COLLABORATIVE MULTI-LEVEL PLAN MONITORING

Mohamad K. ALLOUCHE*, Jean BERGER**

*Defence Scientist, C2 Decision Support Systems Section, Defence Research & Development Canada - Valcartier, Quebec, Canada
** Defence Scientist, Defence Research & Development Canada - Valcartier, Quebec, Canada

The recent worldwide connectivity and the net-centricity of military operations (coalition-based operations) are witnessing an increasing need for the monitoring of plan execution for enhanced resource management and decision making. Monitoring of ongoing operations is the process of continuous observation recording and reporting. In this process the plan becomes a resource that needs to be managed efficiently. The centralized approach to plan monitoring soon reaches its limits when plan execution is distributed across different organizations/countries. We propose a new framework that would allow different monitoring nodes distributed across the network. An efficient propagation mechanism that allows information exchange between the different nodes would also be needed. The main purpose of this mechanism is to present the right information, to the right person, at the right time. To cope with a rapid increase of information flow through the network, an efficient alarm management mechanism allows the presentation of the information with an appropriate level of details.

Key words: *Plan Monitoring, Execution Management, Alarm Management, Resource Management, Multi-Agent Systems, Distributed Monitoring.*

1. INTRODUCTION

The growing connectivity in information framework is constantly challenging the Canadian National Defence to cope with the complexity of operations and to respond to the increasing demand for rapid information sharing capability. The execution of operations is no exception, a great deal of Canadian operations involve different organizations and/or different countries (coalition operations). In this context, an efficient management of resources is a key element for the success for any distributed and decentralized operation. The decentralization of operations makes it even more difficult to monitor their execution. The information is often transmitted through legacy systems that lack integration and synchronization and cause lack of critical information which impact the whole decision making process during the conduct of missions. Monitoring ongoing mission requires considering the mission plan as a specific resource that needs to be managed efficiently.

In order to cope with the increasing demand of networked and collaborative planning and execution of operations, it is important to have multiple representations of the same plan at different levels of details. This allows easy access to any information at the right level of detail based on the user profile, need, and perspective.

2. RELATED WORK

Monitoring, in a broad sense, is a process involving state information gathering specifications and actions, property verification/validation and execution tasks aimed at detecting unsuitable system condition occurrences by controlling and triggering specific alerts or countermeasures whenever necessary. By and large, monitoring tasks may be generally centralized or distributed, information-bounded (*e.g.* cultural, operational/political, privacy, security or competitive constraints purposes), resource-bounded (*e.g.* sensory, computational and communication and related cost), and comprises a variety of characteristics defining property verification, information-sharing protocols, analysis, forecasting and planning (*e.g.* value of monitoring, focus of attention coordination and state variables selection, actions to control or mitigate alert avalanches-tree-based incremental aggregation, window (time-interval)-based state monitoring, pull/push-based polling, false-positive and redundant alerts handling, sampling rates, reporting or response pre-conditions).

Despite a diversity of nomenclatures reported in the literature, some convergence on commonly known concepts can nonetheless be determined. In this respect, a relevant taxonomy which provides users with the ability to understand and perform relevant comparison task with respect to the state-of-the-art in monitoring approaches and techniques is presented in [1]. The specification language branch of the taxonomy classifies the language that is used to define monitored properties, the abstraction level of the specification, and the expressiveness (property type and the level of monitoring) of the language. The latter can be based on algebra, automata, or logic.

Single or multiple monitoring objectives refer to certain properties of significance such as safety, liveness, security oriented and performance related properties. Safety properties [2] are expressing undesirable conditions to occur. These may involve some invariants, a temporal sequence of valid predicates, properties that check values of variables, or properties dealing with resource allocation.

Other temporal categories include properties such as progress and bounded liveness, as well as timing properties. In terms of platform, monitors can be differentiated as software and hardware monitors [3].

Monitoring approaches are usually time-based and event-based. Time-based monitoring involves time point (*e.g.* threshold monitoring [4] or time interval (*e.g.* value monitoring [5] state variable sampling and checking for threshold violations, whereas event-based monitoring relies on dynamic behaviour through analysis of a sequence of events (*e.g.* tracing [6]). However, time-based value monitoring can sometimes solve specific issues related to event-based threshold monitoring [7] by using an alert triggering commonly referred as “Threshold Crossing Alert” (TCA). This represents an important aspect in the context of interactive execution monitoring [8]. The dependency context is also elaborated in [9] while reactivity and its real-time related aspects are discussed in [10]. Issues related to interactive alerting during plan execution represent a vital and challenging topic in relation to the response and adaptive changes in the course of action. In this respect, monitoring technologies have been used in continuous planning frameworks such as those described in [11]. In this area, relevant research efforts are dealing with agent systems as presented in [12]. In other respect, alerts may be classified in categories [13] such as detection, operational constraint violation, suggestions or adversarial activities.

