An Architecture for Decision Support in a Wargame[1]

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Abstract

The structure and operations of a Decision Support System that supports the design and analysis of Courses of Action (COAs) for Effects Based Operations (EBO) is described. This system, called CAESAR II/EB, consists of a suite of tools that transform an influence net into an executable model.

An architecture for the use of CAESAR II/EB was developed and then verified through participation in a military wargame with a realistic command structure. The architecture was depicted using both the object-oriented Unified Modeling Language (UML) and the associated diagrams, as well as elements of structured analysis. A comparison between the planned and actual operational architecture view, as it evolved in the wargame, is made. Furthermore, issues regarding visualization of the results are discussed.

The CAESAR II/EB system was exercised at the Global 2000 Wargame where several problems were addressed. Observations are presented concerning the requirements that such a decision support system should meet in order to provide utility to the Command cell.

1. Introduction

Command and Control (C^2) has always been, and will always be, a challenging field, as proved by the degree of training and experience necessary to conduct it successfully. However, even well-trained officers are facing new challenges as the scope of military operations is expanding into operations other than conventional war. The overall mission success may well hinge on a combined set of military, political, and social objectives.

The CAESAR II/EB tool suite participated in the Global 2000 Wargame, which was held at The Naval War College in Newport, Rhode Island, in August, 2000. Background information, including a description of the tool suite and analysis process, is presented in this section, as well as a short description of the Global 2000 wargame, which served as the experimental testbed. Section 2 presents the predicted operational architecture view, which was developed prior to the wargame, and Section 3 presents the observed operational architecture view. The development of an operational architecture prior to the wargame and the revision of that architecture to reflect what actually happened provided the basis for the findings and conclusions presented in Section 4.

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1.1 The CAESAR II/EB Tool suite and Analysis Capabilities

The CAESAR II/EB tool suite is a collection of tools and an associated analytical process that is aimed at providing commanders and their staffs the ability to evaluate various Courses of Action in terms of achieving the desired effects. A detailed explanation of the theory underlying each of the elements of CAESAR II/EB can be found in Wagenhals et al., [1998]. The CAESAR II/EB tool suite was described in detail in Wagenhals et al., [1999].

The CAESAR II/EB tool suite software consists of two major components: an influence net application and a Colored Petri net application. We currently have two influence net applications: SIAM (built by SAIC [SIAM, 1998]) and CAT (from the Air Force Research Laboratory, AFRL/IF, NY [Lemmer, 1993; 1996]). Either of these can be used to construct an influence net and output that net in a form readable by the Colored Petri Net application.[2] Design/CPN (developed by the University of Aarhus [Design/CPN Online, 1999; CPN Group, 1999]) is the Colored Petri Net application, and code was written within that application to read the interface file produced by the influence net application.

The CAESAR II/EB analysis process consists of three major activities: the construction of the influence net, development of the Petri Net from the influence net (currently an automated function performed via a web browser interface) and the analysis of alternative COAs via the Petri Net. The inputs to these processes are in two major structures: the inputs required to build an influence net, and the inputs required to specify the timing factors which must be associated with the actionable events or inputs and the processes represented by the influence net. These steps are described in more detail in the following sections.

1.2 Global Wargame & Friendly Team Organizational Structure

The Global wargame has been held annually at the U. S. Naval War College in Newport, Rhode Island for over 20 years, and serves a multitude of missions, including being a testbed for new decision support tools. The System Architectures Laboratory at George Mason University was invited to bring CAESAR II/EB to Global 2000 in order to evaluate its capabilities as a decision support tool.

The command structure used in Global 2000 consisted of a Coalition Joint Task Force and several subordinate component commands. A “Friendly’s Enemy Cell” or FEC supported the command structure. The CAESAR II/EB tool suite and its team were assigned to support this cell. The FEC within the Friendly Command Structure provided the Friendly Commander with assessments of possible or probable Enemy reactions to Friendly actions. These possible reactions spanned a wide spectrum of areas other than purely military, although, as the wargame progressed, the focus narrowed to essentially purely military operations. The Commander and his immediate staff would issue “Inquiries” to the FEC on a particular topic, and the FEC would prepare responsive reports (“Assessments”) in a timely manner. The output of the FEC back to the Commander and his staff consisted of a number of short reports or position papers, usually not more than 2 pages long. These reports were reviewed by the FEC chief and others prior to

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[2] A special edition of SIAM version 2 is capable of producing the appropriate file. The current version of SIAM, version 3, does not export this file.

their release. These reports were disseminated throughout the command structure via the Global intranet and other mechanisms.

The output position papers had very concise format and content. Their intent was to transmit information and conclusion succinctly and directly, since the workload at the higher levels of command precluded an in-depth review of lower-level products.

2. Predicted Operational Architecture and Procedures

This section presents the operational architecture for CAESAR II/EB that was developed in the months prior to our participation in the wargame. This early version served two significant purposes by providing: (1) a form of top-level requirements which served as guidance in the development of the CAESAR II/EB user interface, and (2) top level capabilities description of the tool which allowed program managers to understand where the tool would best fit within the Global wargame command structure. The initial operational architecture view consisted of a set of sequence diagrams (which imply a set of object class diagrams as well), and these are presented in this section.

