and evaluating their individual merits. In our early work with Subject Matter Experts (SMEs) at Fort Benning, Georgia, USA, we worked to understand the points where plan information would become available, could be further developed, and could potentially be brought to the attention of soldiers in a militarily beneficial and feasible way. What surprised us from the earliest meetings with SMEs was that even in high tempo situations it may be possible to provide appropriate planning and decision aids that could be of use. Even when confronted with an unexpected situation needing rapid decision making, there are situations where a platoon or fire team leader will get their soldiers into a safe position to regroup and re-approach a target - often needing coordination with other parts of their company.

We have found that a separation of a number of distinct types of planning and decision support concerning action selection and monitoring is helpful to ensure that appropriate mechanisms are considered when thinking of the different situations involved in SUOs. We have identified the stages in the overall process at company level from receipt of mission through to a successful outcome and after-action activities. Within this process there are opportunities for a range of planning and decision aids, all facilitated by a common approach to representing the objectives and plans involved. An outline of this is shown in Figure 1.

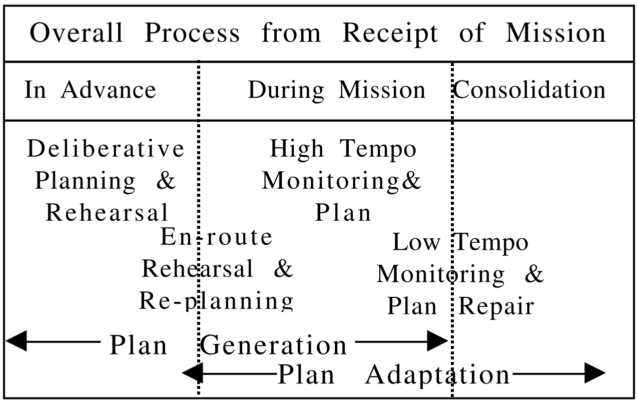

Figure 1: Phases of Planning and Execution in the MOUT Scenario

Operations are divide into three phases. The advance preparation encompasses the receipt of an order to undertake a mission through to the planning and preparation for that mission. The mission phase encompasses the infiltration, approach to target, and execution of the mission. The consolidation phase is composed of the post mission tasks such as dealing with casualties and prisoners and securing or leaving the target area. The planning requirements at each phase are distinct and also depend upon the tempo of combat. These categories are included within Figure 1 and are positioned across the phases to which they relate. The properties of each category is detailed in the list below:

- **Deliberative Planning & Rehearsal:** a company usually has a few hours to plan and rehearse a mission before moving to the next phase. At this time the Company Commander and his or her Platoon Leaders want to explore the space of approaches to the mission. They have maximum flexibility at this time with respect to the form of the operation, the constitution of the force, the specialized equipment to take, and the distribution of that equipment within the force. The team can also communicate face-to-face and rehearse and war-game options to evaluate them and familiarize their force with the operation. Workstations or laptop computers may be available and aids such as white boards are easily accessible for communication.

- **En-route Rehearsal & Re-planning:** while the previous phase sets the overall approach to an operation, during its approach to a target a Company will continue to rehearse the forthcoming operation and must adapt its plans in the light of new information. Critical decisions in the mission plan may become invalid, and the Company Commander needs assistance in identifying when this has occurred and in adjusting the original mission plan to compensate. The flexibility for re-planning is now reduced as the Company has started to deploy. Re-planning must account for this. Elements of the Company will also now be separated and communication is limited.

- **Low Tempo Adaptation & Plan Repair:** this type of reasoning occurs when elements of the company are in close proximity to the enemy but are not engaged in combat. As in the previous phase, new information may invalidate the current plan; however, the options for re-planning are now much more constrained. The Company Commander and Platoon Leaders require support in identifying changes which threaten the current plan, and in rapidly identifying repairs that will enable the plan to proceed.