Distributed monitoring tasks aim at revealing accurate condition verification in multi-player settings. This research area supports the use of game theory and mechanism design. In addition, the "theories of collaboration" involve directing agents in conjunction with the monitoring of the execution, by modeling elements of team collaboration along with levels of partial knowledge.

3. PLANS AND PLANNING

In our framework, plans are considered as the main resources to be monitored during plan execution. It is then important to describe the different types of existing plans and the different planning processes that build them.

A Campaign Plan is a sequence of planned, resourced and executed military operations designed to achieve strategic and operational objectives within a given time and area. A campaign plan would be monitored by insuring that decision points on different lines of operations are met.

An Operations Plan (OPLAN) is by definition the Main Plan to which all supporting plans will refer to. Some examples of OPLAN are:

Attack Plan, Defensive Plan, or Counter-Movements Plan.

A Support Plan supports an OPLAN usually in terms of resources. The resource will be available for a predefined period of time at a given location. The availability of a resource does not imply the consumption of this resource. Depending on the evolution of the supported plan these resources could be used or not. Some examples of supporting plans are: Mobility-Counter Mobility Plan, Fire Plan, Air Support Plan, etc.

A Contingency Plan is designed for contingencies, has been wargamed and can be reasonably anticipated in an area of operations. The commander's reserve could be part of such a plan.

The Enemy Plan is used during the wargaming sessions during which intelligence Staff will proof many Enemy COAs in order to better prepare our own troops for an operation.

The types of plans discussed above must not be confused with the types of planning. Planning is the process followed by the Staff to design and build a plan. Depending on different constraints, there are different types of planning processes:

• The Deliberate Planning is usually chosen in the absence of time constraints or threats. It consists in elaborating and adopting plans in view of a known situation or incident.

• The Crisis Planning consists in the elaboration and adoption of plans in order to face an existing crisis or an expected one. The first three stages of the Operational Planning Process (OPP) are often shortened in crisis planning.

• The Forces Planning is usually done in stage two of the OPP in order to evaluate our own Forces and the opposing ones.

• The Multinational Planning or Joint Planning is usually performed by a Joint Operation Planning Group (JOPG), which is normally formed for a coalition or inter-army operations.

4. PLAN MONITONRING CONCEPT (PMC)

This section describes a conceptual representation of the different plan abstract levels. **Figure 1** depicts the multi-relations between a plan and the multiple abstract levels. The information axis is composed of four (4) dimensions. Therefore, each task has information in each dimension. Each layer is oriented to present the information with a specific view or a specific concern. The graph in the cube represents one plan (one instance of a plan) in the dimension of plans. This plan is spread all over the other four (4) dimensions. This conceptual model is intended to present the right information at the right level of detail for the right person, in such manner that an operator does not have the impression of information overload but only the necessary information needed to perform a task.

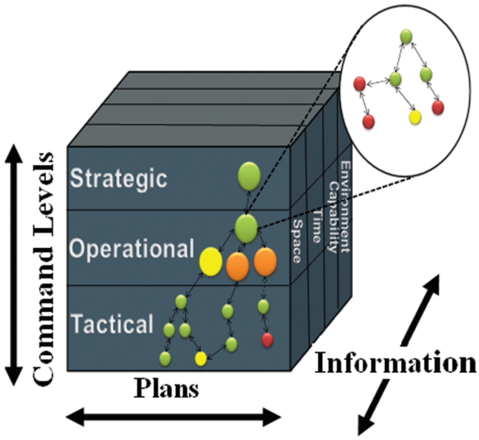

Fig. 1 *Plan Monitoring Concept (PMC)*

4.1. COMMAND LEVELS

The first dimension covers the traditional levels of Command. A plan is usually associated with a level of Command.

At the Strategic Level a nation, often as a member of a group of nations, determines national or multinational (alliance or coalition) strategic security objectives and guidance, develops and uses national resources to achieve these objectives. This level has a temporal horizon of more than 1 year.