The initial inputs to the CAESAR II/EB component are the Desired Effects, the Candidate Actions (Actionable Events) and their Relations (influence relationships), and timing information. Then, a sequence of interactions between the CAESAR II/EB analyst and the FEC Staff (intelligence specialists and Subject Matter Experts) will refine the influence net model and guide the Course of Action (COA) analysis. The results from the CAESAR II/EB component consist of COA evaluations, which are sent to the Staff. These are used by the Staff as the basis for recommending specific candidate COAs to the Commander.

Figures 1-6 show the initial assumed operational architecture for the CAESAR II/EB within the Global command structure. The operations involving CAESAR II/EB were assumed to fall into two “stages”: a model-building stage prior to the wargame, and an interactive stage during the wargame (Fig. 1).

Two basic scenarios for the use of CAESAR II/EB were modeled. The first scenario covers the development and use of a new model, and the second scenario covers the refinement of an existing model and its use. These two scenarios involve a fair amount of common interactions. Sequence diagrams can be broken down into sequence segments, which can then be combined in a somewhat “modular” fashion. Figure 2 shows how the component event sequence diagrams can be combined to form one of two complete “scenarios” or operational sequences. Consequently, as is shown in Fig. 2, regardless of whether sequence ES1a or ES1b is first executed, the “system” should then execute sequence ES 2 then ES 3 to complete the overall process.

Figure 3 shows the detailed event sequence for segment ES 1a. This diagram captures the basic events of being assigned a problem (“Situation & Goals”), constructing a candidate influence net with the intelligence analyst, and having the model reviewed and approved, with edits.

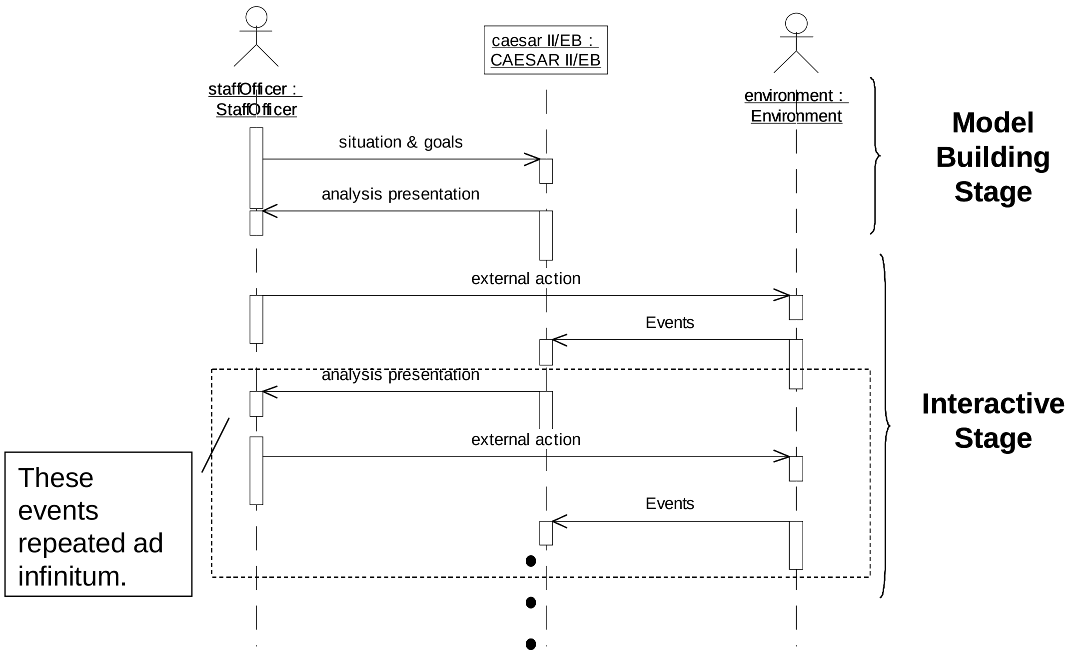

Fig. 1. The model building stage was assumed to come first, followed by an interactive stage.

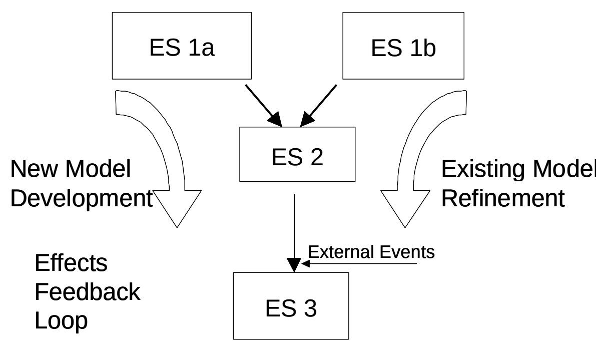

Fig. 2. How the sequence segments “fit” together to form one of the two operational scenarios.

Note that the predicted sequence consisted of one major influence net building process, with a second “adjustment” process. At the end of this sequence segment, the influence net model is completed and ready for conversion to the Colored Petri net.

