A Survey of Military Planning Systems

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Abstract

Future military operations rely on increasingly complex joint and multinational environments. This calls for innovative concepts, doctrine, and technologies to support the emergence of new planning and execution systems that are more flexible, adaptive, interoperable, and responsive to a time-varying uncertain environment. The ability to conduct joint operations imposes shared information and interoperability requirements to operate among coalition members as growing complexity and rapid pace of military operations transit from a rigid vertical organizational structure to a more integrated, modular and tailored one. In that regard, Network Centric Operations (NCO) offers a unique setting to take on emerging challenges. Even though deliberate planning tools focus on providing "on the fly" precise tailoring and time phasing of force deployment in crisis situations, suitable coordinated responses are subject to a variety of real-time constraints, local views reflecting incomplete time-varying uncertain information from multiple sources, bounded computational resources and communication bandwidth. The combination of artificial intelligence, operations research and data mining techniques to mention a few, and web-based and information technologies, offer a great opportunity to address new planning system design and integration requirements. In this paper pertinent mission planning and scheduling systems designed to support relevant and specific Air Force and in a certain extent Joint and Navy Forces needs were reviewed. The survey addresses various issues associated with mission planning functions and provides a brief description of methods, tools, and procedures used to plan and schedule complex military operations. Emerging techniques used to build advanced mission planning systems are also examined.

1. Introduction

Recent Canadian Forces participation in military operations have provided some opportunity to anticipate many challenges driven by uncertainty and rapidly emerging technologies. The ability to conduct out-of-area operations requires far more than combat capabilities and highly qualified personnel. Despite relative success, these operations have shown persistent problems associated with planning and execution, suggesting an urgent need to develop mission planning capabilities involving a more integrated view of the battlefield, more accurate and timely force deployment and employment, and an efficient information system infrastructure at multiple levels.

Deliberate planning procedures may require considerable time to evaluate a situation and generate an adequate response whereas a fast breaking crisis reflecting a dynamic and uncertain situation requires fast and timely decisions. Even though recent attempts in deliberate planning tools focus on providing "on the fly" precise tailoring and time phasing of force deployment in crisis situations, suitable responses generated by remote military planners and commanders still impose incomplete time-varying information analysis from dynamic uncertain sources of information, subject to a variety of constraints including bounded computational resources and communication bandwidth as well as other real-time requirements.

Distributed or collaborative planning issues are additional elements having an impact on the resulting complexity of operational planning. However, the absence of a universal or commonly accepted collaboration model among military planners resulted in the development of a variety of technological approaches reflecting a wider operational disparity. Therefore, collaborative mission planning is largely promoted in new information systems and databases aimed at providing an integrated environment in which multi-level operators, planners, and logisticians are able to coordinate their activities within and across organizational boundaries while reducing the duration of the decision making process.

This paper reviews a number of missions planning and scheduling systems designed to support relevant specific Air Force, and in certain extent Joint and Navy Forces needs. Moreover, the study addresses various issues associated with the mission planning function and provides a review of methods, tools, and procedures used to plan and schedule increasingly complex military operations. It also examines emerging techniques used to build advanced mission planning systems. The paper is organized as follows. Section 2 introduces the basic military planning process describing the planning hierarchy, deliberate and crisis action planning and, the Canadian military planning process. Section 3 then presents some background information related to basic technologies used for the development of mission planning systems. Taxonomy of the most important systems devoted mainly to air operations planning is then given in section 4. Finally, some conclusions and remarks are given in section 5.

2. Mission Planning Process

Usually the development of planning systems is based on a military doctrinal process, which is used for creating and monitoring military operations. The planning process, as it will be discussed later, begins with trigger receipt. After this step, the mission is analyzed and the tasks that will be associated to the plan are identified. Using information from the mission analysis[1] the planners develop and analyze the Courses of Actions (COAs) dealing with plans for friendly as well as enemy units. Several possible COAs for accomplishing the mission are developed and compared using a set of criteria. The best ones are then presented to the commander.

An obvious commitment to a successful planning process is that the commander, the staff and all people involved in this action view the importance of the said process and are willing to invest time and effort in it. This commitment facilitates the preparation and execution of the mission. Monitoring the mission requires a continuous evaluation of the execution of the plan. The commander is alerted when the current situation diverges from the original intent of the plan.

A good mission planning is generally characterized by quick response, decisive action and flexibility to adapt to the exogenous events and changing situations. A COA developed for a mission must consider an *employment* plan for dealing with one or more enemy COAs and should identify a *deployment* plan for moving forces and their equipment. By performing mission planning, plans are developed to bring the appropriate combat and supporting forces including their equipment and supplies to the operational field in time for the successful completion of their mission Planning hierarchy, deliberate and crisis action planning and, the Canadian Military planning process are presented next.

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[1] This step is called orientation in the Canadian Forces employment doctrine [1]

2.1 Planning Hierarchy

Three levels of planning are considered in the Canadian Forces (CF) doctrine, namely, strategic, operational, and tactical. Each level of planning corresponds to a level of conflict. The definitions of each level, as addressed in [1], are given as follows:

> "The strategic level of a conflict is that level at which a nation or group of nations determines national or alliance security objectives and develops and uses national resources to accomplish those objectives. Activities at this level establish strategic military objectives, sequence the objectives, define limits and assess risks for the use of military and other instruments of power, develop strategic plans to achieve the objectives, and provide armed forces and other capabilities in accordance with strategic plans."
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> "The operational level of a conflict is the level at which campaigns and major operations are planned, conducted and sustained to accomplish strategic objectives within theatres or areas of operations. Activities at this level link tactics and strategy by establishing operational objectives needed to accomplish the strategic objectives, sequencing events to achieve the operational objectives, and initiating actions and applying resources to bring about and sustain those events."
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> "The tactical level of a conflict is the level at which battles and engagements are planned and executed to accomplish military objectives assigned to tactical units. Activities at this level focus on the ordered arrangement and manoeuvre of combat elements in relation to each other and to the enemy to achieve combat objectives established by the operational level commander."

2.2 Deliberate and Crisis Action Planning

The planning environment is relative to the operational situation and conditions under which a plan is produced (time available and the degree of urgency). Two categories of planning, from an environment perspective, can be considered: deliberate planning and crisis action planning or time-sensitive planning, as it is called in US army doctrine.

The deliberate planning process is not generally subject to the immediate time lines or prevailing threats. It develops operation plans for contingencies and for later execution.

The crisis action planning process is needed when the degree of urgency of the crisis demands an accelerated operation planning process. The most significant factor to consider in such planning is time. Consequently, the crisis action planning process is characterized by quick response, decisive action, and flexibility to adapt to the contingency situation.

The deliberate and crisis action planning can be interrelated, in the sense that the deliberate planning contributes to crisis action planning. Deliberate plans establish a framework for the transition to crisis response. Deliberate and crisis action planning are structured formal processes. The planning process described below applies to any type of operational or strategic operation; it applies to deliberate and crisis action planning (see Figure 1). The deliberate planning process usually refers to the operational level of a mission.

2.3 Canadian Military Planning Process

Strategic and operational levels of planning are structured formal processes. The operation planning process that will be addressed later applies to both. In contrast, the tactical level is not a well-known structured process. This level of planning is not addressed in the CF employment report [2] that covers the operation planning process. Tactical planning is a very dynamic multi-dimensional process where the decision-maker must execute the decision process within the timeframe of the enemy's decision cycle. By doing that, the decision-maker forces the enemy to abandon its plans and objectives and drives him into a mode of reactive decision-making process.

The output of the planning process is a plan or an Op O (Operation Order). A military operation planning process (Fig. 1) is generally completed in five steps:

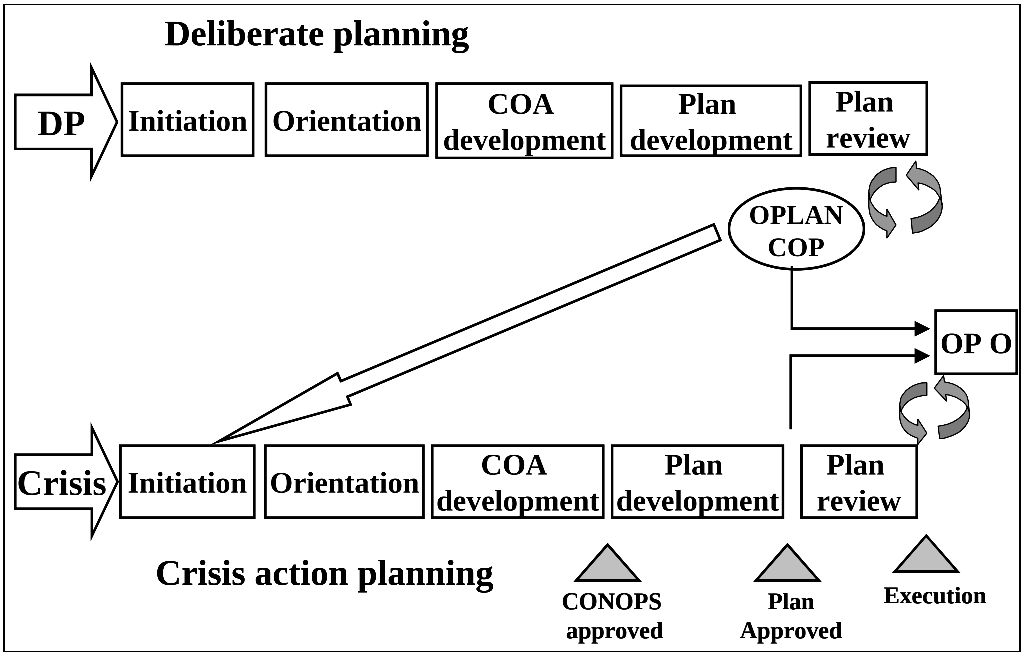

Fig. 1: The Planning Process [2].

Initiation: the initiation step starts with the reception, by the Chief of Defence Staff (CDS), of a political direction from the Government. Designation and notification of the planning staff and assembly of all relevant material are initiated in this step.

Orientation: at this step a commander orients the staff towards requirements of the initiated operation and the mission is developed and analyzed. This mission analysis, which is usually initiated with a brainstorming between the commander and his staff, determines the nature of the problem and confirms the results to be achieved. The commander's planning guidance regarding the tasks required are developed and issued at the end of this step.

