An Architecture for Effects Based Course of Action Development

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Summary: A prototype system to assist in developing Courses of Action and evaluating them with respect to the effects they are expected to achieve has been developed and is called CAESAR II/EB. The key components of the system are an influence net modeler and an executable model generator and simulator. The executable model is exercised using the plan that is derived from the selected Course of Action and the probabilities of achieving the desired effects are calculated. The architecture of CAESAR II/EB is presented and an illustrative example is used to show its operation.

INTRODUCTION

Since Desert Storm, the concept of integrated Planning and Execution is becoming accepted and systems and procedures are being implemented to achieve it (e.g., concepts are being tested in Advanced Warfighting Experiments by the Services). Integrated Planning and Execution enables dynamic battle control, (sometimes referred to as dynamic planning). Bosnia and especially operation Allied Force in Kosovo, have focused broad attention on effects-based planning and effects assessment (see Washington Post, Sept. 20-22, 1999). This leads to closer interaction of intelligence and planning: intelligence is not only an input to the process, but a key component of the effects assessment feedback loop. Given the potential complexity of future situations and the many consequences of the responses, an approach is needed that (a) relates actions to events and events to effects; (b) allows for the critical time phasing of counter-actions for maximum effect, and (c) provides in a timely manner the ability to carry out in near real time trade-off analyses of alternative COAs. Such an approach, based on research and development carried out over the last five years, is now feasible. The approach is described in this paper.

The first step is to develop and select a *Course of Action* that will lead to a desired outcome. A Course of Action is composed of a timed sequence of *actionable events* that are expected to cause the desired effects. In current practice, probabilistic models that relate causes to effects are used to identify the set of actionable events that yield the greatest likelihood of achieving the desired outcomes and effects. Note that these models do not include timing information. The selected set of actionable events is provided to planners who use experience to select, assign, and schedule resources to perform tasks that will cause the actionable events to occur. The schedule of tasks with the assigned resources constitutes a plan. Outcomes, in terms of effects, are critically dependent on the timing of the actionable events.

APPROACH

The problem requires the synthesis of a number of approaches that have been emerging in the last few years from basic research efforts by DOD and industry. Indeed, the rapid improvement in computational capability and the availability of design tools have made the process of going from an idea to a proof of principle much more rapid.

The process diagram in Figure 1 identifies four principal functions of Effects Based Operations and three feedback mechanisms that enable these functions to be accomplished. This conceptualization expands the conventional C2 process to include not only the traditional Battle Damage Assessment (BDA) feedback loop, referred to here as Action Assessment, but also two other feedback loops: Dynamic Battle Control and Effects Assessment. There is also a fourth loop not considered here, the real time shooter assessment loop, often referred to as Execution Control. The distinction between Execution Control and Dynamic Battle Control is that the latter involves the controllers and sometimes the planners. The Dynamic Battle Control loop allows for changes in the plans after the plan has been disseminated, while the longer loop involves assessment on how

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well the actions being taken are achieving the desired effects or how well the goals are being met. Each one of these loops precipitates different responses. The Dynamic Battle Control loop affects the execution of the plan by doing real and near real time retasking of assets. The Action Assessment loop affects the development of the next days plan. The Effect Assessment loop leads to the reconsideration of the Course of Action being followed and possibly to the selection of an alternative COA to meet the changing circumstances.

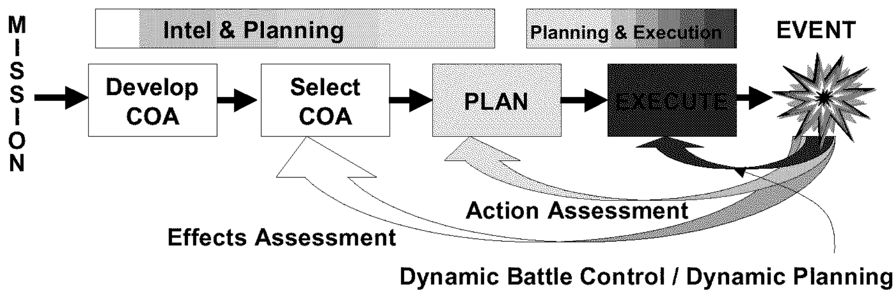

Figure 1 Block Diagram of Process for Dynamic Effects Based Command and Control

More specifically, the forward process includes COA development. COA selection, Planning, and Execution. As Fig. 1 shows, the first three stages require the close interaction of Intelligence and Planning, while the last two require the integration of Planning and Execution. The latter is already occurring in the case of air operations, while the former is beginning to take form.