- **High Tempo Adaptation & Plan Selection:** when in contact with the enemy, behavioral options are limited, the pace of decision making must increase, and the outcomes of those decisions are critical. At this stage support is needed for monitoring plan execution and the identification of when a unit's forced reaction to enemy activity threatens that plan. This can be brought to the attention of friendly units not engaged who can take action to repair the plan. Those involved in the combat look for support in terms of plan options for ensuring their safety. In situations of this type, only lightweight soldier-borne computers may be available with limited interfaces and modalities.

With the operational requirements of a Planning and Decision Aid introduced, we describe in the following sections the demonstration scenario and prototype system that we have built to address them. We emphasize the AI planning technology exploited at each stage.

Demonstration Scenario

To both motivate and demonstrate our PDA system, we worked with a MOUT scenario, San Roberto, which was designed by SMEs within the DARPA SUO/SAS program to demonstrate the full range of situations that occur when operating in this environment. We introduce this scenario briefly before describing the support for the requirements identified in the previous section.

Operation San Roberto

Operation San Roberto takes place in a small town occupied by hostile forces that have imprisoned the local civilian population and are calling artillery fire onto friendly positions. The task in Operation San Roberto is to enter the town to liberate the local civilian population and capture the hostile force. A map of San Roberto is given in Figure 2. The small town involved is an actual MOUT training facility at Fort. Benning, Georgia, USA, and is designed to accommodate the typical features found in urban environments. The MOUT site consists of around forty buildings with a church, a town hall, and a hospital at its center. The hostile forces are holding the civilian population in these central buildings. The standard approach to an operation of this type would be to send a platoon at each building, keeping a reserve platoon in the rear. The platoons will covertly approach the target buildings through "toe-hold" buildings before storming the target buildings and neutralizing the hostile force in each.

Modeling Objectives and Actions in the MOUT Domain

In this section we describe the approaches taken to modeling the objectives that a small army unit can be set to achieve in a MOUT environment, the input to the planning problem, the actions that the unit can perform to achieve those objectives, and the domain operators.

Modeling the Objectives

Prior to actually performing a mission, an Army Small Unit will be provided with an Operations Order (OPORD) prepared at a higher echelon. OPORDs are written in natural language but follow a strict five-paragraph structure and use stereotyped phrases. The paragraphs describe the situation, the mission, how that mission is to be executed, the service and support plan, and the command and signal arrangements.

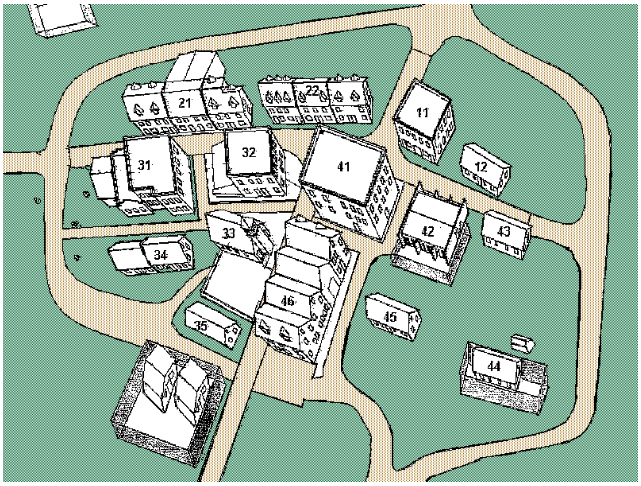

Figure 2: Layout of the town featured in Operation San Roberto

We mapped the contents of the US Army OPORDs for Operation San Roberto to the <I-N-OVA> (Tate 1996a) ontology for plan representation. This enabled us to cast the information contained in these documents in planning terms. In overview, the OPORD situation section contains information about the state of the world in which the plan is to be executed. It includes the terrain, the buildings, and the locations of friendly and hostile forces. The mission and task sections describe the objectives that a small unit is to achieve. Details on the actual input of OPORD information to the prototype are given in the section on *Generating and Comparing Options* below.