When basing the current analysis on an existing model, the model must first be selected, and then modified to some degree prior to use. This is shown in Fig. 4. At the end of this sequence segment, the influence net model is completed and ready for conversion to the Colored Petri net. So, from the standpoint of the following analyses and sequence segments, it does not matter which of these sequence segments was executed – both leave the "system" (i.e., the command officers and the CAESAR II/EB component) in the same "state".

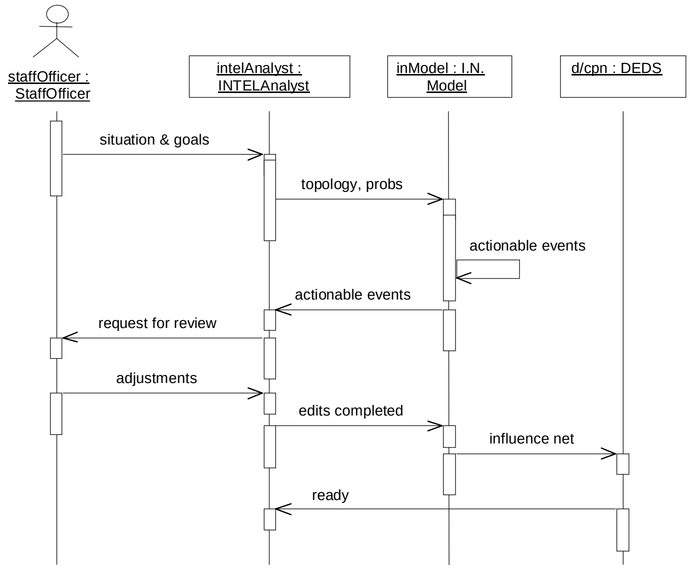

Fig. 3. Event Segment ES 1a: The predicted process of new model construction.

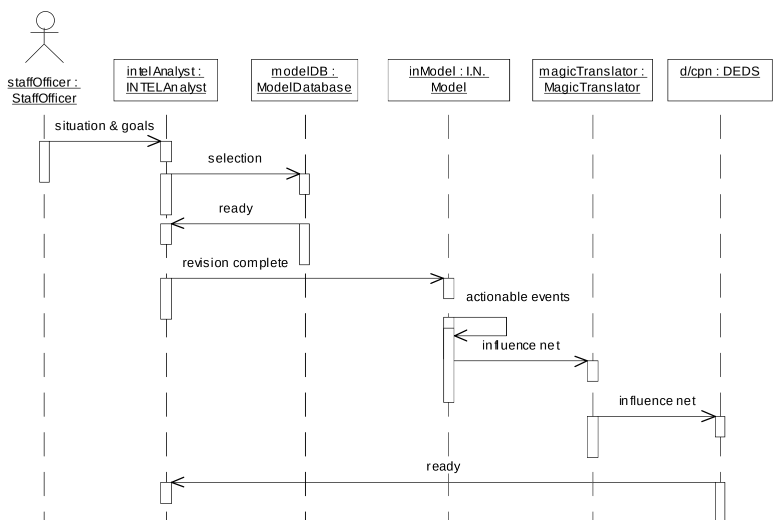

Fig. 4. Event Segment ES 1b: The sequence segment describing the selection of an existing influence net model and the modification of the model for the current command situation.

Given that an influence net model has been constructed (via either Event Segment 1a or 1b – Figs. 3 & 4, respectively), the process will follow the next two event segments. Figure 5 shows the details of translating the influence net into the Colored Petri net form, which requires an additional set of inputs. Although the topology of the Petri net is determined solely by the topology of the influence net, the timing factors must be added at this point in the analysis.

Timing information, including the times of events and the process delays, must be entered. These data set must also be reviewed by the analysts, and additional iterations may occur, if the data have high uncertainties associated with them.

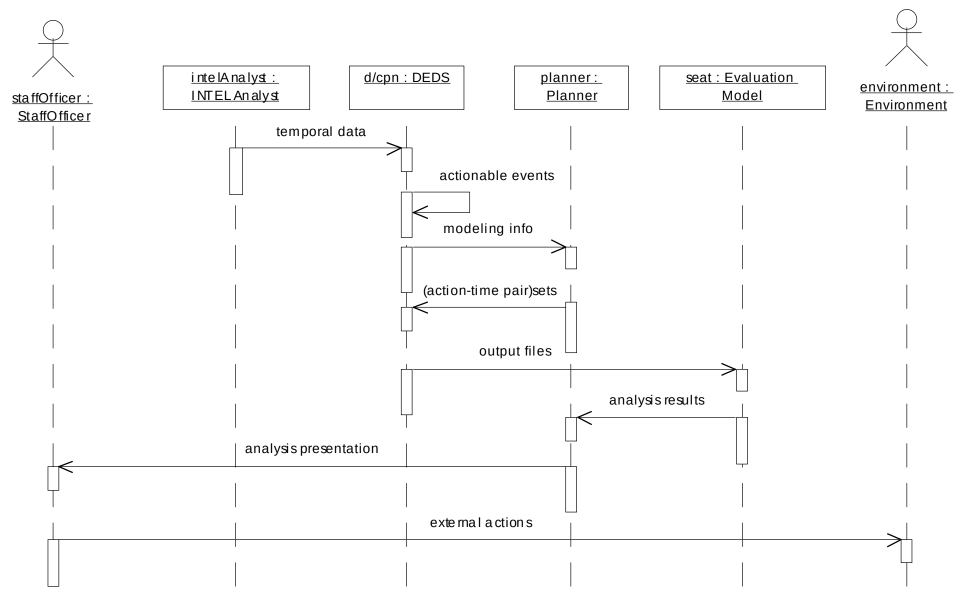

Fig. 5. Event Segment ES 2: The sequence segment describing the conversion of the influence nets into colored Petri net, with the addition of the timing information. The command staff executes the first "external actions" upon the environment, based on the CAESAR II/EB analysis presentation.