At the Operational Level, the headquarters determine objectives and provide resources for tactical operations. The operational level links employing tactical forces to achieving the strategic end state. The Operational Level defines the objectives to achieve the desired final state of the Strategic Level. This level has a temporal horizon of 1 to 12 months.

At the tactical level, the commanders use combat power to accomplish missions. This level has a horizon of days.

4.2. PLANS AND RESOURCES

The second dimension covers all available plans and resources to be managed or monitored at the different levels of Command. The top level (*e.g.* Strategic) gives a macro representation of a plan (orientation or desired effects), which will be more detailed according to the current perspective, as we move down through the Operational and the Tactical levels.

4.3. INFORMATION

The third dimension covers all types of information required to cope with the current military context. This dimension has four (4) general categories: Space, Time, Capability and Environment, which encompass all relevant information that contributes to answering the following questions: who is doing what, where, when, why and how?

The Time dimension covers the synchronization aspects of an object such as the beginning and end times of a task for instance. Time is a measure of a continuum expressed in terms of hours, minutes and seconds in a precise manner. Time dimension value can be real, relative to an action or scheduled for a future action. For example, a task can be started only if the enemy reaches a particular position in the field.

The Space dimension covers the spatial characteristics of an object (geo-referencing objects).

The Capability dimension gives all relevant information about the state of an object such as specification, consumable rate and availability.

The Environment dimension gives all external information that may have an impact on an object such as terrain or weather conditions or the enemy presence in the field.

With this approach, an operator can navigate (zoom in or zoom out) and have the right level of detail for the required information. The four aforementioned categories can be used to model the commander's intent at any level of Command.

5. MONITORING FUNCTIONS AND APPLICATION

Curiously, the military doctrine is not very clear about plan monitoring and frequently refers to the "Operation Planning Execution Art". In our framework, we use the S.M.A.R.T. model used by the United Nations (UN) to qualify a good monitoring function. This model checks if the information is Specific, Measurable, Attainable, Relevant and Time-based.

An important aspect of the monitoring functions is to be able not only to measure any deviation or change within the object itself but also to be able to detect or even better, to measure the impact of the change on the other objects of interest.

To illustrate the application of our Plan Monitoring Concept (PMC), we use an Army generic scenario often referred to during captain training: "A Canadian Mechanized Brigade Group is part of a coalition in a NATO lead operation in a friendly fictitious country in order to push back an enemy invasion". The details of this scenario go beyond the scope of this paper. **Figure 2** presents the different elements of the operational plan that was developed in order to reach the high-level goal of pushing back the invader. It is important to notice that there are four views for the plan corresponding to the four dimensions of the PMC: Time, Space, Capability and Environment. Furthermore, in each of the views, each presented element has four hooks (T, S, C, E) that allow to link this element to other elements according to the four dimensions. For instance, in Figure 2, an Enemy Air Drop would have a direct impact on the Canalize task, which is linked by its Environment hook. The Time view will then allow the user to see what delays are caused by this event (Gantt chart part of Figure 2). The Space view (the part with the smaller map view of Figure 2) allows the user to visualize the possible maneuvers of the enemy after the air drop (dashed red lines on the central smaller map). These maneuvers are usually analyzed during the wargaming phase performed during the operational planning process.

Finally, the Capability view would allow the user to have an idea about the current state of the resources (view at the bottom of Figure 2).

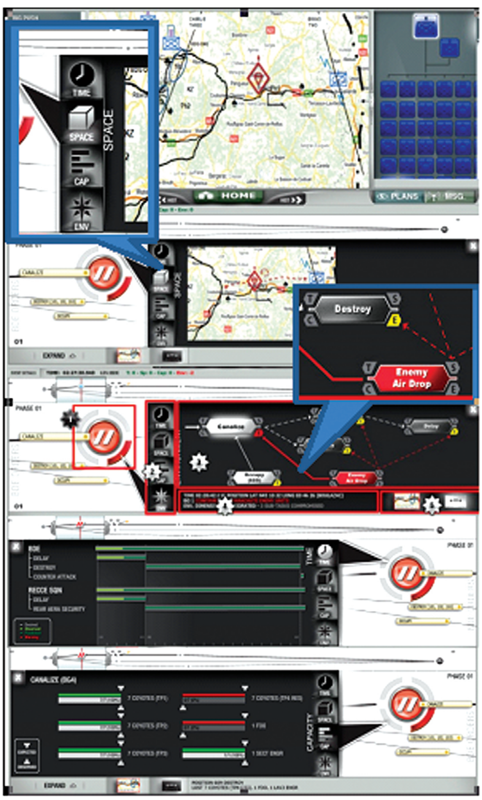

Fig. 2 *Application of the monitoring functions*

In this case, two of the resources (red lines) were severely affected by the enemy air drop. The Commander needs then to choose among the available courses of actions available in the plan by taking into account the current state of the resources.