COA development: The commander's planning guidance developed in the previous step is used as a framework by the planning staff to develop the initial COAs. Factors, such as theatre situation, opposing forces, military capabilities time and space, assessment of the tasks are analyzed in the COAs development. Planners perform a comprehensive range of COAs that focus on achieving the mission. Different COAs are compared in order to determine the most effective one.

Plan development: Considerable expansion or alteration are considered at this step to convert a developed COA into a **Contingency Operations** (COP) plan in the case of the deliberate planning and an **Operations Order** (OP O) plan in the case of crisis action planning.

The COP plans are prepared when contingency has important interest (national security), the nature of contingency requires detailed prior planning for complex issues, detailed plans are needed to support a multinational operation, etc. A COP plan is a complete and detailed operation plan that includes:

- A full description of the concept of the operations
- Identification of specific forces and specific resources necessary to implement the plan
- Estimates of the forces movement in the theatre.

The concept of operation (CONOPS) "explains" how component forces will accomplish the selected courses of action, but it is less detailed than the more formal Operations Order. A COP plan can be converted into an OP O plan. An OP O is the plan where details of the mission are filled in to include all supporting forces and activities. The OP O plans are presented in the form of a directive issued by a commander to the staff or subordinate commanders to effect the coordinated execution of an operation.

The COP plans developed for specific military operations in non-hostile environment (intra-theatre logistics communications, and continuity of operations) or to address peacetime operations such as disaster relief, humanitarian assistance, or peace operations are called *Functional Plans* in US force doctrine [4].

Plan review: a COP and OP O plans must be reviewed by evaluating their corresponding COAs through exercises, war gaming or other techniques such as logistics flow modelling. The choice of the review method depends on the time and the availability of resources. COP plans must be reviewed regularly due to the circumstances and the technological changes upon which they were based. OP O plans must be continually reviewed.

Most of planning systems presented in this paper do not cover all of the above-mentioned steps of the planning process. The planning process related to US army doctrine is very similar to the Canadian one. The documentation associated to JOPES system gives a good description of the US forces planning process (Jopes will be discussed later). The most important paradigms and technologies used for military planning systems will be briefly discussed below.

3. Paradigms used for Military Planning Systems

The technologies used to model a planning process depend on the structure of the problem itself. Special structure can help simplifying considerably the approach to be employed.

For a long time, war gaming has been used by the military for planning operations. Germany used war games to plan its successful invasion of France in 1940. Japan used war games to plan its attack on Pearl Harbor, Hawaii in 1941 [3]. As outlined in the US Army Staff Organisation and Operations manual [4], the military planning process, which consists in developing COAs, is an *ad hoc* process developed by members of staffs and the commander after discussing the various COAs. This ad *hoc* method suffers from a few weaknesses. The effectiveness of the war-gaming approach is subject to the skills of the commander and the individual staff members. Usually, a large percentage of the members of a planning staff have no feel of the battlefield. On the other hand, the effectiveness of an analysis of a COA is subject to the quality of the interaction between the various members of the planning staff. Finally, the strengths and weaknesses of the COAs are analyzed by the same staff that developed the COAs. Therefore, the members of the planning staff carry with them personal biases about which plan is better than others (see [3] and [4]). War gaming is sometimes, if time permits and resources are available, computer assisted using simulation models [1]. Whereas the *ad hoc* military planning process, based on war-gaming, is a manual planning method.

Decision theory provides new tools to the planning process. It addresses the problem of how a decision-maker could or should choose an action knowing the state of nature and about its capabilities and preferences. Uncertainty, exogenous events, knowledge, and information are usually modeled within decision-theoretic planning frameworks. The decision-theoretic planning process in its original version tends to be extremely complex to solve. Exploitation of the problem structure and abstraction techniques is usually used to reduce the complexity of the decision-theoretic problem. Decision-theoretic planning models based on an Operation Research (OR) paradigm usually use optimization techniques for the development of optimal plans. The decision-theoretic planning is a field that was developed primarily within the artificial intelligence community. The first problems addressed in decision-theoretic planning were based on decision theory (the origin of decision-theoretic name). The probability theory and the utility theory, belonging to decision theory, provide attractive tools for evaluating a particular COA. Besides decision theory, other OR techniques such as mathematical programming, graph theory, Petri networks and game theory are promising tools that have been used in developing mission planning systems. The challenges now lie in understanding relative strengths and weaknesses of the different technologies and to study how they can be extended and combined to develop better approaches to model the planning process.

Artificial intelligence represents a popular alternate paradigm in building intelligent planning system [5]. Plan generation algorithms have been developed since AI’s early age. An overview of techniques adopted for developing them is presented in Yang [6]. Some planning systems inspired from artificial intelligence (AI) rely on replanning-based methods to develop deliberate plans. Such planners, reactive in nature, generate plans and then modify them based on unexpected events or situations. Replanning approaches have been used in developing many military planners: DART (Dynamic Analysis and Replanning tool)[2], TARGET (Theatre-level Analysis, and Graphical Extension Toolbox)[3], and Cypress-SIPE2 [7], etc. Logic-based and hierarchical task network (HTN) approaches have also been proposed in early and current planning systems and remain very popular. A different AI-

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[2] This system will be discussed later

[3] DART and TARGET are developed by BBN Technologies for U.S. Department of Defense.

based method, namely, constraint programming [5] has also been the subject of investigation in planning systems. Other Information Technologies (IT) such as data mining (used for extracting hidden predictive information from databases), knowledge management, on-line analytical processing (a way of presenting relational data to users) and business intelligence tools have also been widely exploited in developing military planning systems.

On the other hand the research community has benefits from adequate commercial off-the-shelf (COTS) components in developing planning systems. Implementing COTS hardware and software into defence planning and scheduling systems would obviously result in significant cost and time savings. However, a carefully controlled approach to pre-packaged COTS software selection and integration within a larger system requires the need to develop guidelines, verification methods, and assessment and acceptance criteria.

Taxonomy of the most important planning systems devoted mainly to air operations is presented in the next section. Four categories of systems have been considered: Deployment and battle operations systems, airlift resource allocation and transportation systems, flight planning systems or route planning, and other specific military planning systems

4. Planning System Taxonomy

4.1 Deployment and Battle Operations Systems

i. FOX Genetic Algorithm (FOX-GA)

The Decision Support Systems Laboratory at the University of Minnesota and the Illinois Genetic Algorithms Laboratory at the University of Illinois collaborated to develop the FOX Genetic Algorithm (FOX-GA) [8] under the auspices of the US Army Research Laboratory (ARL). This system provides an intelligent decision support tool for assisting US Army planners and military intelligence in rapidly generating and assessing large numbers of battlefield COAs. Indeed, since the battlefield environment is uncertain, dynamic, incompletely known and risky, standard procedures are limited in addressing and exploring sufficient number of COAs and less replanning happens than is desired. Thus, FOX-GA was designed to provide the capability to automate and therefore speed up military planning and re-planning process during execution (i.e. the course of the battle) in order to allow users flexibility and control over planning objectives and options.

In this respect, the approach used by FOX-GA is based on the Genetic Algorithm (GA) technology [8]. Indeed, this approach allows the decision support system to rapidly generate a large numbers of potential COAs through crossover and mutation. Then, FOX-GA uses a Wargamer based on coarse-grained representations to allow efficient assessments and therefore, rapidly evaluate the “fitness” of the generated COAs. In this respect, this system can evaluate up to 3000 friendly COAs per minute while manually, the process requires 10-15 minutes to wargame one friendly COA against one enemy COA. Since standard Genetic Algorithms has the tendency to generate a group of very similar or identical “best” solutions, a scheme, called “fixed” niching strategy, is used in order to ensure diversity in the solutions. In other words, newly generated COAs will be in fact different from the existing ones, providing users with a more satisfactory range of choices. At the end, planners according to their own judgment reevaluate the best few COAs provided and select a small group for further development.

Currently, FOX-GA provides the ability to develop offensive COAs for common grounded force including mechanized infantry and armored units. However, due to its architecture, this tactical system can be generalized to support the generation of defensive and enemy COAs. Moreover, it can easily be adapted to other scenarios.

ii. Contingency Theater Automated Planning System (CTAPS)

The Contingency Theater Automated Planning System (CTAPS) [9-10] is a theater-level battle management system developed to respond to specific needs of the US Air Force USAF. It was established to meet requirements for a rapidly responsive Command, Control, Communications, Computers and Intelligence (C4I) system. CTAPS is a command and control system designed to provide the ability to manage complex air/land battle operations. As a complex system, CTAPS is developed to function at the heart of a decision support and battle management process so as to help monitor a given situation and make appropriate diagnosis. CTAPS thus offers the ability to generate, select, and execute operations plan.

The CTAPS development project has adopted a philosophy based on the use of a common core computer system. This approach or methodology has been implemented so as to provide mechanisms for the integration of mission-oriented software applications. Indeed, the CTAPS core module is not designed to provide mission-oriented functions. Others mission systems are created, tailored, and integrated into the core to provide mix applications. In this respect, the CTAPS core module can continually adapt emerging standards and technologies to meet evolving needs of all integrated applications.

The CTAPS core module is an open system, reusable software environment that has been critical in the evolution towards a Department of Defense DoD-wide Theater Battle Management Core Software (TBMCS). The TBMCS system is the future replacement for the CTAPS applications and communication interfaces that allow ground commanders to nominate, track, and verify targets in the Air Tasking Order. The CTAPS open module is an open architecture that includes and provides the following fundamental components:

- Host, network, database, and security configuration software.
- A configurable support environment for functional user duty positions incorporating discretionary access profiles, a top-level human-machine interface (HMI), and communication utilities.
- US Message Text Format (USMTF) message parsing and preparation to be used to send and receive messages.

iii. Joint Assistant for Development and Execution (JADE)

Based on novel techniques, the Joint Assistant for Development and Execution (JADE) [11] is being developed to particularly suit increasing needs for rapid deployment planning in crisis situations. This effort is conducted within the ARPA-Rome Planning Initiative to design and produce a system that can be incorporated in the Global Command and Control System (GCCS). Although the Joint Operation Planning and Execution System (JOPES) is currently used in GCCS, military planners intend to move beyond JOPES-like tools to overcome shortcomings associated with the speed at which Time Phased Force Deployment Data TPFDDs are generated. JADE is thus being developed to respond to the need to use a system that can provide required information in support of time sensitive planning. In this context, state of the art technology is used to provide the ability to reduce the time required to build a package commonly known as TPFDD.