The final event segment was predicted to consist of a repeated sequence of analyses, based on a somewhat fixed model, but incorporating evidence from observations of events associated with the influence nodes/Petri net transitions. The concept for the model usage at this point envisioned that as information was gathered from the game events, the analysts would update the probabilities in the model, re-run COA analyses, and present the adjusted analysis results to the command staff. This process is illustrated in Fig. 6.

Feedback from the external Environment consists of Events, which are used to update the timing and marginal probabilities of the nodes in the net. This allows revised analyses to be performed, which then lead to another set of external actions.

These diagrams comprised the initial design of the CAESAR II/EB-Global operational architecture. Even though brief, they were able to successfully help define the role for CAESAR II/EB at the Global wargame, and serve as guidance for the development of the CAESAR II/EB user interface and the internal operational design of the CAESAR II/EB tool suite.

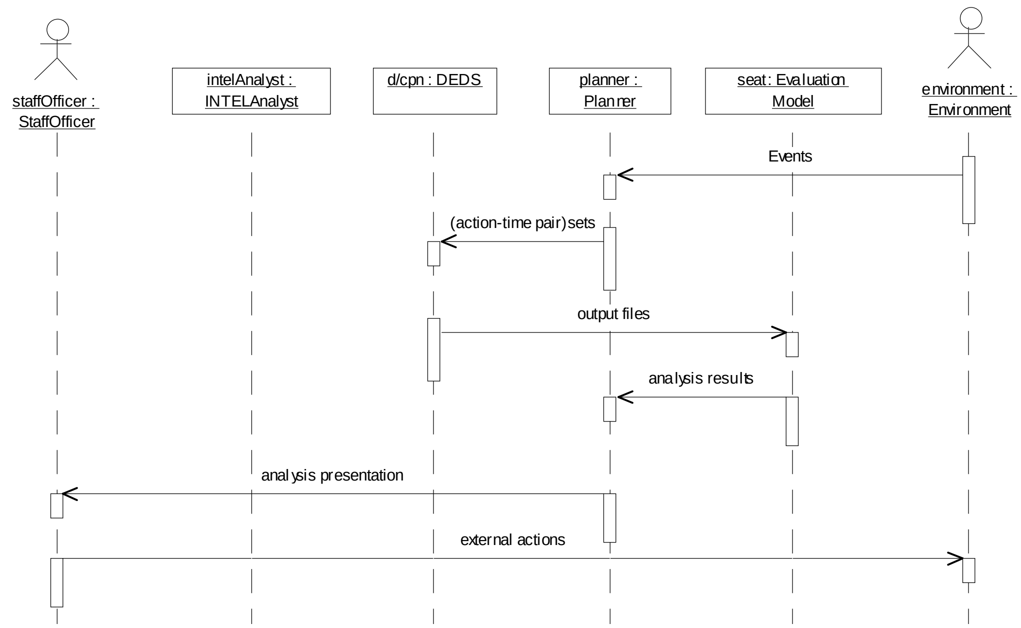

Fig. 6. Event Segment ES 3: The sequence segment describing the feedback sequence from the Environment (via Events), through re-analysis, to a new set of commanded external actions.

3. Observed Operational Architecture View and Procedures

The preceding section presented the predicted operational architecture view, while this section presents the operational architecture view that was defined after participation in the Global wargame. The actual participation allowed a much more detailed understanding of the necessary activities of CAESAR II/EB as a decision support tool, and the context at Global in which this tool functioned.

One significant difference between this architecture view and the one presented in Section 2 is the scoping of the CAESAR II/EB involvement. The generic "intelligence analyst" from Section 2 has been replaced by the more specific "FEC" in the observed operations. Also, because the CAESAR II/EB functioned solely within this FEC, we had little visibility into the operations within the Higher Authority (HA) Cell and almost no visibility into the operations of the umpires and simulators on the game floor. Although we helped develop reports and assessments which went to the HA Cell, and saw orders and other directives from that group, we had essentially no visibility into the internal operations of that group. Thus, the HA Cell is treated simply as a black box, and no descriptions of the internals of that box are within the scope of this paper.

3.1. Overall Operational Architecture View Description

The operational architecture view is described here through different perspectives. First, there is the organizational architecture, which describes the organizations and groups within those organizations (i.e., an organization or command relationship chart). This is shown in Figures 8 through 11. Next, the operational node connectivity description is illustrated; it defines how these groups and organizations interact by specifying the kinds of information that pass between them. Activity models are used to represent the activities and flow of information between activities within the architecture. Sequence Diagrams provide representations of the dynamic message passing between entities in the architecture.

