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Dynamic planning and execution toward a Canadian perspective TTCP C3I - AG1

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Dynamic Planning and Execution

Toward a Canadian Perspective

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Abstract. This short working paper is an attempt to highlight the limitations of the various systems currently used by and investigated for the Canadian military regarding dynamic planning and execution tasks, and identify key research areas to be further explored. In order to maintain exclusively the focus on those tasks, deficiencies or requirements as well as tools associated to other relevant but subordinate problems have been deliberately ignored. This summary uniquely reflects the author's view on what constitutes the most important deficiencies and challenges based on document analysis and interviews conducted with Canadian military officers, operation research analysts and defence scientists over a very limited period of time.

1. Introduction

This note attempts to present the various systems currently used by and investigated for the Canadian military regarding dynamic planning and execution tasks, while emphasizing key research areas to be further explored. In so doing, deficiencies, requirements and tools associated with other subordinate problems have been deliberately ignored. The summary does reflect according to the author the most important deficiencies and challenges lying ahead for dynamic planning and execution. It is based on document analysis and interviews conducted with Canadian military officers, operation research analysts and defence scientists over a very limited period of time.

2. Current Capabilities

At strategic level and, operational level in a lesser extent, efforts for the three Force components are mainly directed toward providing an integrated environment to generate a global picture of the situation in order to facilitate cognitive tasks such as situation assessment and planning still largely performed for most part by human minds. Therefore the current requirements and efforts focus mainly on the development of authoring tools to produce/consume information, capabilities to achieve data integration, information aggregation, information access through generic user interface, consultation, visualization, information dissemination and interoperability of these services rather than sophisticated planning tools adapted to a dynamic environment. At this level, it is generally or implicitly assumed that the rate of change is such that the value of information is slowly changing over time. Planning largely remains a cognitive task almost entirely achieved by humans involving limited automated capabilities beyond basic COTS software (word processing, spreadsheet, etc.) to generate hierarchical plans through the chain of command in a traditional manner. This does not mean that dynamic planning is not important, just that it has not been until recently the focus of attention. The main challenge for the Canadian Forces in facing dynamic environments primarily lies at the tactical level. Timescale is shorter, situation changes quickly, cognitive tasks are performed concurrently, the value of information drastically decreases over time, plan construction is interleaved with plan execution and, timely execution monitoring becomes essential. For increasing tempo of operations, current systems cannot keep up and, as human users, quickly suffer from task overload and limited capabilities. Recognition of the timeliness and need to further investigate, develop and provide new dynamic planning and execution monitoring capabilities is growing rapidly in military ranks as evolving technology increasingly shape the planning and conduct of operations.

2.1 Land

To our knowledge, the only existing system (prototype) eventually anticipated to address dynamic planning and execution monitoring issues to some extent is OPERA.

OPERA (Operational Planning Environment and Reference Application):
An operational planning process is long, involves a variety of staff experts and does require intensive calculations such as the estimation of necessary resource to achieve a typical task. OPERA is a multi-user environment providing authoring and calculation tools to support the planning of tasks for the Canadian Forces Operations allowing information exchange based on the NATO LC2IEDM data model and that includes all reference data on resources. It also provides information access on doctrines, organizations, equipment and resources. The data model used by OPERA for the operational planning process is based on the Land Command and Control Information Exchange Data Model (LC2IEDM), fully compliant to the NATO exchange data model facilitating interoperability.
Workload and decisions in dynamic situations are entirely devoted to humans.
Status: prototype
Application domain: Operational Land Force

2.2 Air

To our knowledge, the main systems (prototype) partly addressing dynamic planning and execution monitoring problems include the following system prototypes:

COPlanS (Collaborative Operational Planning System):
Workflow-based system prototype supporting the Canadian Force Operational Planning Process (CFOPP). It mediates group decision-making in the creation and selection of a common course of actions providing an integrated flexible suite of planning, multi-criteria decision-aid and analysis tools. It is a mixed-initiative decision support environment involving multiple users exploiting web-based tools as well as some capabilities to integrate selected group decision-making commercial of the shelf technology software.
Workload and decisions in dynamic situations are entirely devoted to humans.
Status: prototype
Application domain: Operational Air Force