Based on AI technology, JADE implements case-based and generative planning methods so as to provide the ability to handle large-scale, complex plans. The system is designed to enable rapid retrieval and reuse of previous plan elements. Using map-oriented drag and drop interface, JADE is being designed to offer the opportunity to drag force modes used in previous plans from the plan library so as to drop them into a geographic destination. In this respect, JADE architecture (Fig. 2) integrates major software modules such as The Force Module Analysis and Management Tool (ForMAT), “Prodigy”, and “PARKA”. The resulting system is thus designed to enable a user to modify force compositions, describe force capabilities, and tailor the evolving force deployment plan to changing mission requirements. To build a deployment plan containing both forces modules and their attributes, JADE uses mission guidance, task, and force information provided by the Adaptive Course of Action (ACOA) tools.

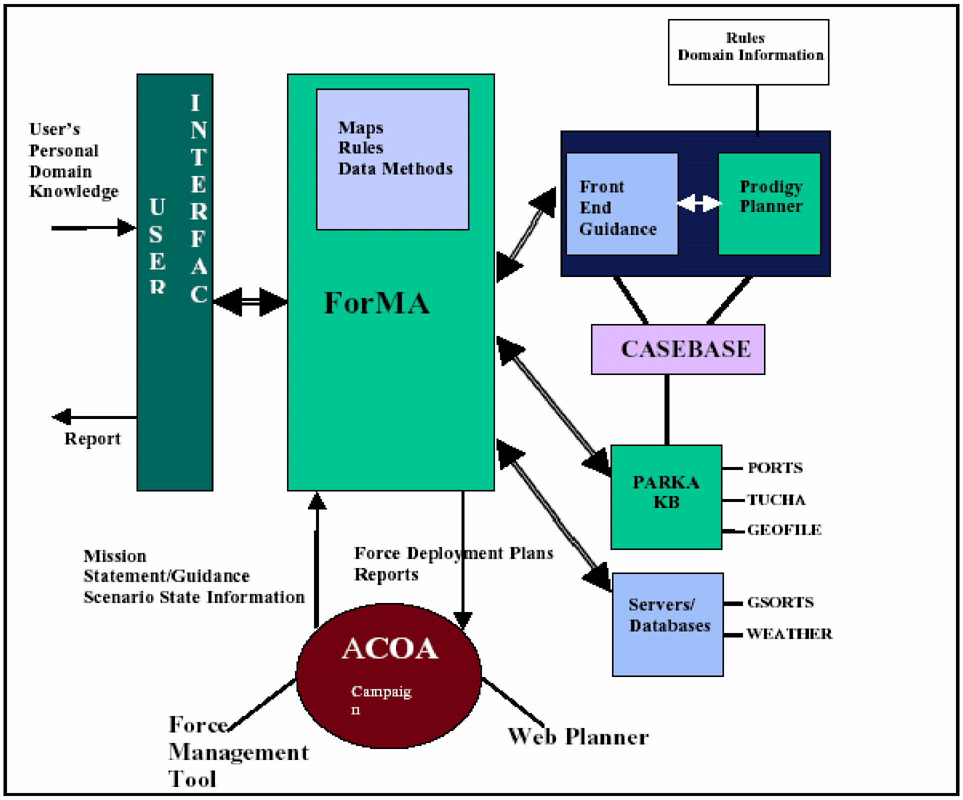

Fig. 2: JADE Architecture [11]

iv. Dynamic Analysis and Re-planning Tool (DART)

The Dynamic Analysis and Re-planning Tool (DART) [12] is a user-interactive information system that assists military planners in developing and analyzing war plans for deploying large number of troops and equipment. Each deployment plan is indeed defined by a data structure commonly called the Time Phased Force and Deployment Data (TPFDD) that describes the movement requirements for troops and equipment.

In this respect, DART is part of a set of automated data processing tools and a database management system designed to provide the ability to rapidly create, view and edit TPFDDs and analyze the transportation feasibility of a plan. As a result, DART allows planners to modify TPFDDs and to set up and run strategic transportation models in a period of minutes. Consequently, using DART provides the ability to consider more alternatives and to produce, in less time, a potentially feasible course of action.

The Integrated Feasibility Demonstration IFD-1 was launched in March 1990 as part of the ARPA-Rome Planning Initiative to create DART, a system designed to support the U.S. Transportation Command "USTRANSCOM". Spurred by the needs of Operation Desert Shield, the development phase was sped up in August 1990. After eight weeks of intense effort conducted on site at USTRANSCOM in close proximity to military planners, a sufficiently mature system was ready and moved to the U.S. European Command "USEUCOM".

Although the DART prototype showed satisfactory results at USEUCOM, it remained then a fragile system. From January to July 1991 (Phase 2), a list of known problems in the prototype was fixed, the user interface was improved and unified to enhance and harden the system. October 1991 marked the start of the deployment phase (phase 4) of DART. The system was thus fielded to 13 sites where it was used and evaluated by military planners on a daily basis. In April 1992, phase 4 was initiated to transition DART into the World Wide Military Command and Control (WWMCC) ADP Modernization system through the Technology Insertion Project (TIP), which offered the opportunity to add numerous enhancement to the system. Finally, in July 1992, DART was successfully completed and transitioned to the Defense Information System Agency "DISA" as an operational system.

v. Anticipatory Planning Support System (APSS)

The Anticipatory Planning Support System (APSS) [13-16] has been developed by the Department of Computer Science at Texas A&M University to provide a sophisticated automated decision support system for the planning and execution of military operations. The APSS prototype was built to mix planning and execution, and also to provide the capability to anticipate events rather than reacting to them in a dynamic and uncertain battlefield environment. In this respect, new techniques from several areas such as AI, planning, inference mechanisms, evolutionary algorithms and software agents have been modified and applied to tackle military planning in such a complex environment.

Indeed, while in the traditional planning process only one single COA is chosen for use during execution this new approach allows the ability to develop and maintain as many possible friendly actions against as many enemy actions as possible. In this context, the plan is described, as shown in Figure 3, by a tree with nodes and branches representing, respectively, actual or predicted states and transition between those states. Using inference mechanisms for determining branches, the goal to reach is to develop as many reasonable branches in the plan as possible in the initial planning process and dynamically modify and update the plan during execution. Moreover, as the operation progresses invalid future branches, according to the actual state, will be pruned and new ones will be developed and predicted using simulations well before their execution state. In other words, the APSS combines execution monitoring and planning by comparing anticipated states and the planned states to predict deficiency and allow then replanning.

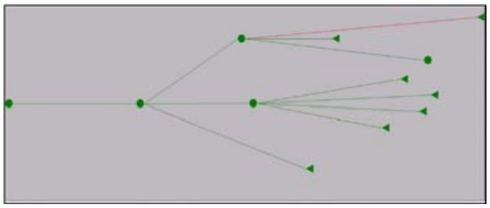

Fig. 3: Plan Description [13].

As shown below, the overall architecture of the APSS prototype system (Fig. 4) includes the following major components:

1. ***World View*** and ***World Integrator*:** Information on actual state of the operation is monitored by the World Integrator, and passed to the World View module after it's processing.
2. ***Execution Monitors*:** Using forward simulation from the actual state, Execution Monitors generate an anticipated state at the node of interest. In addition, the Execution Monitor determines the significance of differences between the anticipated state and the planned state at a particular node, and if replanning is necessary a recommendation is then sent to the *Planning Executive*.
3. ***Planning Executive*:** Using the inputs from *Execution Monitors*, the Planning Executive controls the overall operation of the APSS system. According to the differences between the plan and the actual operation, the Planning Executive can control the activities of *Planners* and *Execution Monitors* in anticipating future branches to the plan.
4. ***Plan Description*:** Based on the inputs from *Planners*, *Execution Monitors* and *Planning Executive*, the Plan Description is dynamically built to represent and manage the plan tree. Possible alternatives of the operation progress can also be shown. Using the Graphical User Interface (GUI), the plan can be manually modified by a human planner.
5. ***Planners*:** Receiving a state (either planned, anticipated or actual) with a mission objective from the *Planning Executive*, Planners develops representative new branches and determine their viability measure as well. In this respect, a *Branches Generator* using a genetic algorithm and inference mechanisms is invoked.

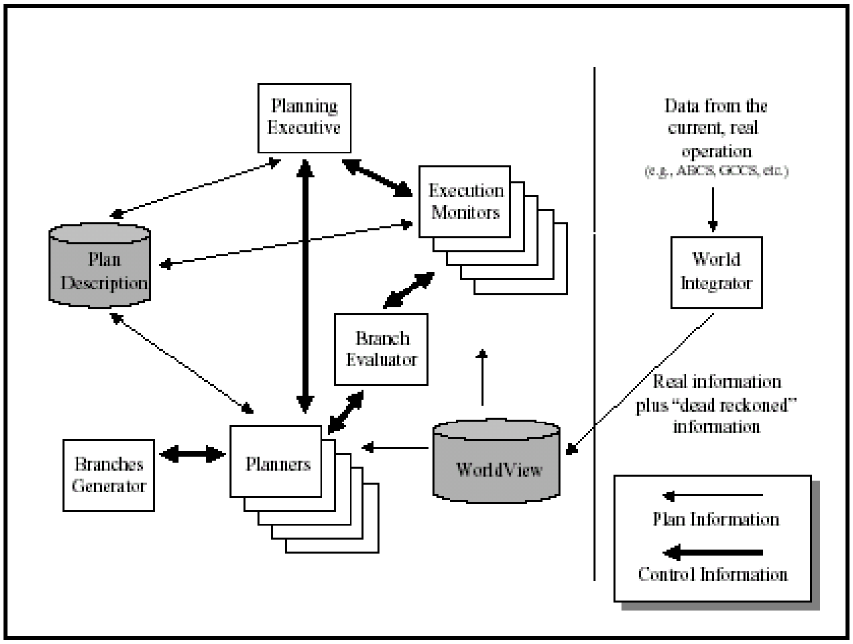

Fig. 4: APSS Architecture [14-16].

vi. Time-Phased Force Deployment Data Editor (TPEDIT)

Developed by Ascent Technology [17] during Operation Desert Shield, the Time-Phased Force Deployment Data Editor (TPEDIT) is a temporal constraint-based tool designed to help military planners to plan troop deployment. In this respect, TPEDIT provides the capability to enter, manipulate, and analyze force and movement requirements.