Modeling the Actions

In realistic applications the quantity of domain knowledge that must be captured and formalized is significant, and this task demands a considered approach. In modeling the MOUT domain we exploited IBM's Business Systems Design Method (BDSM) (IBM 1992), the Task Formalism Method (Tate, Polyak, & Jarvis 1998), and the Common Process Method (Polyak 1998). We used the tool support provided for the Common Process Method in the form of the Common Domain Editor.

These methods provided considered stages that included checklists and modeling notations for capturing aspects of the domain. The task was significantly helped by the US Army practice of recording Standard Operating Procedures (SOPs) for the tasks it performs (US Army 1999). SOPs are detailed descriptions of the steps a unit should take in order to achieve a task. Several methods are typically provided for a given task and each method is annotated with the situation for which it is best suited. Figure 3 shows a screen capture of the MOUT model represented in the Common Domain Editor. The tool's graphical facilities aided the visualization of the knowledge and its checking tools helped identify inconsistencies.

General methods such as BSDM do not provide tools for checking planning specific information such as the state transitions allowed by precondition and effect descriptions. CDE provides a planning specific tool for checking the consistency of the temporal relations in HTN operators, detecting circular sub-graphs etc. We also used the OCLh framework (McCluskey and Kitchin 1998) to provide planning specific model checking. OCLh's focus on specifying the objects in a domain and the substates that each can occupy made us think deeply. While the differences between the Task Formalism used by O-Plan and the OCLh formalism prevented us from using the tool support for OCLh directly, the concepts provided a useful pencil and paper exercise alongside the model development. Its use enabled us to capture modeling errors such as inconsistent substates inadvertently allowed by operator definitions.

Figure 3: MOUT SOPs encoded in the Common Domain Editor

Generating and Comparing Options

OPORDs can be shared between military planners and AI Planning Assistants and form the initial requirements against which a Company Commander can establish options for the Course of Action (COA) to be taken. At this early stage, workstations and other "Back at HQ" type tools can be utilized and there is time to explore differing initial assumptions, advice on tactics, etc., in a mixed initiative planning fashion with support from the AI planner.

O-Plan Technology has been used to support this phase. We have developed a prototype based upon the O-Plan system's ability to assist the user in generating and reviewing qualitatively different solutions (Tate, Dalton & Levine 1998). Multiple users performing different task assignment (command), planning and execution monitoring roles can use O-Plan concurrently. The users can interface to O-Plan and each other via Open Planning Process Panels (Tate et. al., 1999). These panels are configurable interfaces accessible through any World Wide Web browser. The panels support the workflow of the planning process and assist in the coordination of the multiple participants.

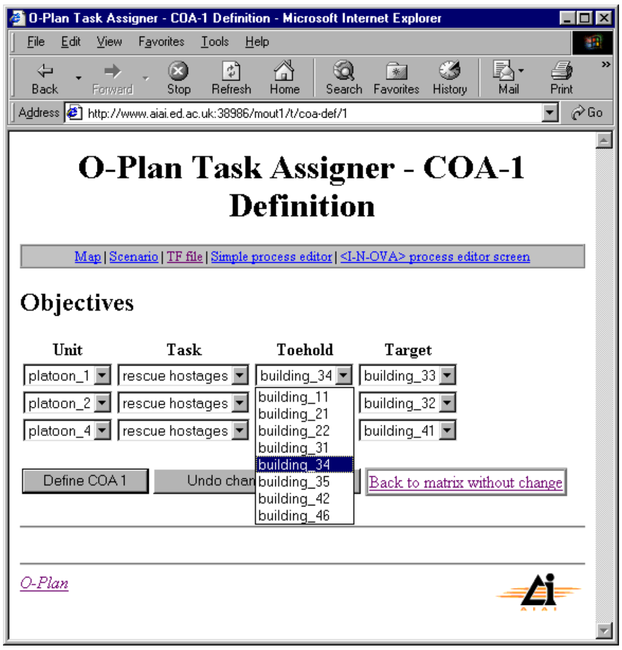

Figure 4: Commander's Objectives Screen

The first stage of the process supports the user in defining the objectives he or she wishes to achieve. In this domain, that mostly consists of accurately inputting the requirements set for the small unit mission by the upper echelon as communicated in an OPORD. A simple pull down menu style of objectives setting screen is provided in this system (see Figure 4), though more comprehensive objectives setting aids using grammars of objectives are possible (Valente et al., 1999). The user is presented with a list of objectives and possible resources, time limits and approaches and sets these as required for each option to be explored.