Once the forward process has been completed, the execution of the resultant plan induces the feedback process. Once we begin to take actions and other events occur, the process and tools must track our progress in achieving the desired effects. Measures (triggers) must be developed for changing COAs. The tools and the process must facilitate the ability to make changes to plans in a dynamic manner, while the plans are being executed. The actionable events are specific; the first feedback loop, dynamic battle control/dynamic planning, involves local adjustments to the specific actions of resources as they perform planned tasks. The assessment is conducted by operational controllers attempting to ensure that the tasks and actionable events occur according to the plan. The second feedback loop, action assessment, addresses the measurement and evaluation of whether the actionable event occurred and to what extent. For example, in conventional air warfare, this would be equivalent to measuring whether the bombs hit their targets and the extent of damage they have inflicted. Adjustments are made to future plans to account for actionable events that were scheduled but did not occur or observations about the immediate impact of the actionable events The third feedback loop assesses progress toward the overall desired effects. Given that the actionable events have occurred, have the effects been achieved? Given that the blue forces have achieved a planned level of bomb damage through the air campaign, have they forced the adversary to change his policies? Changing the policy is a desired effect. If events are not unfolding as originally envisioned, it may be necessary to change or adapt the COA. Ultimately, this feedback is used to assess whether the goal has been met when certain effects have been achieved.

The first observation is that the internal loop, if it is fast enough, permits dynamic planning. The latter forces the integration of planning and execution, since the concept of dynamic planning breaks down the paradigm of a fixed plan to which ad hoc changes are being made. Implementation of dynamic planning results in a fluid, evolving integrated plan that is being modified as it is being executed.

The presence of the two outside feedback loops in Fig. 1 distinguishes traditional planning and execution from Dynamic Effects Based Command and Control (DEBC2). In the same way that dynamic planning integrates planning and execution, DEBC2 integrates intelligence with planning. The establishment of cause – effect relationships between actionable events and effects, or in the reverse direction, the inferencing of the occurrence of events from the observation of effects, is an activity that is carried out by intelligence analysts. By closing the two loops, the paradigm requires intelligence to become an integral part of the dynamics of the planning process, rather than only providing inputs to it.

This process can now be expressed in terms of specific activities that need to be performed and the tools and techniques that support them. This is illustrated in Fig. 2 using the IDEF0 formalism. The first activity is the analysis of the situation using several modeling techniques. This activity is carried out by situation analysts who are usually intelligence analysts. The second activity is the development and selection of alternative courses of action. In the case of DEBC2, the proposed system should be capable of being used to generate a variety of contingency COAs and plans and also be used (with scenarios) to evaluate these COAs and plans in terms of their likelihood of achieving desired effects. It should also be capable to be used in generating plans in near real time for unanticipated circumstances. The third activity is to generate plans for the alternative Courses of Action. The approved plan is disseminated to the units that carry out the tasks in the plan and to operational controllers who monitor the execution. In the fourth activity, the execution of the plan is controlled using the capability to exercise all three feedback loops shown in Figure 1.