Operationally employed by U.S. Atlantic Command, TPEDIT provides the ability to represent Time-Phased Force Deployment Data (TPFDD) graphically, using Gantt chart. It also allows planners to modify their contents as well as provides the ability to build new ones taking into account other successful scenarios stored in an ORACLE database.

vii. Collaborative Operational Planning System (COPlanS)

The Collaborative Operational Planning System (COPlanS) [18] is a workflow-based system prototype developed at DRDC-Valcartier supporting the Canadian Force Operations Planning Process. Mainly targeted to support the Operational Air Force, it can be applied to more complex environment (e.g. joint operations). It mediates group decision-making in the creation and selection of a common COA 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. It also includes a variety of computerized tools and graphical user interfaces to facilitate visualization and cognitive tasks (planning, simulation, information retrieval). Workload and decisions in dynamic situations remain entirely devoted to humans though.

COPlanS provides the ability to plan an operation in a net-centric environment with integrated collaborative tools. The system offers functions to design and manage multiple concurrent distributed battle rhythms at different planning levels. It helps synchronize workflows, document processes and replay the decision-making path. Planning tools allow sketching COAs on maps, to perform time and space synchronization, to manage capabilities and ORBAT, and to perform logistics analyses. The decision-aid tools rationalize the process, improve the COAs evaluation and comparison, and rapidly produce documents to support the Commander's decisions.

COPlanS is based on distributed application architecture. It is Client-Server system architecture with different Layers. It is developed using WEB-Technology concept. Different Client configurations are engineered: Web, Light and Full clients. The data and meta-data models used in COPlans are generated via Sylverun. Three databases are managed by COPlanS: an Oracle 9i Database, an Application database and a Luciad GIS database. A data business layer manages all the databases. COPlanS is then independent of dataset management systems.

The system prototype has been tested during multiple international military exercises and is currently subject to military trials.

4.2 Airlift Resource Allocation and Transportation Systems

Transportation is an important domain of military activities. It supports and makes possible most other activities (logistics, deployment, air to air refueling, etc). Civil as well as military transportation operations are one of today's most important activities, not only measured by the yardstick of their own share of a nation's gross national product (GNP), but also by the increasing influence that the transportation and distribution of goods have on the performance of virtually all other sectors.

i. Joint Operations Planning and Execution System (JOPES)

The Joint Operations Planning and Execution System (JOPES) [19-25] has been designed to support joint planning, execution and monitoring activities from the National Command Authority's (NCA)[4] level throughout the Joint Planning and Execution Community (JPEC). Indeed, this all levels, joint conventional command and control system is the principal system within the US Department of Defense (DoD) that provides the ability to translate NCA's policy decisions into combatant commander's joint operations. Developed to replace and integrate the planning capabilities of deliberate Joint Operations Planning System (JOPS) and crisis-action Joint Deployment System (JDS), JOPES is therefore a comprehensive and integrated system of personal, policies, procedures, training and reporting structure supported by automated systems and applications for planning and execution. In this respect, the Global Command and Control System (GCCS)[5] currently provides Automatic Data Processing (ADP) support for the JOPES.

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[4] The NCA, which include the US President and the Secretary of Defense, sets the national policy and strategic direction of the U.S. Armed Forces.

[5] Developed to replace the World Wide Military Command and Control System (WWMCCS), the GCCS, is a Command, Control, Communication, Computer, and Intelligence (C4I) system, is an integrated architecture of telecommunications, software, and computer equipment.

Designed to support mobilization, deployment, employment, re-deployment and sustainment associated with joint activities, the JOPES system is used for deliberate planning during peacetime conditions to develop Operation Plans (OPLANs), Concept of Operation Plans (CONPLANS) with or without Time-Phased Force Deployment Data (TPFDDs), and Functional Plans. In crisis situation, JOPES is used for Crisis Action Planning to support a time-sensitive development of Campaign Plans as well as Operations Orders (OPORDs) for execution. The JOPES applications are grouped by functions as follows:

- **Requirements:** Requirements Development and Analysis (RDA) for TPFDDs edition and analysis and COA transportation feasibility, Force Module Editor (FMEDIT), and GCCS Status of Resources and Training System (GSORTS) for units status and location.
- **Transportation and Scheduling:** Joint Flow and Analysis System for Transportation (JFAST) feasibility of an OPLAN or COA, Scheduling and Movement (S&M), and Transportation Component Command (TCC) External System Interface (ESI) links JOPES and TCC scheduling systems.
- **Sustainment Modeling:** Joint Engineer Planning and Execution System (JEPES) for civil engineering planning, Force Augmentation Planning and Execution System (FAPES) for mobilization planning, Individual Manpower Requirements and Availability System (IMRAS) for manpower and personnel planning, Logistics Sustainment Analysis and Feasibility Estimator (LOGSAFE) for logistics planning, and Medical Planning and Execution System (MEPES) for gross medical feasibility and supportability assessments of OPLANs.
- **Reports and Retrievals:** Ad-Hoc Query (AHQ), Reports.
- **System Resources:** System Services (SS) for database management, Reference File Administration (RFA) for reference table update and maintenance, and JOPES Information Trace (JSIT) Commands.
- **Communication:** Internet News, Internet Chatter, and Secret Internet Protocol Router Network (SIPRNET), Web (SWEB).

The JOPES allows US Military Departments and Commands to link with Joint War Planners through the following automated systems:

- The Deliberate Crisis Action Planning and Execution System (DCAPES)[6] is the new interface between the Air Force planners and JOPES.
- The Computerized Movement Planning and Status System-Army (COMPASS-A), a logistical system that supports deployments, re-deployments, mobilization planning, and the execution of any military operation, provides accurate and timely strategic transportation data to JOPES.
- The US Marine Corps (USMC) uses the Marine Air Ground Task Force (MAGTF II) system between the USMC Family of automated information systems and JOPES.
- The Air Mobility Command (AMC) is linked to JOPES through the Consolidated Air Mobility Planning System (CAMPS)[7].

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[6] The Deliberate Crisis Action Planning and Execution System (DCAPES) replaced the Contingency Operations and Mobility Planning and Execution System (COMPES) in March 2002.

ii. System for Operations Crisis Action Planning (SOCAP)

The System for Operations Crisis Action Planning (SOCAP) [26-28] was developed by SRI International to provide decision support for planning a COA in response to a crisis. In this context, SOCAP was built to integrate mature AI planning systems so as to provide military planners with advanced capabilities required to produce more flexible and accurate joint military COAs.

As an overall system based on the integration of various independently developed AI subsystems, SOCAP architecture, shown in Figure 5, incorporates advanced generative planning, temporal case-based reasoning, scheduling techniques, and capacity analysis to generate military operations plans. Through the integration of various mature AI based subsystems, SOCAP was designed to provide the following capabilities:

- help planners select the correct operations to form a set of plans,
- maintain dependencies and check consistency among the operations in a plan,
- set up input for different feasibility estimators,
- support changes to the plan.

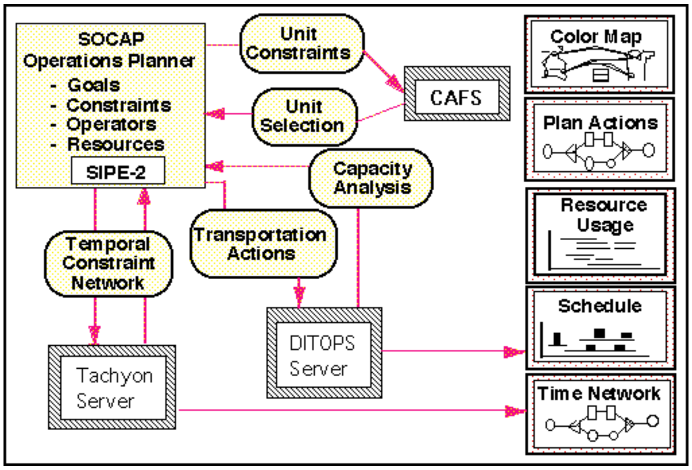

Fig. 5: SOCAP Architecture [27].

At the heart of SOCAP is SIPE-2 (System For Interactive planning and Execution), a hierarchical, domain-independent, non-linear planning subsystem with powerful formalism for representing domains and generating partially ordered plans. As a result, SIPE-2 provides the core-reasoning engine for plan generation. The architecture and interactive abilities specific to SIPE-2 offered the opportunity to integrate additional technologies into SOCAP as way to satisfy the military domain requirements.

At the beginning, SOCAP was unable to reason about the utilization of resources or place temporal constraints between actions in the plans. This shortcoming was associated to the limited temporal reasoning capability of SIPE-2. In this respect, SOCAP's ability to represent and reason about time was extended through an additional layer placed on top of SIPE-2 so

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[7] The Consolidated Air Mobility Planning System (CAMPS) replaced the Air Mobility Command (AMC) Deployment Analysis System (ADANS) in February 2002.

as to keep track of the temporal constraints within a plan. The added module is **Tachyon**, a general-purpose constraint-based subsystem developed by GE's R&D Center to provide temporal reasoning.

On the other hand, a user of SOCAP had initially to rely on personnel preferences to select a unit included in a list that meets the constraints of the operator. As a result, users expressed the desire to be able to modify the units in the list. The need to select and tailor a force was seen as a request that would be dealt with through the introduction of case-based reasoning mechanisms. In this context, a case-based reasoning module called Case-based Force Selection (CAFS) was incorporated to enhance the capabilities of SOCAP. CAFS was indeed modified to handle SOCAP objects and operators. Instead of presenting a list of units to the user, SIPE-2 was also modified to call CAFS module for major force selection.

To overcome SOCAP's simplified model of resource management, a constraint-based scheduler called Distributed Transportation Scheduling in OPIS (DITOPS) was thus integrated to assess the feasibility of the partial plan, taking into account the transportation-resource capacity requirements.

As shown in Figure 6, the input to the system includes a description of the mission, threat assessments, terrain analysis, apportioned forces, transport capabilities, planning goals, key assumptions, and operational constraints. Based on this data, SOCAP is set to generate and address plans with known military employment and deployment actions. Then the system generates a plan representation that can be displayed or excerpted in different ways to suit different purposes: a network and map display, time-phased actions for transportation analysis, or natural language.