The commander may at this stage wish to add guidance, additional constraints or advice (as is done in versions of SIPE-2 in the work of Myers (1996)). In the current system only additional constraints on the solution can be added through the interfaces provided. The outline plan incorporating the constraints and objectives is then passed over to the planner user for work.

The planner user can work with O-Plan to generate and explore any of a number of sub-options to address each top level option that the commander is seeking plans for. Each can have varying approaches or assumptions – added by way of additional constraints and limitations. A screen (see Figure 5) is provided in which the planner role user can set the freedom of operation of the AI planner itself (which we term authorities (Tate, 1993)). In fact all users and the AI planning system have their own authorities to perform and this is the basis of the mixed initiative modes in which they can all interact (Tate, 1994, Allen et. al., 1996).

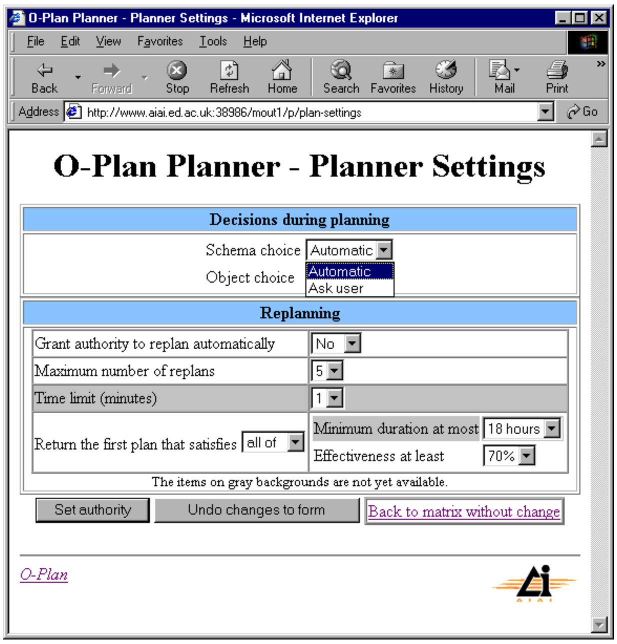

Figure 5: Planner's Screen: Plan Authority Settings

The planner works to establish one or more sub-options for the task in hand, and may select which of these are to be returned to the commander.

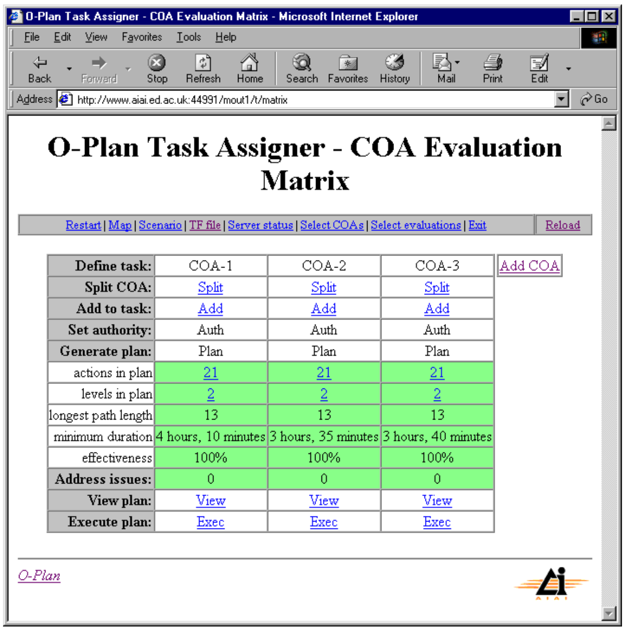

Figure 6: Commanders' Screen: Course of Action Evaluations and Comparison Matrix

The commander may then view the various options and approaches available, consider the assumptions on which they are based and review any of a number of plug-in evaluations performed for each. This is shown in Figure 6.