The Friendly command structure is shown in Figure 8 as a Command Relationship Chart. The Commander of the Friendly forces had several Component Commands under him as well as several other standard staff offices, including Intelligence. Specifically represented at Global 2000 was the Friendly's Enemy Cell (FEC), which was responsible for trying to think like the Enemy, and suggest or predict possible or probable Enemy reactions to Friendly actions. As shown in Figure 7, it was within this group that the CAESAR II/EB Decision Support Component was placed and operated during the Global 2000 wargame.

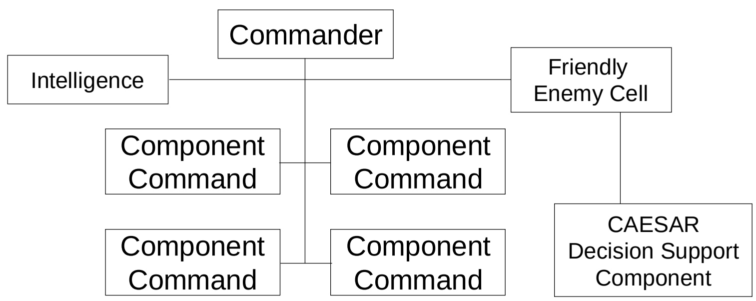

Fig. 7. A partial organizational chart representation of the Friendly Command Structure, showing the organizational placement of the CAESAR II/EB Component.

The operational architecture view captures the information flow between the organizational elements. In C4ISR AF terms, this is called an OV-2 Operational Node Connectivity Description, and Fig. 8 schematically illustrates the connectivity discussed here. A basic Command Node, consisting of a Commander and his Subordinates (i.e., the Command Staff of the Force in question), is responsible to the Higher Authority (HA), and has a set of Resources that it commands. The Resources interact with the Threat (within the Environment). Resources can both act against the Threat as well as gather information about the Threat and the Environment. It is only through the Resources that the Command Node can gather any information about the Threat and the Environment.

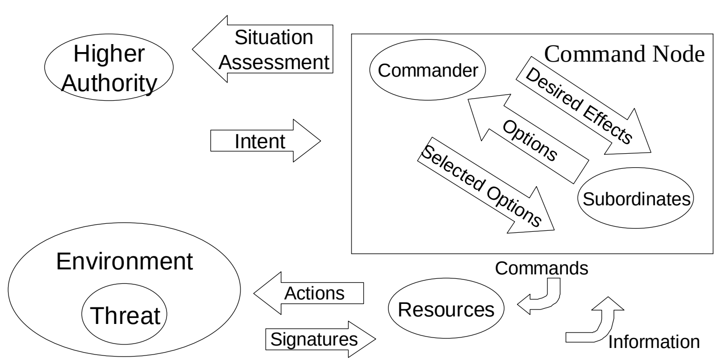

Fig. 8. The basic skeleton of the Operational Node Connectivity Description (C4ISR AF OV-2 diagram).

A key feature that is important to note, however, is that the Command Node has no direct connection to the Environment and/or the Threat. It is assumed that all information about the Environment/Threat is collected and transmitted to the Command Node via some of the Resources. Likewise, the Command Node can only act on the Environment/Threat via Commands sent to the Resources.

3.1.1. Functional Model of CAESAR II/EB at Global

A different perspective of the architecture can be provided by functional analysis, and an IDEF0 model was created for the entire command process used at Global 2000. The entire functional model is too large to be included in this paper. The specific description of the activity supported by the CAESAR II/EB team was called "Evaluate Candidate COAs". Figure 9 shows the IDEF0 representation of this activity.

Figure 9 presents the final level of functional decomposition of the problem, where the details of the CAESAR II/EB operations are visible in good detail. Although the mechanisms for all functions on this diagram include both the Component Commands and the Cells, we focus solely on the operations that occurred within the CAESAR II/EB Component as an element within the FEC. It is assumed that the other Component Commands did not in fact follow this process, and only performed a more traditional evaluation of alternative COAs based on their experience and other data.

Figure 9 illustrates how the individual functions and processes that comprise a CAESAR II/EB analysis fit together. The discussion from Section 2 on the process of using CAESAR II/EB is supported by this functional description.