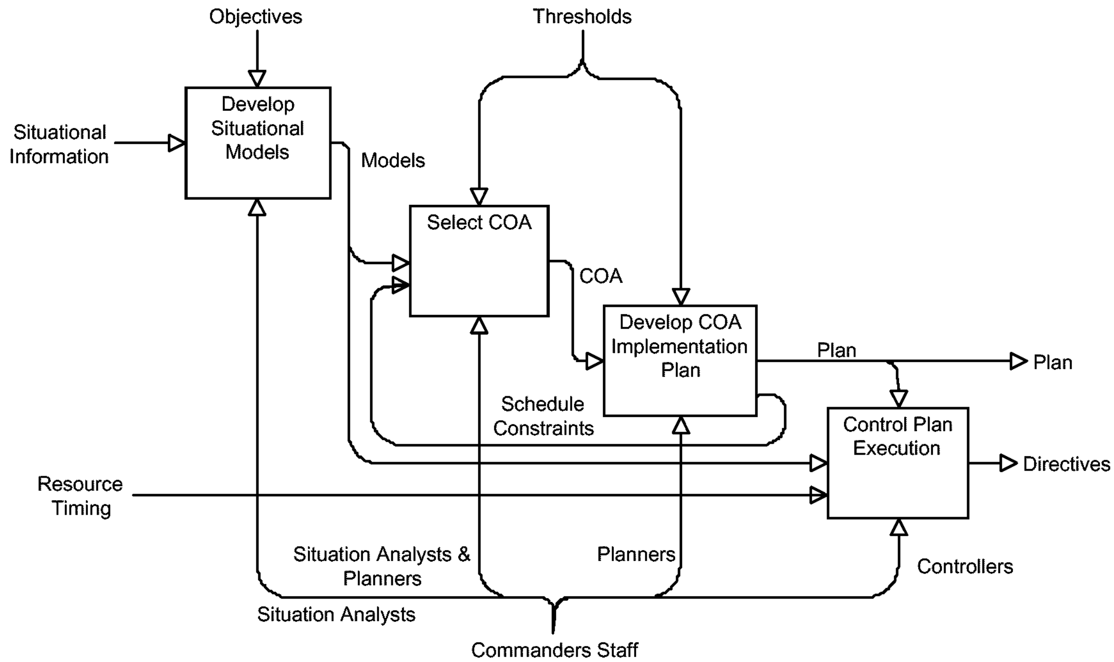

Figure 2 IDEF0 Process Model for Dynamic Effects Based Command and Control

The first activity produces a set of models that are at the heart of providing the capability for dynamic effects based command and control. The development of the first of these models starts with the process shown schematically in Fig. 3. The goals are set by the National Command Authority at the strategic level and by the Commander for the operational level. It is then determined that, to reach the goals, certain effects must be achieved. This determination can be accomplished using probabilistic modeling tools (e.g., Influence net modeling) such as SIAM,[1] as shown in Fig. 4. An influence net model allows the intelligence analyst to build complex models of probabilistic influences between causes and effects and effects and actionable events. This is shown in Fig. 5 which also implies the existence of a library of models that can be used as modules to create new influence models that are appropriate for the specific situation.

[1] SIAM is a COTS product developed by SAIC (Rosen and Smith, 1996) to support the intelligence community and is used as a module in the CAESAR II suite of tools. Other probabilistic modeling tools such as Hugin, Analytica, and the Effects Based Campaign Planning and Assessment Tool (CAT) under development at AFRL/IF can support the modeling of actionable events and effects.

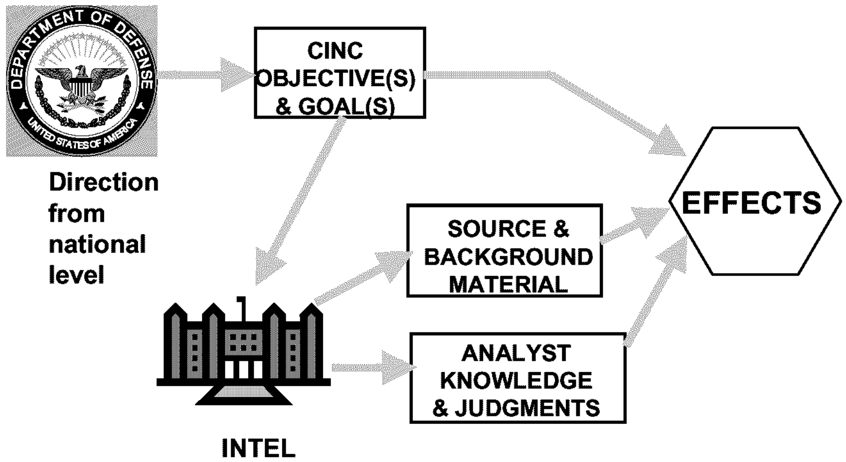

Figure 3 Effects determination in Dynamic Effects Based C2

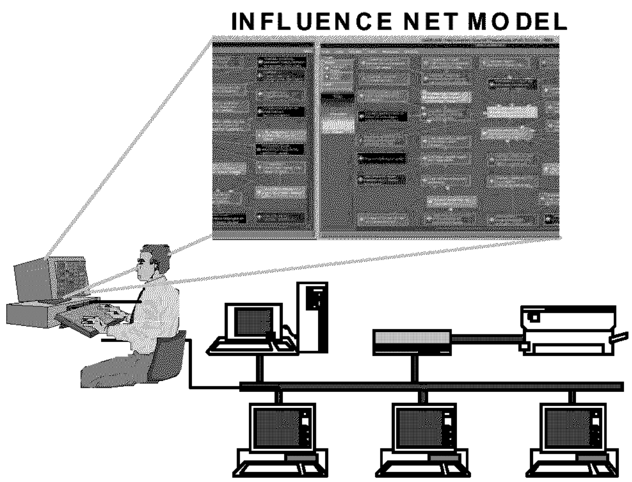

Figure 4 An intelligence analyst developing an Influence net model relating goals to effects and to actionable events. The network implies access to diverse data sources (e.g., through the Joint Battlespace Infosphere or any other network-centric architecture)