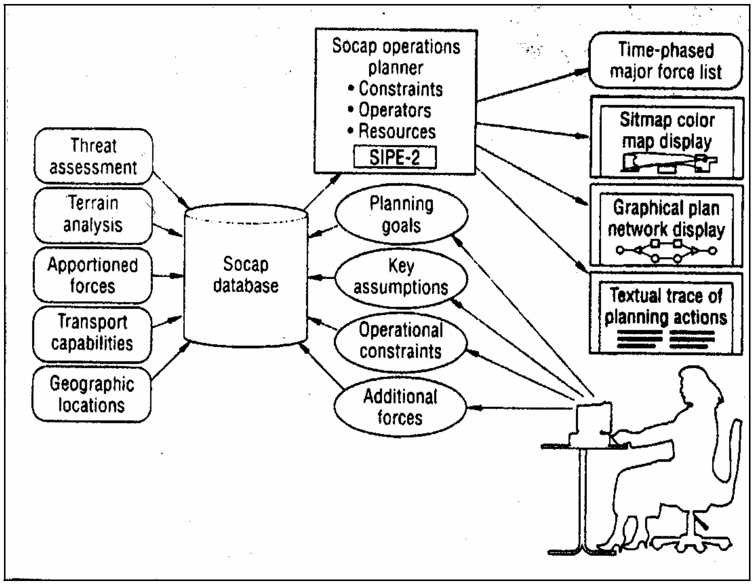

Fig. 6: SOCAP Functional Representation [12]

iii. Airlift (or AMC) Deployment Analysis System (ADANS)

The Airlift (or AMC) Deployment Analysis System (ADANS) [29] is designed to provide the Air Mobility Command[8] (AMC) with an integrated automated airlift and air refueling planning, scheduling and analysis system to support peacetime, crisis, contingency and wartime operations. Developed by Oak Ridge National Laboratory (ORNL) this system is currently maintained by Logicon Inc. as a part of the effort to merge its functionality and capabilities with those of the Combined Mating and Ranging Planning System (CMARPS) to create the Combined (Consolidated) Air Mobility Planning System (CAMPS).

One of the major goals of this system is to integrate the existing slower scheduling systems into a faster single system that would have a common user interface and a centralized database. In this respect, the first component of ADANS was operational in early 1990, which allowed this system to replace the Advanced Mission Planning System (AMPS). Later, it was successfully used to plan and schedule airlift missions for Operations Desert Shields and Desert Storm, for refugee relief, and for disaster response.

Integrated into the Global Command and Control System (GCCS), ADANS provides the mission planner with a set of decision support tools for matching movement requirements with airlift resources in order to create a schedule for an airlift operation. In other words, ADANS provides the ability to:

- Enter and evaluate cargo and passenger movement requests such as the use of commercial or military aircraft.
- Allocate airlift resources, including aircraft availability and characteristics, crews, airfield resources, and airlift network configuration.
- Create schedules for routine *channel missions* (regular routes to deliver mail, food, etc.), *Quick response missions* (movement of critical items on extremely short notice), *civilian aircraft missions,* and *Time-phased airlift flow missions* (movement of multiple military units from one or more on-load airfields to one or more off-load airfields).
- Analyze schedules using tools that allow mission planners to quickly and easily evaluate any individual mission details. In addition to textual displays, movement requirement deliveries, resources commitments, and aircraft activities can further be analyzed using graphical displays such as the rainbow chart.
- Distribute the schedule to AMC's worldwide command and control systems in order to follow and manage each aircraft throughout its mission.

iv. Consolidated Air Mobility Planning System (CAMPS)

Logicon Inc, a Northrop Grumman Corporation company, and other companies and research establishments such as BBN Technologies, Kestrel Institute and Carnegie Mellon University developed CAMPS [30-34]. It is designed to support the rapid deployment of the Air Mobility Command (AMC). Responsible for scheduling, executing, and monitoring airlift

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[8] The Air Mobility Command (AMC) is the successor of the Military Airlift Command (MAC) which was a major command of the US Air Force and a component of the US Transportation Command (USTRANSCOM).

operations to carry out the global deployment of U. S. forces, AMC uses CAMPS for planning and scheduling airlift missions. In this context, the CAMPS mission planner (MP) provides the ability to rapidly build AMC's portion of the Time Phased Force Deployment Data (TPFDD) that supports the projection of combat forces required to enable the command to deploy combat-ready forces.

Indeed, the CAMPS-MP is designed to work against an organization-wide database to provide unified planning and control of AMC operations. Integrated into the Global Command and Control System (GCCS), the CAMPS-MP provides the mission planner with an integrated view for planning and scheduling AMC air mobility resources to support peacetime, contingency, humanitarian, and wartime operations.

The CAMPS-MP provides advanced user capabilities for operational planning and allocation management. In this respect, it has a graphical user interface for specifying input parameters and a variety of views of the schedules produced, including maps, tables and charts. Based on a set of requirements, the task faced by a user of the CAMPS-MP is to specify a set of suitable aircraft resources, ports to be made available for refuelling (or locations for aerial refueling), should that be necessary, and to ensure that the schedule produced moves all of the requirements by their due dates.

v. Contingency Operations/Mobility Planning and Execution System (COMPES)

The Contingency Operations/Mobility Planning and Execution System (COMPES) represents the US Air Force (USAF) planning system used to support the Joint Operations Planning and Execution System (JOPES) [21-24]. Interfacing with JOPES, COMPES provides USAF planners access to near real time logistics, manpower and personnel data, including the entire Air Force – Active, Guard, and Reserve. While JOPES provides the Time-Phased Force Deployment Data (TPFDD), COMPES translates and tailors the operations plan for Air Force tasking. In this respect, COMPES supports deliberate planning by translating joint tasking into detailed unit tasking and then defines and task manpower and equipment required.

Indeed, COMPES is used to support planning functions not only within the Global Command and Control System (GCCS) operating environment/architecture at Headquarters United States Air Force (HQ USAF), Major Command (MAJCOM), and Numbered Air Force (NAF) but also at the base/unit. Within the GCCS operating environment/architecture, COMPES operates at the secret level to allow, as mentioned above, the USAF to support service and joint deliberate/crisis action planning and execution operations. At base/unit level, COMPES operates in the unclassified and classified modes to allow planners to receive deployment-planning tasks that support service and joint operations. As a result, it is used to provide tools required to support deployment operations by assisting with preparation of personnel orders, cargo manifests/documentation, and tracking capabilities.

The COMPES system includes the following modules:

- Operational Tasking and Priorities (OT&P), and
- Logistics (LOGMOD).

OT&P is designed to coordinate the information flow between JOPES, Manpower and Personnel MANPER, and LOGMOD during the Operations Plan (OPLAN) tailoring process.

On the other hand, LOGMOD is a computer program designed to manage the database containing logistics equipment and supplies for Air Force Unit Type Codes (UTCs).

vi. Knowledge-based Adaptive Resource Management Agent (KARMA)

The Knowledge-based Adaptive Resource Management Agent (KARMA) [35] is a prototype-automated mission planning system developed at Defence Research and Development Canada at Valcartier. KARMA is indeed conceived to overcome or alleviate concerns associated with a number of tactical mission planning tools operating in highly dynamic and uncertain environments. Substantial development efforts focussed on implementing advanced planning and scheduling technology concepts to automate the sequence generation process while appropriately and reliably responding in a timely fashion to a dynamic and unpredictable environment. Besides the ability to combine plan construction and execution, KARMA provides other features that allow plan repair to support continuous updating of a current plan in light of complex and changing operating conditions.

Motivated by the need to address requirements associated with real-time tactical mission planning subjected to various constraints in complex and uncertain environments, KARMA is designed to provide an open tool framework based on the blackboard paradigm. As a practical approach, a parallel agent-based blackboard-style architecture is indeed implemented to allow handling of complex tasks, multiple interactions among concurrently executing agents, communicating agents with heterogeneous sources of information, and resource-bounded reasoning issues.

As shown below, the overall architecture of the KARMA prototype system (Fig. 7) includes, among other features, the following components:

1. ***The Blackboard Data Storage***. Based on an object-oriented database management scheme, the Blackboard Data Storage represents the common working memory used to support information flow and transactions.

2. ***Knowledge Sources.*** KARMA is a parallel blackboard-based adaptive intelligent system used to accomplish specialized tasks through an expertise embodied within knowledge sources executed concurrently. The execution of a knowledge source corresponds to the activation of the action part aimed at changing the state of the blackboard.

3. ***Control Unit.*** Embedded as a separate control thread, the control unit acts as a mediating component between competing knowledge sources to support the serial execution of various actions, namely, knowledge source triggering, goal management, agenda management, knowledge source scheduling and execution.

The blackboard control cycle involves a triggering process, goal management, agenda management, scheduling phase, and interpreting mechanism. Once a new generated knowledge source instantiation (KSI) is stored on the agenda into a triggered state, the agenda checks the obviation conditions for all KSIs, except those already deactivated.