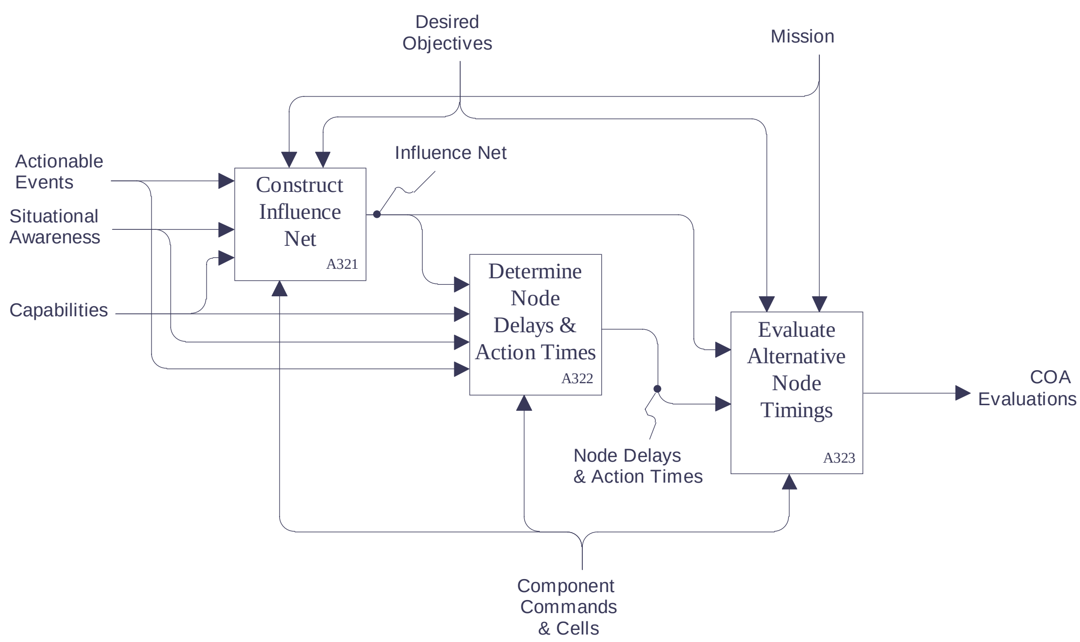

Fig. 9. The decomposition of A32 “Evaluate Candidate COAs”.

3.1.2. Event/Message Sequence View of CAESAR II/EB at Global

The following figures are UML Sequence diagrams representing the time-ordered exchange of messages between the Command Node elements defined earlier in this section. These diagrams can also represent sequences of interactions at a high level (Fig. 10) or a more detailed level.

The detailed process for the comparative evaluation of different COAs with the CAESAR II/EB toolsuite is illustrated via a sequence diagram in Fig. 10.

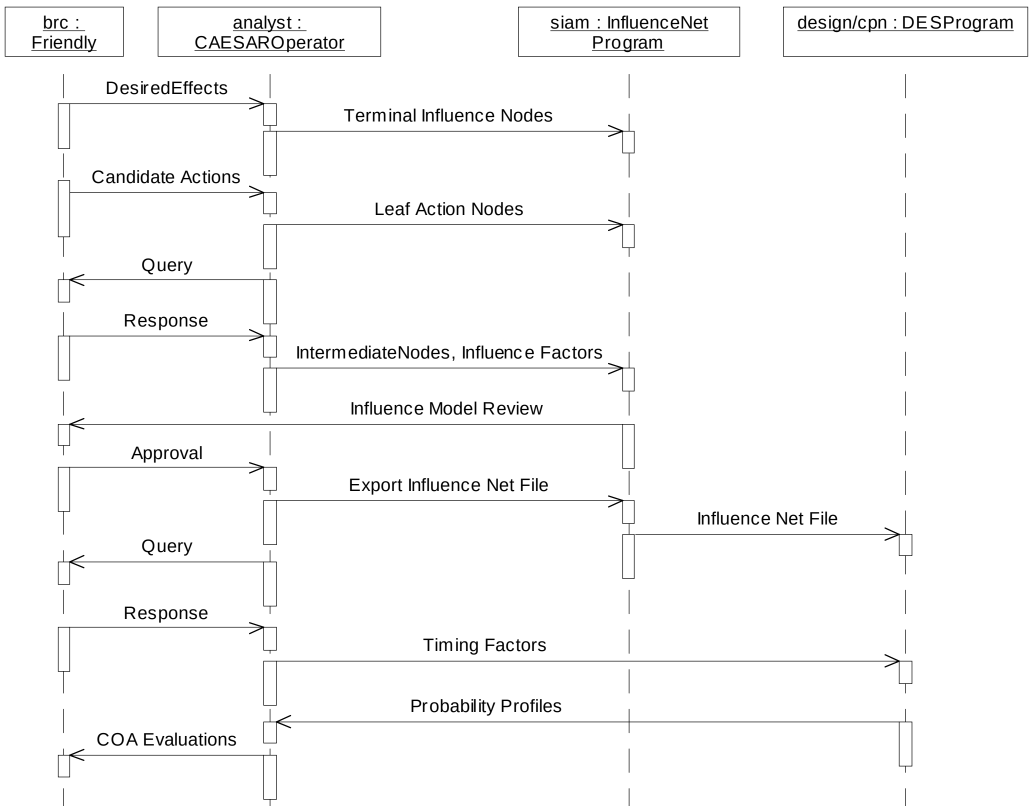

Fig. 10. Detailed Sequence Diagram showing the interactions between the Global intelligence analyst and the components within CAESAR II/EB II.

Remembering that time runs from the top to the bottom, and the horizontal arrows represent the exchange of events or messages between components, the process is seen to start when the Cell staff, having decided to use CAESAR II/EB to analyze a particular problem, states the desired effects or objectives and the candidate actions which are being considered for implementation. The sequence diagram shows these as separate messages, since these data may come from different staff members, and the objectives translate directly to the influence net terminal nodes, while the candidate actions translate directly to the source influence nodes.

Then, an extensive sequence of Query-Response takes place (abbreviated in the above diagram by a single pair of exchanges) where the CAESAR II/EB analyst and the Cell staff, which is often an intelligence analyst, interactively develop the intermediate nodes of the influence net and the relative strengths of the connecting arcs between the nodes. The influence net, once reviewed and approved is then ported to the DES application in the form of an interchange file and the second stage of the analysis begins.