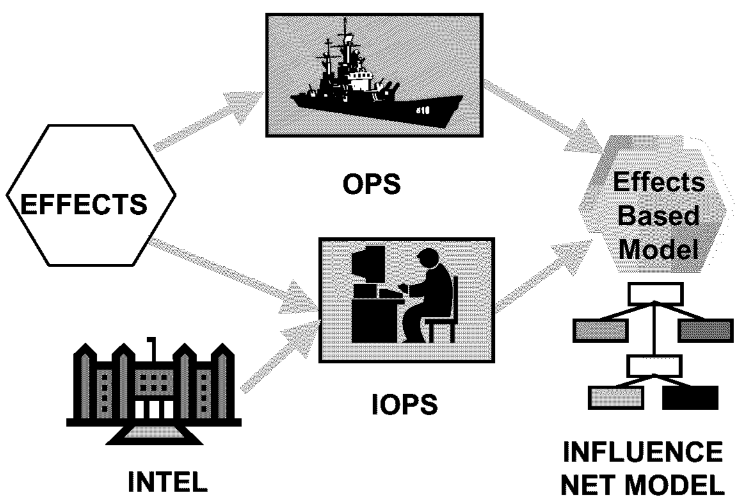

Figure 5 Development of the Influence net model

The Influence net model is then used to carry out sensitivity analyses to determine which actionable events, alone and in combination, appear to produce the desired effects. It should be noted that Influence nets are static probabilistic models; they do not take into account temporal aspects in relating causes and effects. However, they serve an effective role in relating actions to events and in winnowing out the large number of possible combinations. The result of this exercise is the determination of a number of actionable events that appear to produce the desired effects and give an estimate of the extent to which the goal can be achieved.

Once the influence net of the situation has been developed, the situation analyst converts it into an executable model that allows the introduction of temporal aspects (Fig. 6). An automatic algorithm that performs this conversion has been developed, tested, and demonstrated. A Colored Petri Net model is developed using the structural and probabilistic information (the influences) contained in the Influence net model. (Wagenhals et al., 1998) The current probabilistic equilibrium models (Influence nets) used for situation assessment contain a great deal of information in the form of beliefs about the relationships between events and the ultimate outcome or effect. They have an underlying rigorous mathematical model that supports analysis. They provide only a single probability value for a given set of actionable events. They do not capture the effect of the sequence or timing of the actionable events. Additional information needs to be inserted to account for temporal and logical sequencing of actionable events. A particular sequence of actionable events represents an alternative Course of Action. Note that in a threat environment proper sequencing is critical; reversal of two operations can endanger lives and affect critical operations. Consider a trivial example: wear protective equipment then step in hazardous environment vs. step in hazardous environment and then put on protective equipment. While this is obvious, such reversals are not easily observed in a complex scenario with many concurrent tasks. The executable model brings these issues to the fore.