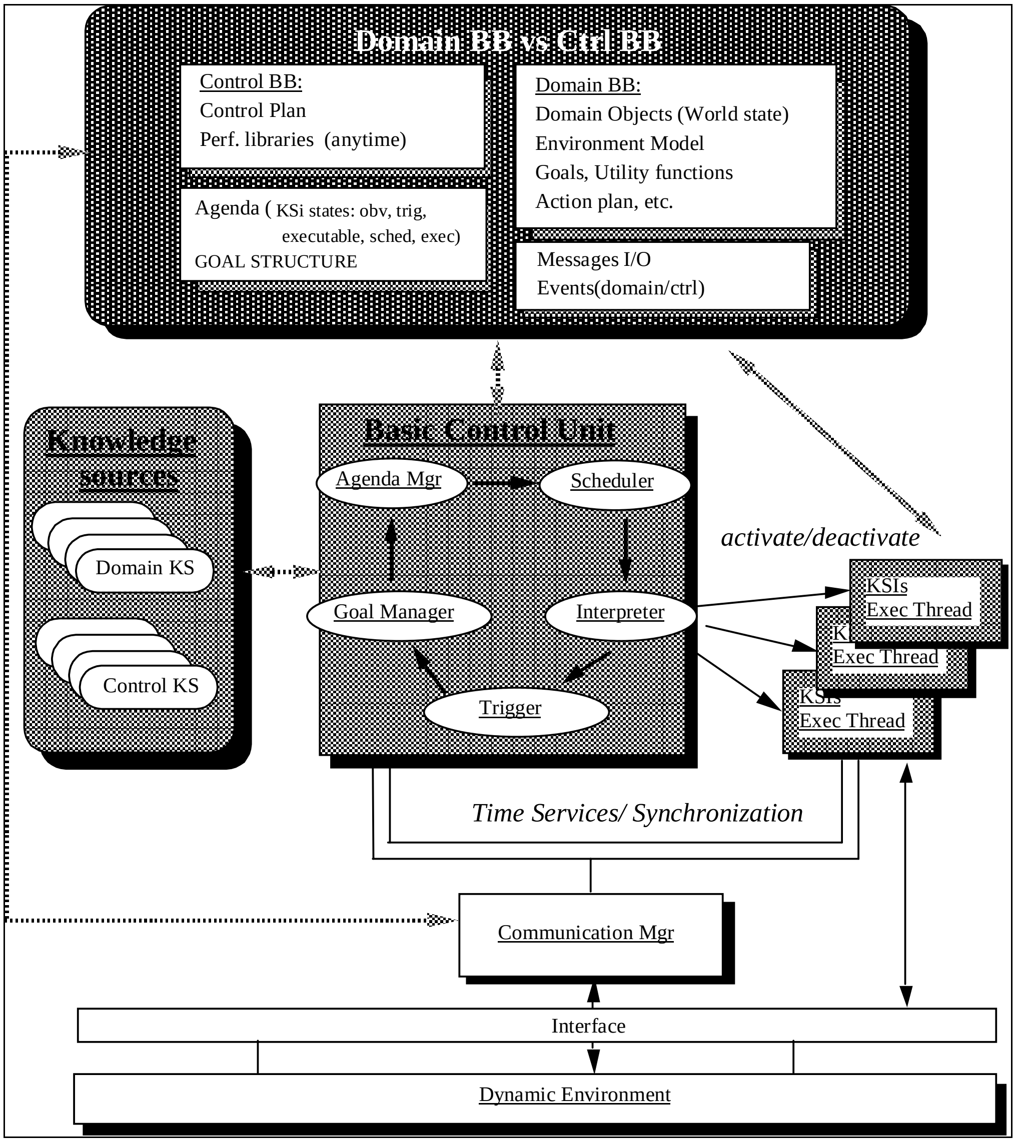

Fig. 7: KARMA Architecture [35].

vii. Decision Scheduling System (DSS)

Optimal resource management has been recognized as a critical issue to be addressed by the Canadian Air Force military community. In 1998, a joint venture involving university, private industry and DND was created to address simultaneous aircraft and crew scheduling (resource management) within the context of air operations management. The Decision Scheduling System (DSS) [36] for Simultaneous Aircraft and Crew Scheduling is a project for which the Defence R&D Canada at Valcartier is involved.

Research focused on the development of an open-loop decision support system using innovative and promising algorithms and decomposition methods from Operations Research. A mathematical programming methodology, based upon multi-commodity non-linear network static model using column generation as a problem-solving technique, was used to solve the Line Tasking problem tackled in DSS. The line-tasking problem consists in selecting airlift requests and constructing strategic airlift missions to be achieved over a specific time horizon, generating a periodic (monthly, yearly) airlift programme. More details on the line tasking problem description and its formulation (problem modeling) may be found Rancourt and Savard [36].

The DSS prototype includes six components, namely, the user manager, the input manager, the mission manager, the scenario manager, the optimizer and the output manager. Figure 8 shows these components and their relationships in the functional model. These components are briefly described next.

The user manager defines the user (planner) profile establishing privileges and preferences managing interactions with databases and connections to local and remote systems. The input manager support user interactions in specifying input information to be further submitted to the optimization component. The mission manager supports user definition of airlift requests (sequence of legs, time windows, travel time, etc.) and related constraints as well as explicit missions to be imposed by the user if needed.

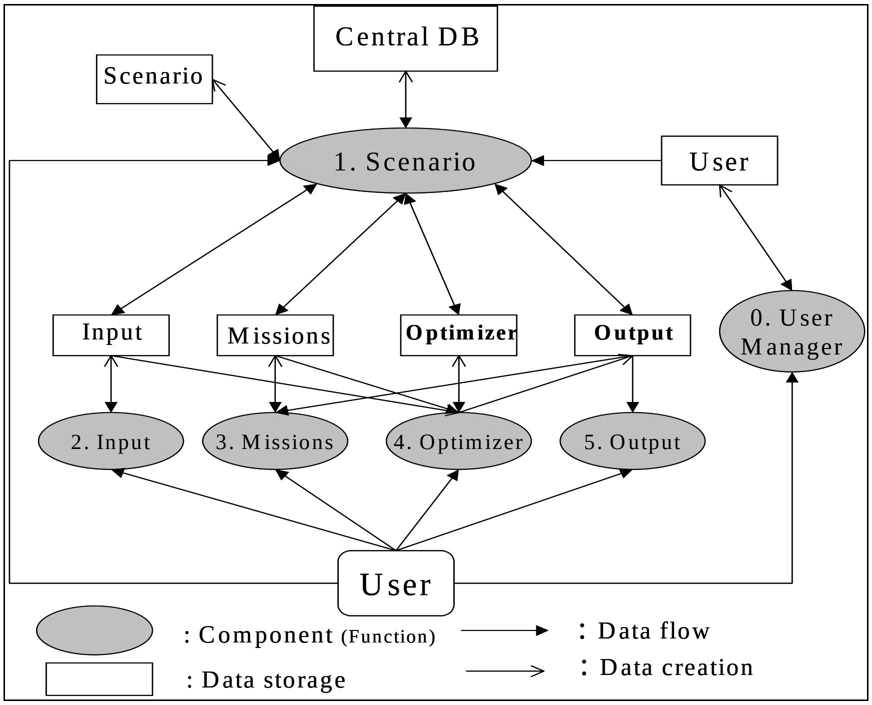

Fig. 8: DSS functional model [36]

The scenario manager provides the basic tools to piece together scenario elements and then organize or file the resulting scenarios created by the user on external data storage. Through a user-system dialog capability, the optimizer manager provides the user with the commands to activate and control the optimization engine for a specific scenario while monitoring its working status. The output manager provides the user with capabilities to visualize the computed solution based on different perspectives and formats.

4.3 Flight Planning Systems or Route Planning

i. In-Flight Planner (IFP)

The In-Flight Planner (IFP) [37] is a real-time, computer-aided mission replanning system designed to greatly increase flight safety and hence the survivability and effectiveness of an aircraft through continued reduction of exposure to threat. It is also designed to reduce pilot workload associated with the complex and time-consuming task of replanning a mission whilst operating the aircraft and weapon system.

The availability of an on-board replanning capability is critical as new events can significantly change the course of a mission and force the pilot to replan the mission based on the latest information. Initially, data output from ground-based mission planning systems such as the Air Force Mission Support System (AFMSS) or the Navy's Theater Automated Mission Planning System (TAMPS) is transferred to an aircraft platform through a Data Transfer Unit (DTU). As the system is initialized and the aircraft is airborne, the IFP can then monitor various parameters associated with the environment, aircraft conditions, and pilot commands.

Given the uncertainty of the threat environment, it is however unlikely that the mission plan would be executed as generated by the ground-based planning system. Indeed, significant events related to new threats, navigation errors, and pilot commands can occur and consequently affect the initial plan. The response would be either to abort the initial mission plan or accept a higher level of risk. In this context, the IFP is designed to provide the ability to generate a new plan through a series of must-fly steer points, provided by the DTU or pilot via the Pilot Vehicle Interface (PVI). When a new plan is proposed, the pilot is allowed to accept or reject it.

Unlike the ground-based planning environment, the cockpit of a single-seat fighter cannot obviously accommodate a large screen display and input devices. As a result, the IFP can only operate with an appropriate screen display and reduced pilot input.

The Real-Time IFP system integrates different software packages. The most important modules or subsystems include the terrain database, threat line-of-sight maps, a map data reduction technique, an auto-router, a SAR planner, and a system executive designed to control the entire system. The most fundamental element of the IFP is the line-of-sight map generated in order to position an identified threat and allows the route planner to avoid it. The line-of-sight maps generated are then merged into a single composite line-of-sight map "CLOSM" so as to depict the required altitude of the aircraft before entering the line of sight of an identified threat. The CLOSM can be very large and overwhelming. As a result, the IFP uses a data reduction technique called quadtree compression in order to achieve real-time performance. Unlike the image compression designed to reduce storage space, the data reduction technique is a method of segmenting the route planning space into quickly usable form. On the other hand, the route planner includes two important components:

- The route planning graph or network representing nodes and links.
- The route planning algorithm is designed to execute on the information associated to the nodes and links.

The Real-Time IFP system has been evaluated and shown to be effective in reducing dramatically the pilot's workload related to replanning a mission. In doing so, the system demonstrated its ability to greatly increase the survivability of the aircraft.

ii. Mission Support System -Computer Aided Mission Planning at Air Base Level (MSS/CAMPAL)

The Mission Support System/Computer Aided Mission Planning at Air Base Level (CAMPAL) [38], also known as MSS/C, is an automated tactical mission planning system designed to support the Royal Netherlands Air Force (RNLAF) flight operations. As a computer-based system, MSS/C provides the ability to perform route planning for each supported aircraft (up to four) as well as to give the opportunity to aircraft pilots to familiarize with the battle theater.

Using electronic maps including intel overlays, MSS/C gives air mission planners the capability to perform planning for the following missions: (i) offensive missions to/and from the destination area, (ii) manoeuvring (e.g. attack and combat air patrol), and (iii) ferry missions (the route from home to the destination base). The System also provides to execute calculation for level flights, climbs and descents. Additional features and functions of MSS/C lies in the possibility to perform in-flight refuelling; aircraft performance package (aircraft's capabilities and fuel requirements); and finally, generating the flight plan and Combat Mission Folder in either peace, war or tension times. Data output from the planning system (coordinates, fuel information, flight plan and overview map) is then transferred to the aircraft via the Data Transfer Cartridge (DTC).

Using external command and control systems and/or database resident in MSS/C, the system can retrieve data information for the actual scenario. This information is divided in three main types: geographical and weather data, friendly, and enemy (intelligence data on enemy defense systems) assets including aircraft and weapon system parameters. In the end, MSS/C has been improved in order to be faster and to run on state-of-the art Commercial Off the Shelf (COTS) hardware. The succeeding system has been named MSS/Pandora.

iii. Portable Flight Planning System (N-PFPS)

The Naval (or Navy) – Portable Flight Planning System, or Software, (N-PFPS**)** [39] is a basic Navy-Marine Corps flight planning system. As an automated computer-based system, N-PFPS provides the ability to perform route planning (time, distance fuel and aircraft performance) taking in account the aircraft's configuration (weight, drag, speed, etc.) as well as the environmental factors (altitude, wind, pressure, humidity, etc.).