6. CONCLUSIONS & PERSPECTIVES

In this paper, we address the execution monitoring of plans. According to Moltke's theory of war, "*no plan survives contact with the enemy*". Consequently, the decision-maker needs to be aware of the performance and progress of current plans and their related resources. The proposed Plan Monitoring Concept draws automatic links between plan elements, allowing the Commander to be aware of any change and also the impact of a change on other plan elements. By doing so, the information will be filtered and only the right level of detail will be presented to the Commander. It is also important to mention that the framework allows different analyses based on the perspective of the user. We are currently investigating the use of multiple representations of plan elements in order to collaboratively monitor the execution of plan at different levels of abstraction. In this context, different players (in a coalition for instance) with different perspectives may join the monitoring task. The information needs to be presented at the right level of detail for each player. For this reason, it is important to have different representations of the plan elements to reflect those levels of detail. In future work, we will investigate the use of influence graphs to represent more complex interrelations between the different plans elements.

REFERENCES

[1] N. Delgado, A. Q. Gates, S. Roach. *A taxonomy and catalog of runtime software-fault monitoring tools*. IEEE Transactions on Software Engineering, 30(12):859-872, December 2004.

[2] Koen Claessen. *Safety property verification of cyclic synchronous circuits*. Electron. Notes Theor. Comput. Sci., 88:55-69, October 2004.

[3] Dennis K. Peters, David Lorge Parnas. *Requirements-based monitors for real-time systems.* IEEE Trans. Softw. Eng., 28:146-158, February 2002.

[4] Graham Cormode, S. Muthukrishnan, and Ke Yi. *Algorithms for distributed functional monitoring. In Proceedings of the nineteenth annual ACM-SIAM symposium on Discrete algorithms*, SODA '08, pages 1076-1085, Philadelphia, PA, USA, 2008. Society for Industrial and Applied Mathematics.

[5] Ling Huang, Minos Garofalakis, Anthony D. Joseph, and Nina Taft. *Approximate decision making in large-scale distributed systems.* NIPS Workshop: Statistical Learning Techniques for Solving Systems Problems (MLSys). Vancouver, B.C, December 2007.

[6] Mohamed Ziad Albari. *A taxonomy of runtime software Monitoring systems.* http://www.informatik.unikiel.de/~wg/Lehre/Seminar-SS05/Mohamed_Ziad_Albari/vortrag.pdf, 2005.

[7] Graham Cormode, S. Muthukrishnan, Ke Yi. *Algorithms for distributed functional monitoring.* In Proceedings of the nineteenth annual ACM-SIAM symposium on Discrete algorithms, SODA '08, pages 1076-1085, Philadelphia, PA, USA, 2008. Society for Industrial and Applied Mathematics.

[8] David E. Wilkins, Thomas J. Lee, Pauline Berry. I*nteractive execution monitoring of agent teams.* Journal of Artificial Intelligence Research, 18:217-261, 2003.

[9] Barbara J. Grosz , Sarit Kraus. *The evolution of sharedplans*. In Foundations and Theories of Rational Agency, pages 227-262. Kluwer Academic Publishers, 1998.

[10] Abdel-Illah Mouaddib, Shlomo Zilberstein. Knowledge-based anytime computation. In Proceedings of the 14th international joint conference on Artificial intelligence - Volume 1, 775-781, San Francisco, CA, USA, 1995. Morgan Kaufmann Publishers Inc.

[11] Karen L. Myers. CPEF: *A continuous planning and execution framework.* AI Magazine, 20(4):63-69, 1999; David E. Wilkins, Karen L. Myers, John D. Lowrance, Leonard P. Wesley. Planning and reacting in uncertain and dynamic environments. Journal of Experimental and Theoretical AI, 7(1):197-227, 1995.

[12] Karen L. Myers, David N. Morley. *Human directability of agents.* In Proceedings of the 1st international conference on Knowledge capture, K-CAP '01, pages 108-115, New York, NY, USA, 2001. ACM.

[13] David E. Wilkins, Thomas J. Lee, and Pauline Berry. *Interactive execution monitoring of agent teams.* Journal of Artificial Intelligence Research, 18:217-261, 2003.