The evaluations are simple in the system produced, but the overall approach allows for sophisticated evaluation plug-ins such as INSPECT (Valente et al., 1999), simulation systems (Cohen, Anderson, and Westbrook, 1997), and critics or plan comparison functions. Such sophisticated evaluators were used with the process panel technology included here for an Air Campaign Planning system under the ARPI program (Wilkins and Myers, 1998).

Monitoring Plan Execution

After a set of plans have been generated, a plan may be selected for execution. While the actions in a plan are being carried out, a situational awareness system can gather information from sensors, or reports by the units that are participating in the operation, in order to form a picture of the current state of the world. This information can be used to detect problems, to determine their effect on the plan, and hence to initiate a process of plan repair.

Our plans contain "goal structure" descriptions in the form of causal links (Tate, 1977) that indicate the purpose of actions in the plan and the causal relationships between actions. An action may set up the situation required for a later action to take place. For instance, a unit must secure its toehold building before it can move to the building where hostages are being detained. In general, actions have preconditions, and the goal structure indicates which other actions, if any, function to satisfy those preconditions.

The presence of goal structure information in the plan has two important consequences. First, the preconditions indicate what aspects of the developing situation are relevant to the successful execution of the plan, and that can in turn guide the selection and placement of sensors and indicate what information it is most important for units to report (Reece and Tate, 1994). Veloso, Pollack, and Cox (1998) provide a related method. Second, if a planned action cannot be completed successfully, or if something else occurs that breaks a precondition (for instance, if a unit cannot move because it is under fire, or if an obstacle blocks its intended route), it is possible to determine what effect this has on the entire rest of the plan and to consider modifications to the plan that would put it back on track. Events that have no effect on the plan need not be brought to the user's attention. For instance, a landslide that blocks a route no one was planning to use can be ignored unless it later becomes relevant. This is a significant advantage of deploying AI technology is this domain. The wealth of information generated by sensors has the danger of consuming soldiers within an information blizzard. This approach of relevance filtering, based on causal structure, ensures that only new information of direct relevance to the current plan is presented to the user.

The operation of the plan monitoring facility in the demonstration system is shown in a simulated world in Figure 7. The dialog at the top of the figure enables the user to specify a world event. This simulates the direct feed from sensors that will occur in the real system. In the figure, a new event entitled "obstacles" has occurred. This event relays the discovery of a minefield and concertina wire in the area between Observation and Reconnaissance Point (ORP) 42 and Building 43. The late discovery of such information is typical because features such as wire and minefields can be swiftly laid and hence may have been placed after the completion of early airborne surveys.

The impact of this world event is shown at the bottom of the figure. The obstacles block the movement of Platoon 4 into Building 43. To relay this information and its effect to the user, the affected planned actions are highlighted in red (appearing darker in this black and white version of Figure 7).

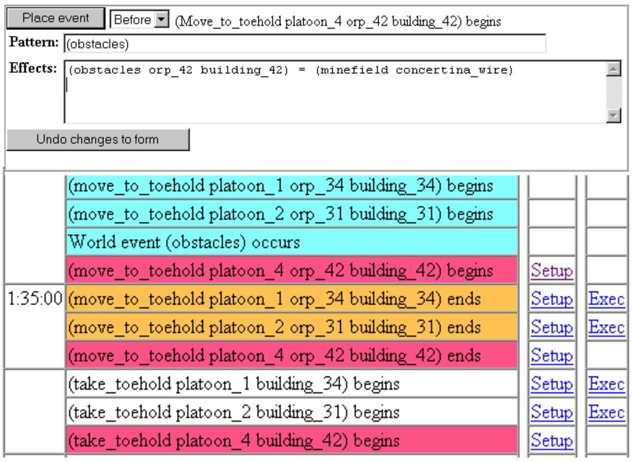

Figure 7: World event "Obstacles" and its effect on plan

By exploiting the plan's goal structure, we can filter information to present what is relevant to the user and tailor that presentation to clearly show the impact on the current operation.