DSS (Decision Support System):
Decision support system (open-loop feedback) based on mathematical programming models and techniques such as decomposition methods from operations research. It is dedicated to address the Air Mobility line tasking planning problem. The line-tasking problem consists in selecting airlift requests and construct strategic airlift missions to be achieved over a specific time horizon, generating a periodic (monthly, yearly) airlift programme. Given a set of prioritized requests with time windows, DSS constructs a set of valid missions (vehicle scheduling) assembled in task lines in order to maximize the number of supported requests while minimizing operational cost subject to a variety of resource and mission constraints.
Workload and decisions in dynamic situations are entirely devoted to humans. Dynamic situations are handled through an open-loop decision model with user feedback (user-controlled re-optimization).
Status: prototype
Application domain: Air Force

KARMA (Knowledge-based Adaptive Resource Management):
Automated capability to support closed-loop dynamic planning and execution monitoring in a time-varying uncertain environment. The parallel blackboard approach allows for the concurrent execution of multiple knowledge sources and provides explicit mechanisms to support event-driven and goal-directed problem solving. It also includes resource-bounded reasoning capabilities represented through a meta-level control of computation responsible for deliberation scheduling and run-time monitoring of anytime knowledge sources. Based upon an object-oriented approach, a prototype of the baseline architecture has been partly implemented. Mixed-initiative capabilities have recently been added to support limited human-computer interaction in closed-loop. This initiative is a significant contribution

toward the development of an automated real-time advisory decision support system for tactical resource management.
Workload and decisions in dynamic situations can be shared between the human and the machine. KARMA can work in an autonomous or semi-autonomous mode in a dynamic uncertain environment but is restricted to operate on limited machine-understandable tasks (e.g. vehicle and crew scheduling).
Status: prototype
Application domain: Tactical Mission Planning (Air Force) – Vehicle (utility and transport helicopters) routing and crew scheduling for single and multiple tactical helicopter units.

Genetic Algorithms:
Status: prototype - algorithm
Application domain: Vehicle Routing Problem with Time Windows.

WASP (Wing and Squadron Planner):
Multi-user mission support environment providing authoring tool capabilities to create/modify/delete plans, access information and disseminate orders. WASP interoperates with a limited number of specialized external components (e.g. weather information system).
Workload and decisions in dynamic situations are entirely devoted to humans.
Status: prototype
Application domain: Operational/tactical Mission Planning (Air Force)

2.3 Naval

To our knowledge, most relevant decision support capabilities are very limited, and in general doctrine-based (rule-based). These capabilities relates to shipboard combat systems for battle management such as basic weapon-target allocation algorithms used to assist the commander in making a decision. Ongoing efforts intended to bring new system planning components are not currently known at this stage.
Workload and decisions in dynamic situations are entirely devoted to humans.

2.4 Joint

To our knowledge, no system currently exists to eventually support or address dynamic planning.

3. Dynamic Planning and Execution Monitoring

This section presents some key research areas and related features to be primarily considered within the Canadian Forces to tackle dynamic planning and execution monitoring tasks. Task environment properties are first introduced. Then, important research areas regrouped under the themes "adaptive planning" and "distributed collaborative and continual planning" (coalition, joint operations, etc.) are briefly described.

3.1 Task Environment Properties

Planning/scheduling task environment primarily determines the complexity of the problem to be handled and solved by human (natural) or artificial agents. Task environments can be characterized by a whole spectrum of properties or dimensions [1], namely:

Fully observable vs. Partially observable (State information)
Deterministic vs. Stochastic (Uncertainty)
Episodic vs. Sequential (current decisions impact on future actions) (Sequential decision)
Static vs. Dynamic (Passage of time - while reasoning)
Discrete vs. Continuous (Domain)

The first property refers to the complete/incomplete knowledge of the world state by the agents. The second feature refers to uncertainty associated with events on which agents have no control (e.g. weather conditions, threat damage model, mission request generation/inter-arrival time, action outcomes, etc.). Sequential decision environment relates to a multi-stage decision process in which the future decisions depend on current selected actions (e.g. game) whereas episodic environment ignores this impact, making decisions all at once (one-stage). Explicitly accounting for the passage of time, dynamic task environment refers to a possible world state transition while agents are reasoning. Otherwise task environment is static.