Although N-PFPS does not support weapons, it provides however the capability to rapidly generate plans from starting point to end point, end point to starting point or portions of a route and allows to load aircraft navigation data such as the Global Positioning System (GPS), the Digital Aeronautics Flight Information File (DAFIF), etc. In addition, flight data can be transferred to aircraft computers by using Data Transfer Device (DTD). This data is then used to initialize the database operated by the on-board aircraft computers.

Based on a modular architecture, N-PFPS includes software modules called Flight Planning Modules (FPMs) allowing the mission planner to prepare missions that are exactly tailored to each supported aircraft. Moreover, without changing the whole system, N-PFPS offers the opportunity to develop new flight planning modules in order to include and support new aircraft. Finally, N-PFPS functionality has been ultimately replaced by The Joint Mission Planning System (JMPS) during the Year 2002.

iv. Tactical Automated Mission Planning System (TAMPS)

The Tactical Automated Mission Planning System (TAMPS) [40-42] is a US Navy-US Marine Corps unit-level aircraft mission planning system. As a computer-based support system, TAMPS is designed to provide the ability to load aircraft software with route-of-flight data files including waypoints and sequential steering files, air-to-air radar presets, navigation aid channels and identification files. In addition, TAMPS offers the opportunity to load independent overlays for aircraft software and bulk files for missile software. As a result, it enables the use of a variety of weapons while decreasing weapon system pre-flight preparation time.

In this respect, TAMPS is a mission support system that can rapidly process large quantities of digitized terrain, threat and environmental data, aircraft and weapon system parameters, and imagery. Data output from the system can be transferred to aircraft platforms using Data Storage Units (DSUs), Memory Units (MUs), Mission Data Loaders (MDLs), and Tactical Tape Cartridges (TTCs).

Based on a modular architecture supporting common planning requirements of various weapon systems, TAMPS includes core modules that allow the integration of independently developed Mission Planning Modules (MPMs) and Mission Planning Functions (MPFs). In other words, the TAMPS architecture offers the opportunity to add and update specific modules without the need to modify the whole system or change the core module.

v. SAIC Mission Planning System (SAIC//MPS)

The SAIC Mission Planning System (SAIC//MPS) [43] provides the ability to conduct air mission planning, analysis, replanning, and rehearsal. As a tactical planning system designed for the air force, navy, marine, as well as the army, the SAIC//MPS is designed to give air mission planners more effective and automated capabilities in developing mission plans for fighters, bombers, transport aircraft and helicopters.

Using digital maps, imagery and elevation data, the system provides the ability to perform route planning (time, distance fuel and aircraft performance) and calculate other key flight parameters regarding weapons configurations, threat analysis, and weapons load effects on weight and balance. In addition, flight performance of each supported aircraft (up to 32 in each mission) can be changed for cruise, climbs, and descents. Another feature provided by the SAIC//MPS lies in the ability to perform optional route segments such as refuelling or orbiting. On the other hand, a user is finally allowed to assess the feasibility of a planned route through mission pre-fly over 3D terrain. In the end, data output from the planning system is then transferred to aircraft using data transfer cartridges.

Used in Command and Control, the SAIC//MPS is a portable system that can be integrated with the SAIC Air Combat Evaluation System, a companion product for post-flight analysis. It is also designed to incorporate RADSIM, a SAIC’s precision radar simulation capability, so as to provide a total and effective mission planning package. Using C++ object oriented

Libraries, the SAIC//MPS system can indeed be configured on either a PC (desktop or laptop) or a UNIX workstation, depending on customers' needs.

vi. CINNA

The CINNA [44] provides the ability to conduct air mission planning from tasking to debriefing. As a tactical ground-based planning system designed for the French[9] air force, this system is designed to give air mission planners and aircrews more effective and automated capabilities in developing route planning, stand off weapon mission preparation, target analysis, data base management and mission rehearsal.

In this respect, CINNA 4 can rapidly process large quantities of the following data type: Digital Terrain Elevation Data (DTED), Satellite Photography (Photo), Intelligence Data (Intel), Operational Data (Ops), and Radar Imagery (Radar). Therefore, the system provides the ability not only to compute in real time fuel flow, heading, distance, etc. but also to calculate other key flight parameters such as weapons delivery.

In the end, using variable speed simulation as well as dynamic events, a user is allowed to assess the feasibility of a planned route through mission pre-fly over 3D (bird's-eye) terrain and 2D simulation/deconfliction.

vii. Air Force Mission Support System (AFMSS)

The Air Force Mission Support System (AFMSS) [45-48] comprises the following subsystems:

- Portable Flight Planning Software (PFPS) (PC-based),
- Family of Mission Planning System (MPS) (UNIX-based)

The Portable Flight Planning Software (PFPS), a PC system of AFMSS, was first designed independently of AFMSS by Air Force (AF) personnel and is currently government-owned and developed with annual revisions by the 46th Test Squadron Mission Planning Flight (TS/OGET).

The two systems, PFPS and AFMSS, can exchange flight plans (routes) and point libraries. By using tools, PFPS is capable of supporting all missions (such as simple day-to-day training proficiency flights, peacetime operational/exercise sorties, or conventional or nuclear conflict) and all aircraft. PFPS also provides supporting planning for air-to-air, air-to-ground, air refuelling, electronic combat, reconnaissance, special operations, conventional gravity weapon releases from high, mid or low altitudes using a wide variety of release procedures, to airlift and rescue missions.

The major system components are:

- Combat Flight Planning Software (CFPS)
- Falcon View (a government-owned mapping package)
- Combat Weapon Delivery Software (CWDS)
- Combat Airdrop Planning Software (CAPS)
- Cartridge Loader (selected aircraft)

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[9] Developed by Matra Systèmes & Information (a subsidiary of EADS, European Aeronautic Defence and Space Company).

The software is available for download from the 46th TS/OGET web page. Currently used by all US Air Force (USAF) aircraft except the B-2, it is also being fielded by the Navy and the United States Special Operations Command (USSOCOM).

4.4 Other Specific Military Planning Systems

i. The Rochester Interactive Planner System (TRIPS)

The Department of Computer Science at the University of Rochester in the United States has developed The Rochester Interactive Planner System (TRIPS) [49-50]. This system integrates speech recognition, natural language understanding, discourse processing, planning and plan recognition and other features. It is designed to provide the human user with an interactive, intelligent problem-solving assistant in a transportation/logistics domain.

TRIPS represents an integrated AI system based on previous experience gained in developing the TRAINS system. However, TRIPS functions in a more complicated logistics domain compared to TRAINS, a simple route-planning domain. In addition, TRIPS supports the construction of much more complex plans than TRAINS could produce or understand, and embodies a more complex model of collaborative problem solving.

The TRIPS system can be regarded as an assistant to a human manager where the two can collaborate to construct plans in crisis situations. As shown in the figure 9, TRIPS includes various modules that communicate by exchanging messages through a central message-passing Input Manager. Indeed, TRIPS is based on an infrastructure designed to allow any program that can read standard input and write standard output to exchange messages.

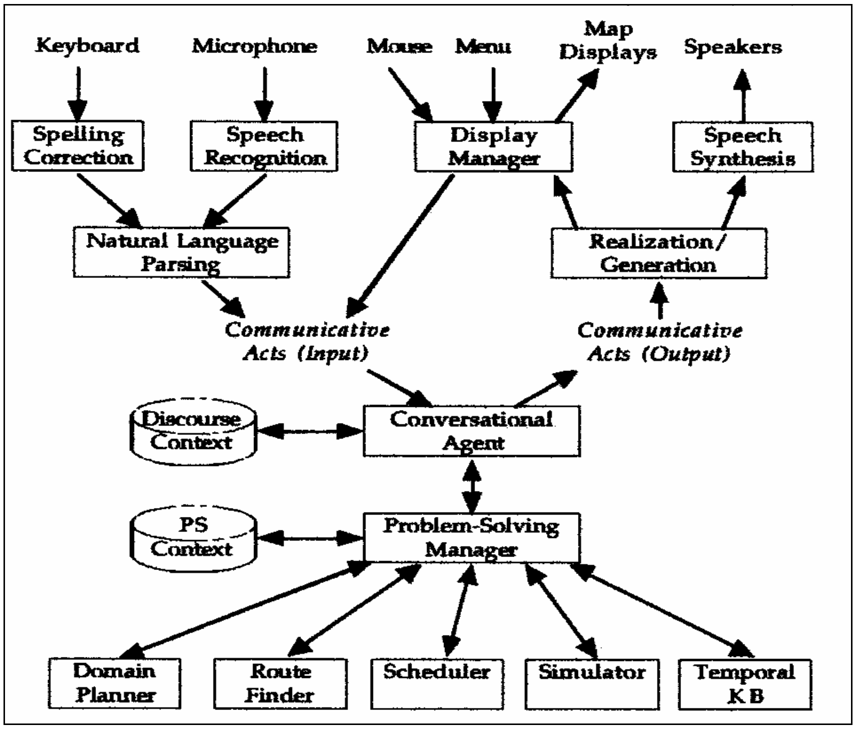

Fig. 9: TRIPS Architecture [49].

ii. Deliberate Crisis Action Planning and Execution Segment (DCAPES)

The Deliberate Crisis Action Planning and Execution Segment (DCAPES) [51] is an application of the Global Command and Control System (GCCS) designed to achieve the Chairman's, Joint Chiefs of Staff (CJCS) goal: develop a Time-Phased Force and Deployment Data (TPFDD) within 72 hours. Operating in a classified, shared data environment on the SECRET Internet Protocol Router Network (SIPRNET), the DCAPES system is used to link Air Force Planners with Joint War Planners through the GCCS Joint Operations Planning and Execution System (JOPES).

Developed (or being developed) by the Air Force to replace the Contingency Operations and Mobility Planning and Execution System "COMPES", the DCAPES system provides data and data manipulation capability to Air Force planners and commanders to:

- perform rapid Operations Plan (OPLAN) development, and
- conduct feasibility and capability analyses

The objective behind the DCAPES system lies in the need to integrate the Air Force "stand-alone" war planning systems into a single, logical database, so as to bring the Air Force one step closer towards supporting the Integrated Command and Control System "IC2S" vision. Designed to support deployment, re-deployment, sustainment, mobilization, and reconstitution, the DCAPES operating as a single system eliminates duplication of efforts and re-work and improves the response time while enhancing the overall data integrity and accuracy.