In other words, an influence net is constructed first, and this structure, along with additional timing information is sufficient [Wagenhals, et al., 1999] to completely and unambiguously define a Colored Petri Net, which can be used to conduct evaluations of different Courses of Action. The influence net alone is sufficient to generate the basic topology of the Colored Petri net, however, the Petri Net cannot be executed successfully until the timing information is also entered.

3.1.3. Object-Oriented Architecture View of CAESAR II/EB in Global

The following set of diagrams present an object-oriented view of CAESAR II/EB in Global. These diagrams serve to illustrate the kinds of components and elements that make up the systems in question, and the kinds of data exchanged between the elements. Figure 11 illustrates the top level relations between the CAESAR II/EB Component and the other high level Command Staff classes discussed earlier. When interpreting this diagram, the Inquiry and CellAssessment objects can be viewed as the interface between the Commander and the Cell – the Commander issues Inquiries, the Cell responds with CellAssessments. The CellAssessment is composed of a Course of Action, which itself is composed of Actions, referenced to a specific Effect.

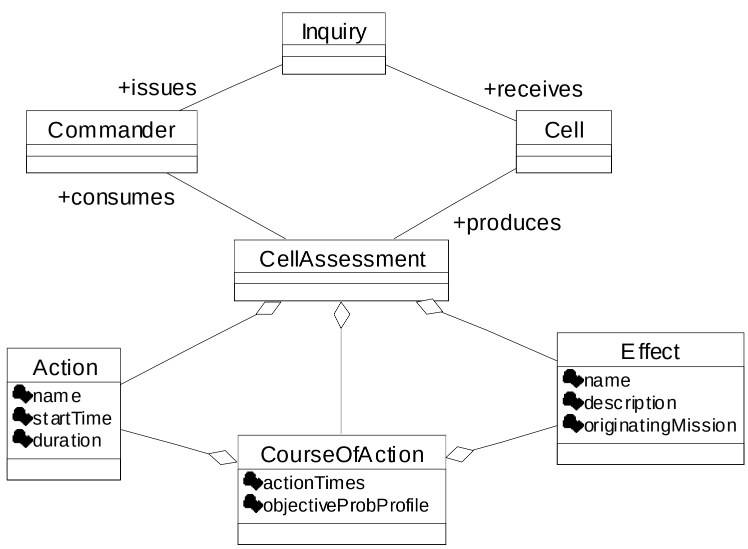

Fig. 11. A UML Class diagram illustrating the relationships between the basic command elements involved in Course of Action development and selection. These object classes and relationships are valid whether the CAESAR II/EB system is involved or not.

Figure 12 illustrates the mapping between the Actions and Objectives, which are primarily in the realm of C^2 and are the things of interest to the Command Staff, and the elements which make up an influence net (nodes and influence links). This diagram shows how these kinds of elements (i.e., object classes) map to each other. The development of this mapping of specific actions and objectives to specific influence nodes and links is the initial process of the CAESAR II/EB analysis process, and, we have found it to be the most time consuming.

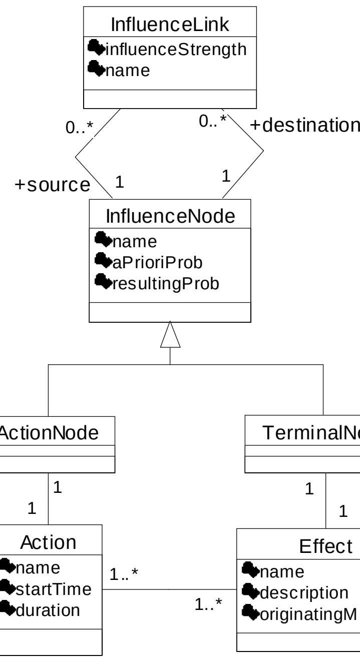

Fig. 12. A UML Class Diagram showing the mapping of Actions and Objectives (from the "real world") to the nodes and influence links of the influence net.

Figure 13 shows the basic components of the CAESAR II/EB Decision Support System. The entire collection is referred to as the "CAESAR II/EB Component", and consists of an Operator, the Influence Net and DES Components, and an Office Program suite. These components support the various application level programs that are run at various points in the analysis process, and the kinds of data that these programs exchange are also shown on the diagram (InfluenceNetFile, ProbabilityProfile, InfluenceNetGraphics, and CAESAR II/EB Report).

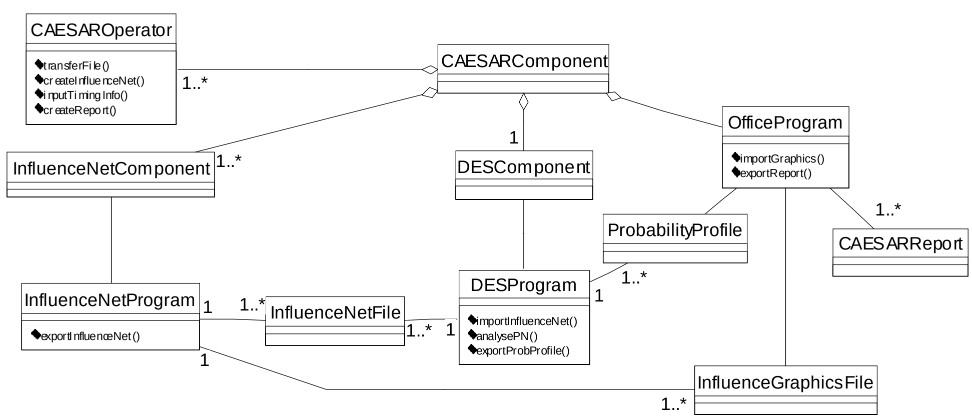

Fig. 13. A UML Class diagram illustrating the details of the CAESAR II/EB Decision Support System itself.