Repairing Plans in High and Low Tempo Situations

A number of different plan-repair mechanisms are possible. In extreme cases, a completely new plan could be generated, based on the current situation. We have concentrated on more local plan repairs in which as much as possible of the current plan is preserved. When the execution monitoring system detects a problem, it sends a report to the planning system to indicate which actions in the plan have already completed and what other events have occurred. The planning system can then add new actions to the remaining, not yet executed, parts of the plan in order to re-establish any preconditions that have been broken. The user is able to participate in this process in the same way as when constructing the initial plan. The repair technology is described in more detail in (Drabble et al, 1997).

In our demonstration system, a discrete event simulator takes the place of the situation awareness system as a source of information about the state of the world. The interface to the simulator is a table that lists the actions in the plan plus any other events that should occur. The actions are grouped into synchronization blocks in such a way that the actions within a block are ones that could execute in parallel, and the actions are color-coded to indicate their status: already completed, ready to execute, unable to execute, and so on. The user can specify new events that will occur during execution and can instruct the simulator to execute the plan, and any additional events, up to an indicated point. The simulation stops as soon as a problem is detected, so that the user can consider plan repairs that could be made at that point in (simulated) time.

The user can opt to repair the damage caused to a plan by a world event. Returning to the obstacle example from the previous section, if the user opts to repair the plan then O-Plan will search for actions that will re-instate the effects damaged by the event. In the case of obstacles, obstacle clearance actions provide effects for getting the plan back on track. Figure 8 shows the options presented by O-Plan. O-Plan has filtered irrelevant repair actions such as the use of Bangalor Torpedoes as no unit in the operation is equipped with them in this scenario. The user must simply select from those available in the list.

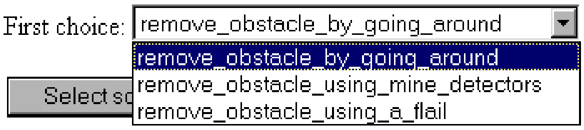

Figure 8: Repair options for event "Obstacles"

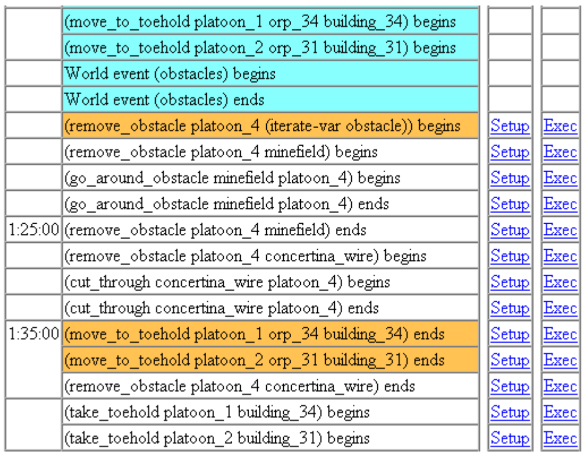

Figure 9: Plan repaired to counter event "Obstacles"

The plan resulting from the application of the chosen repair is inserted as shown in Figure 9. Note the new obstacle avoidance actions for Platoon 4.

User Interfaces

For some time, O-Plan developments have sought to provide concurrent support to a number of users each of whom play different roles in the planning process, such as:

- Task assigner
- Planner
- Execution monitor

The workflow and coordination for the overall collaborative planning and execution process has been supported through Planning Process Panels (Tate et. al., 1999). These link users and the planning system components and ensure that shared results are available at appropriate times. The Panels can be configured to specialize them to each user role and can be accessed through any web browser.