Indeed, DCAPES supports all levels of command, across the operational continuum using modern integrated tools, shared infrastructure, and common data consistent with the Air Force C2 Vision. While supporting collaborative planning, DCAPES offers the ability to track individuals and equipment from home station through deployment. Designed to be standard compliant, DCAPES is capable of coexisting with other established data systems.

iii. Joint Maritime Crisis Action Planning (JMCAP)

The Joint Maritime Crisis Action Planning (JMCAP) [52] System is still under development as a combined effort of the U.S. Navy Space and Naval Warfare Systems Center (SPAWAR), formerly Naval Research and Development (NraD). Sponsored by the Office of Naval Research (ONR), the JMCAP prototype was built as part of a project designed to ensure a transfer of the technology and applications developed by SRI International and other supported research institutions into operational navy systems. The idea behind this project was to conduct user-centered, participatory design of end-to-end systems, supported by both commercial technologies and advanced research prototypes that were already shown to be feasible for military planning and execution problems.

Based on available information, the present description can only briefly report the applied research undertaken within the Advanced Concept Technology Demonstration (ACTD) that led to the development of systems and concepts called Extending the Littoral Battle space (ELB). Indeed, these systems and concepts were considered at the time as likely to provide the basis for a JMCAP prototype. The problem addressed by this research was to provide the ability to semi-automatically generate crisis response options, in the presence of multiple, competing objectives and constraints, within a distributed computing environment that includes multiple agents collaboratively solving the overall planning problem.

In this respect, the efforts undertaken within this project were focused on the development of a technology for distributed, collaborative, continuous planning in a maritime campaign domain. The problem addressed consists in developing advanced knowledge-based technologies required to provide the ability to generate crisis response options, in the presence of multiple, competing objectives and constraints. The whole planning process is indeed designed to be conducted within a distributed computing environment that includes multiple agents collaboratively solving the overall planning problem.

Based on these requirements, the technical challenges associated with the JMCAP project lie in the need to:

- identify a common plan representation that allows distributed plan authoring, plan generation, and execution monitoring components to share knowledge about the evolving plan,
- develop techniques for distributing the planning problem, managing the distributed planning and plan de-confliction process, and merging the resulting component plan,
- develop and apply a hybrid approach to plan generation that integrates AI generative planning and case-based reasoning methods, and
- provide support for re-planning as a result of conflicts that may arise during planning, or execution failures.

iv. Joint Strategic Planning System (JSPS)

The Joint Strategic Planning System (JSPS) [53] represents the primary formal means by which the Chairman of the Joint Chiefs of Staff (CJCS), in consultation with the other members of the Joint Staff and Unified Commanders in Chiefs (CINCs), carries out planning and policy responsibilities detailed in Title 10, US Code. Through the JSPS system, the CJCS can, as the primary military advisor to the National Command Authorities (NCA), provide:

- assistance to the US President and Secretary of Defense on matters regarding the strategic direction of the Armed Forces,
- military strategy and strategic plans and assessments in support of strategic national objectives,
- advice to the Secretary of Defense on US Forces capability deficiencies and strengths in conducting national security objectives,
- recommendations on defense programs and budget proposals.

In addition, the JSPS system can also provide the ability to monitor strategic environment so as to identify changes in conditions or trends that may justify changes in the strategic direction of US Armed Forces. The Joint Strategic Planning System is designed to help the CJCS to prepare and review strategic and contingency plans and advice both the US President and Secretary of Defense on programs and budgets. The JSPS is also used to assist the CJCS in his task of providing advice to the President and Secretary of Defense on matters related to provision of net assessment on the capabilities of the US Armed Forces. Integrated into JOPES, the Joint Strategic Planning System indeed provides extended flexibility in interacting with other Department of Defense DoD systems such as the Planning, Programming, and Budgeting System (PPBS).

v. Open Planning Architecture (O-Plan)

The Open Planning Architecture (O-Plan) resulted from a project conducted at the Artificial Intelligence Applications Institute (AIAI) [54] of the University of Edinburgh around computer based generative planning. The O-Plan project grew out of a research work into AI planning conducted in the late 70s and 80s. O-Plan inherited features from NOAH, NonLin, Deviser, Molgen, and OPM. Its architecture or framework was designed and built to incorporate all these borrowed features into a single system.

O-Plan1 represents the initial project conducted in order to build a knowledge-based system capable of generating plans. The idea behind stemmed also from the need to develop a system to experiment with and integrate novel ideas and concepts. Indeed, the system was tailored to suit particular applications. In this respect, time and resources constraints were handled to restrict search and still work within an activity based plan representation.

Launched in 1989, O-Plan2 was designed to offer a generic domain independent computational architecture suitable for command, planning and execution applications. The O-Plan2 research provided the opportunity to gain a complete vision of a modular and flexible planning and control system incorporating artificial intelligence methods.

In O-Plan2, the task assignment process consists in enabling a user to specify a task, which can be performed through some suitable interface. On the other hand, the execution system seeks to carry out the detailed tasks specified by the planner while working with a more detailed model of the execution environment. Indeed, the system is designed to operate both as a planner and a simple execution agent.

The O-Plan2 agent oriented architecture (Fig. 10) consists of the following components:

- **Domain Information –** this component contains the information required to describe an application and the tasks to the agent,
- **Plan State –** the identified tasks associated with the emerging plan to carry out,
- **Knowledge Sources –** the processing capabilities of the agent,
- **Support Modules** - functions designed to support the processing capabilities of the agent and its components,
- **Controller –** controls the order in which processing is done.

Similarly to SIPE-2, O-Plan technology has been used to support various military projects undertaken within the ARPA-Rome Planning Initiative. The approach was designed to incorporate O-Plan as a subsystem to assist military users in generating plans and reviewing qualitatively different solutions. O-Plan can be used to perform concurrently different task assignment, planning and execution monitoring. Indeed, multiple users can interface to this planning system and each other via Open Planning Process Panels that are configurable interfaces through any World Wide Web browser.

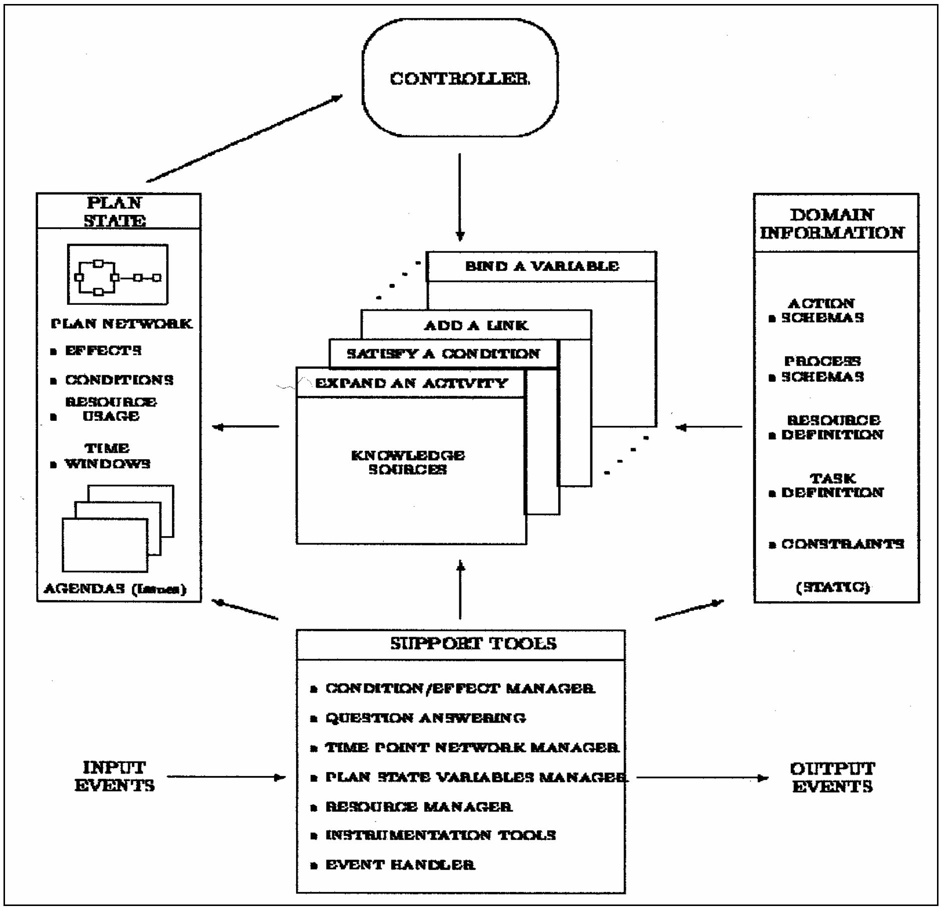

Fig. 10: O-Plan2 Architecture [54].

vi. Joint Standoff Weapon - Mission Planning Module (JSOW-MPM)

The prototype Joint Standoff Weapon (JSOW) Mission Planning Module (MPM) [55] was developed under a contract with the Naval Air Systems Command (NAVAIR) to improve JSOW mission planning by using real-time Meteorological and Oceanographic (METOC) data. In this context, the developer has collaborated with JSOW mission planners and METOC personnel in order to provide the mission planner with a tactical display and a tool for environmental data management.

This planning module provides the ability to edit the missile's route (route information) and modify preferences. Moreover, using Metplan (the Meteorological and Oceanographic data management server), JSOW MPM allows the capability to edit data management preferences as well as view METOC products. Finally, the mapping functionality of Falcon View is used to provide the user with up-to-date charts, drawing routes and objects.

5. Conclusion

A number of mission planning and scheduling systems addressing specific military needs has been surveyed. The review covered various issues associated with mission planning function, methods, tools and procedures used to plan and schedule complex military operations.

Emerging techniques involved in the design of advanced mission planning systems were also examined. The Canadian military planning process describing the doctrinal elements driving the development of planning systems was first presented. Key paradigms and technologies characterizing such mission planning systems were then depicted. Finally, taxonomy was proposed to classify the most important joint and air operation planning systems.

Despite a wide variety of systems and prototypes currently available and relevant to military operations, new challenges emerge in the progressive evolution or trend toward the network centric operations era. This dictates requirements to achieve adaptive planning on a continual basis, interleaving plan construction and execution in distributed environments. In addition to plan generation and execution monitoring tasks, distributed continual planning includes critical issues associated with shared plan representation, adaptive coordination, and interoperability. Developing, selecting, and incorporating suitable technological innovations to provide integrated and interoperable systems and tools can enhance military capability to accomplish multi-level operational planning and execution.

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