3.2. Data Sources and Process Timelines

As demonstrated in the preceding sections, the input data requirements for CAESAR II/EB consist of:

- Candidate Actions which are elements of the Course of Action,
- Effects which are the desired outcomes of a COA,
- Influence links between Actions and Effects,
- Intermediate influence nodes, and associated Influence Links,
- Delays associated with each node in the influence net, and
- Relative event or action times.

The vast majority of these data are obtained from interactions between the CAESAR II/EB Operators and the Intelligence Analysts on the staff of the Cells. In some cases, the delays for the influence net nodes were obtained from information available on the Global websites. The relative event/action times are not necessarily derived, but are parametrically studied in order to achieve a preferable COA given all of the other data.

The process timelines clearly indicated that most of the time spent in executing a CAESAR II/EB analysis was spent on the construction and refinement of the influence net. Specific measured process durations are shown in Table 1. The time for the first model includes participation in pregame activities, meetings with intelligence analysts, and familiarization with the game materials (scenario, order of battle, etc.)

Table 1. Labor-hours required to perform the primary functions for the three analysis problems addressed during Global.

	Labor Hours Required per function		
Primary Function	**Analysis #1**	**Analysis #2**	**Analysis #3**
Influence Net Construction	3 weeks	8 hrs	3 hrs
COA Evaluation	4 hrs	3 hrs	2 hrs
Reporting	2 hrs	1hr	1hr

These amounts of labor were sufficient to provide answers to the Command staff before the questions were overcome by events. This is due partially to the fact that the decision support specifically was targeted at an echelon of command and control where the response time requirements were approximately concomitant with CAESAR II/EB's capabilities at this stage of its development.

4. Observations and Conclusions

Participation in Global 2000 provided an invaluable opportunity to test the theories, tools, and techniques of using CAESAR II/EB in an operationally realistic environment. Several observations and lessons were learned from that experience.

The CAESAR II/EB Decision Support System performed acceptably at the Global 2000 wargame. Expected measures of merit for the experimental participation of CAESAR II/EB at Global 2000 included:

Q: Was the CAESAR II/EB component used as the primary tool to answer any COA questions by the command staff? Are the CAESAR II/EB results trusted and utilized?

A: Yes, the CAESAR II/EB component demonstrated significant utility in three different analyses conducted before and during the Global Wargame.

Q: What are the sources of the necessary input information, and what level of effort is required to collect that information? Is it available in a timely manner? What are the timeline characteristics of the model building and analysis process using CAESAR II/EB? How do these processing delays compare to the decision timeline requirements of the Global command staff?
A: The information is primarily derived through interaction with intelligence analysts and/or subject matter experts (SMEs). The process, being essentially one based on discussions, is labor intensive, but could not be speeded up by adding more labor. The timeline characteristics of CAESAR II/EB analysis were measured and presented in Section 3. The CAESAR II/EB analysis timelines were acceptable when compared with the decision cycle timeline observed at Global 2000 at the echelon of command where CAESAR II/EB was located.

Q: Given the initial operational concepts for the CAESAR II/EB component, what changes were found to be necessary, and for what reason?
A: No changes were required to the basic operational concepts of CAESAR II/EB.

Sufficient insight was gained to create an operational concept for future use of CAESAR II/EB and to develop an operational architecture view. As a result of the extensive utilization of CAESAR II/EB during the game, several fixes and enhancements both to the tool and the concepts were identified.

CAESAR II/EB embodies a non-traditional concept for supporting Effects Based Planning and Operations. One of the key findings from the Global 2000 experience is that its use requires the concerted effort of specialist from different disciplines: intelligence, operational planning (current and future), information operations, and command. At Global 2000, CAESAR II/EB was used in support of the Friendly Enemy Cell because this cell's mission was most closely aligned with CAESAR II/EB's capabilities. The composition of the Friendly Enemy Cell provided a rich combination of SMEs that assisted the CAESAR II/EB developer/operator in model construction and analysis.

We believe that the use of CAESAR II/EB in Global 2000 successfully demonstrated the utility of the approach and the selected tool suite components. The use of architectures for describing the operation of this new capability in a realistic command environment served two significant purposes: (1) a form of top-level requirements which served as guidance in the development of the CAESAR II/EB user interface, and (2) top level capabilities description of the tool which allowed program managers to understand where the tool would best fit within the Global wargame command structure. The architectures developed from the experience in Global are guiding the further development of both the CAESAR II/EB tool suite and the operational concept for its use in Global 2001 and other C2 environments.

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