For the current work, the process panels were extended to provide richer execution and plan repair support. This functionality was previously available in O-Plan (Drabble et. al., 1997) but not accessible through the web and panel interfaces provided in earlier demonstrations - such as was shown for Non-combatant Evacuation Planning and Air Campaign Planning (Tate et. al., 1998). A generalized mechanism has been added to O-Plan version 3.3 which allows the O-Plan planning server to provide a communications socket to which any execution applet or system can connect (possibly several at once) to access O-Plan services and information.

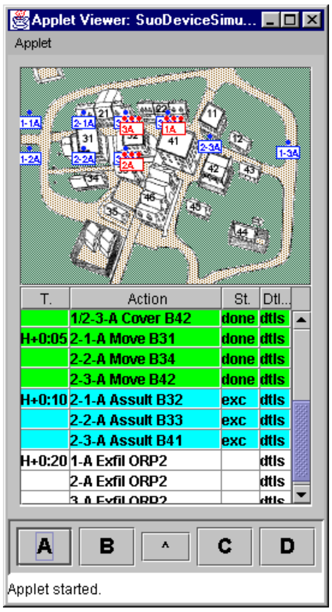

Figure 10: Prototype PDA interface to a soldier-borne device

One specific use of this interface has been to experiment with an interface that might be suitable for a soldier-borne Small Unit Operations Situation Assessment System (SUO/SAS) on which additional Planning and Decision Aids might be provided. The functionality could be provided via a portable system carried by the soldier into action. Such a device (not necessarily with a user interface such as that shown here) is being developed on the DARPA SUO/SAS program by a contracting team including ITT and SRI International.

The experimental development took the premise that the soldier, especially in high tempo parts of plan execution, would need rapid ways to deal with dynamically emerging situations. In particular, they might need to repair plans to resynchronize their operations with adjacent friendly forces who might otherwise be threatened or put at risk of not achieving their objectives. In some high tempo situations a "**glance and select**" style of interface requiring very limited modalities of input and output may be all that was feasible. This is quite a different style of interface to planning and decision aids than might be appropriate for "Back at HQ" style deliberative planning, for example.

A prototype of the limited modality interface running as a Java applet is shown in Figure 10. It includes a multiple resolution map display on which time phased positions of friendly and opposing forces can be shown, along with synchronization points and times in relation to adjacent friendly forces, and an execution checklist. A number of other related projects seeking to support small military units are using interfaces which provide map-based overlays or sketches, temporal "synchronization matrix" and "execution checklist" displays (DARPA, 1999).

Conclusion

This paper described work to apply AI planning technology to an actual military planning problem faced by US Army Small Units operating in urban terrain. Applications of AI methods have largely focussed to date on "backroom" plan generation and scheduling ahead of plan execution, and where little dynamic replanning and coordination is required. The paper reports on work that uses O-Plan and its associated planning technology to address the whole lifecycle of the generation and use of plans:

- Domain and initial plan representation
- Deliberative initial planning and generation of multiple options
- Plan execution monitoring and dynamic repair of plans
- Tailored interfaces for various user roles including planning process workflow support

The requirements for this work were set by the user community, which also validated the military realism of the approach and the knowledge base used. While this domain proved to be quite simple from a search perspective, it does show how the whole problem can be represented to and reasoned about by mixed initiative systems where AI planners and a range of different users have their own perspectives and needs which must be addressed. The different needs of initial requirements specification, deliberative ("Back at HQ") planning and option generation, en-route reconsideration of the various plans to address incoming information, and the needs to refine and repair plans in low and high tempo ("in the field") execution contexts were considered in this research.

The demonstration system produced is available on-line at `http://www.aiai.ed.ac.uk/~oplan` where full details, a sample scenario and demonstration script, and access to a copy of the code of the system itself are available for educational and further research purposes. A password to run the demonstration on-line is available on request to `oplan@ed.ac.uk`.

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