Finally, task environment may be characterized through discrete or continuous variables or a mix of both. Both extremes of the spectrum for the given properties define relative problem complexity. For instance, a problem instance involving a partially observable, stochastic, sequential, dynamic and continuous environment is likely to be far more challenging than its fully observable, deterministic, episodic, static and discrete counterpart. Besides, a solution to a complex problem will generally constitute a suitable or valid candidate solution to a lower complexity problem as the latter represents a particular instance of the former. By and large, the opposite situation is untrue. However, it may occur that a problem solution naturally proposed for a task environment be a reasonable alternative for a subset of instances of a more complex problem, if for example task environment properties are not significantly different for those instances. Ultimately, it is the assumptions made about task environment properties and the relative validity of these assumptions over a representative subset of problem instances characterizing a realistic application domain that will critically determine the value and the limitations of the solution proposed.

3.2 Adaptive planning

Current reactive planning systems work in real-time but cannot guarantee efficient solutions, whereas deliberative systems are able to obtain optimal solutions but conditionally to the perfect knowledge of the world state and the use of unbounded computational resources. But a real agent (artificial or natural) must address the problems of uncertainty, incomplete information domain, finite and limited computational power and, imprecise sensing. As a result, a tradeoff between reactive and deliberative planning must be reached. Adaptive planning consists in balancing deliberativeness and reactivity while combining plan construction and plan execution and dealing with real-time issues such as speed, responsiveness, timeliness and graceful adaptation.

The development of supporting capability to plan, direct and control tactical assets is required to accomplish various mission tasks such as surveillance, identification, threat engagement, contingency operations (domestic and international), strategic and tactical airlift, emergency management and other mission management activities.

3.3 Distributed collaborative and continual planning

The growing interest and investigation for distributed collaborative environment are primarily driven by requirements associated with domain complexity (time-constrained, uncertain environment, task structure and constraints), precedence constraints, local view, inherent collaboration/coordination nature of problem domains, reasoning tasks and competence diversity, sensing and execution capabilities as well as distributed resources. The emergence of such distributed collaborative environment presents new challenges to be met in order to serve its intended purpose.

Military coalitions and mixed civilian-military joint operations revealed that existing command and control information systems (C2IS) generally show some major limitations to properly support collaborative decision-making in complex, dynamic, and uncertain environments such as contingency situations. Distributing the decision-making process among collaborative partners and assisting them with proper advanced technologies represent major challenges to be met. Particular problem domain features to be considered include:

- Organizational structure: distributed vs. hierarchical, hierarchical task decomposition at various level (organization, coordination and execution).
- System limitations: bounded rationality (information processing capabilities, quality of planning/coordination, timely resources utilization and coordination) and reactivity (effectors, sensors).
- System integration: heterogeneous systems, meeting infrastructure, communication and interoperability issues.
- Task environment properties.

New efforts aimed at investigating technologies to endow capabilities of distributed collaborative command and control information systems (C2IS) are required. Such endeavour should include innovative decision aids and collaborative infrastructures that will leverage capabilities of future C2IS for the Canadian Forces as well as benefit other agencies. Performance gains to be potentially achieved represent a significant challenge to be taken on as well. Higher expected value of joint course of actions integrating economic issues constitutes certainly one out of many tangible benefits to be anticipated. Promising research areas to be investigated involve baseline system architecture (meeting infrastructure and services, etc.), distributed collaborative continual planning which include dynamic planning (joint) and execution monitoring, plan and information representation (framework to support the joint development of shared objectives, plans and monitoring control), deliberation and plan generation, task allocation (agent roles and responsibilities, load-balancing)), negotiation, coordination, communication (mechanisms, agent multi-objectives/utilities, mediation) and coalition formation.

4. Conclusion

Some systems currently used by and investigated for the Canadian military regarding dynamic planning and execution tasks have been presented. Emphasizing key research areas to be further explored, the document based on the author's view, summarized the most important deficiencies and challenges lying ahead for dynamic planning and execution. The note has been generated from document analysis and interviews conducted with Canadian military officers, operation research analysts and defence scientists over a very limited period of time.

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[1] Russell, S. and Norvig, P. Artificial Intelligence – A Modern Approach, 2nd edition. Prentice Hall; December 2002.

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This short working paper is an attempt to highlight the limitations of the various systems currently used by and investigated for the Canadian military regarding dynamic planning and execution tasks, and identify key research areas to be further explored. In order to maintain exclusively the focus on those tasks, deficiencies or requirements as well as tools associated to other relevant but subordinate problems have been deliberately ignored. This summary uniquely reflects the author’s view on what constitutes the most important deficiencies and challenges based on document analysis and interviews conducted with Canadian military officers, operation research analysts and defence scientists over a very limited period of time.

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