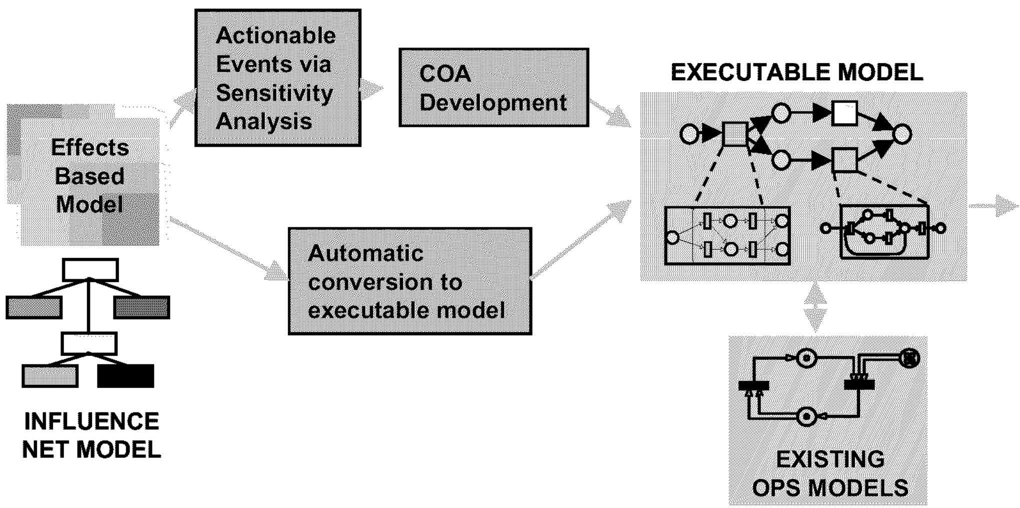

Figure 6 Development of executable model

Recent research by the GMU System Architectures Laboratory has shown that it is possible to enhance these models so that the impact of timing of the inputs on the outcomes/effects can be determined. This impact can be represented by the timed sequence of changes in the likelihood of the outcomes/effects determined by the timing of the actionable events. The sequence of changes in probability is called the *probability profile.* It is a key measure of the effectiveness of a COA that can be used to evaluate COAs during their development and to determine when and how to change the COA during execution.

The executable model, when properly initialized with a scenario, can be used in simulation mode to test the various COAs to determine their effectiveness by generating the timed probability profile for the particular COA. (Fig. 7) The problem and the assumptions can be shown on the future Display Wall at the Joint Task Force level in which the situation is presented (say, the relevant Common Operating Picture) along with alternative Courses of Action and their assessment. A Commander can then make an informed choice and direct the planning staff to prepare the detailed plan for the chosen COA.

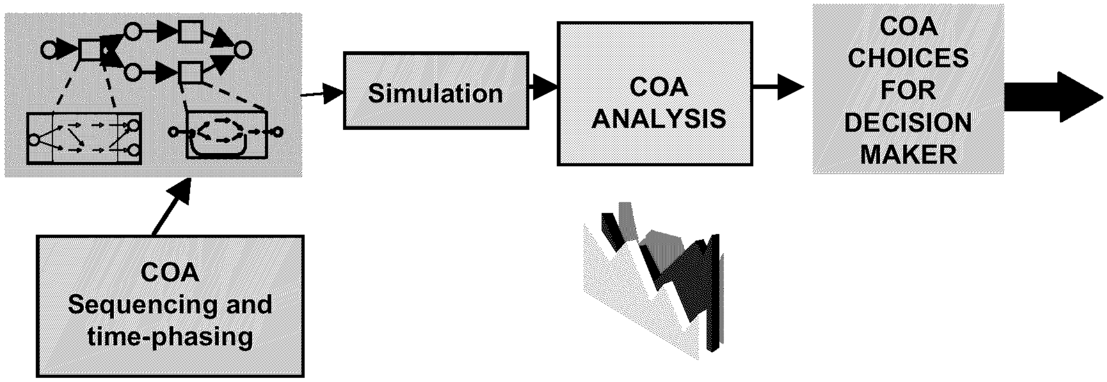

Figure 7 Analysis of Alternative COAs

Carrying out simulations using the executable model is not the only way in which COA analysis and evaluation can be conducted. State Space Analysis of the Colored Petri net model of the influence net can be conducted to reveal all of the probability sequences that can be generated by any timed sequence of actionable events. The result of the state space analysis is a State Transition Diagram that is mathematically a lattice. This state transition diagram can be easily converted to a plot showing the range of probability values that can exist at each step in any probability profile. This technique allows the analysts to see, at a glance, all of the potential effects that timing of the actionable events can have. The analyst can then select the profile that gives the best results. Once the untimed profile has been selected, procedures using a temporal logic application called TEMPER 2, (Zaidi and Levis, 1997) can be used to determine the temporal relationships between the actionable events that will generate the selected probability profile. The set of model composed of the influence net, the Colored Petri Net, Timed Point Graphs from the Temporal Logic formulation, and the State Transition Diagram are called the Common Planning Problem. It is these models created in the first activity that can enable the forward and feedback Dynamic Effects Based Command and Control process illustrated in Figures 1.

In the second activity of the process, the operational planners and the situation analysts use the models of the common planning problem to select candidate COAs. The concept for this procedure is shown in Fig. 8. The analyst uses the State Transition Diagram to construct the plot of the untimed probability profiles. He selects candidate profiles using a set of metrics and determines the temporal relationships of the actionable events that will generate these sequences using the temporal logic algorithms. These COAs are run in the executable model to generate the timed probability profile for final selection. In the example of Figure 9, COA 1 is preferred of COA 2 because it has the higher probability values at all time points and reaches the highest probability the fastest.

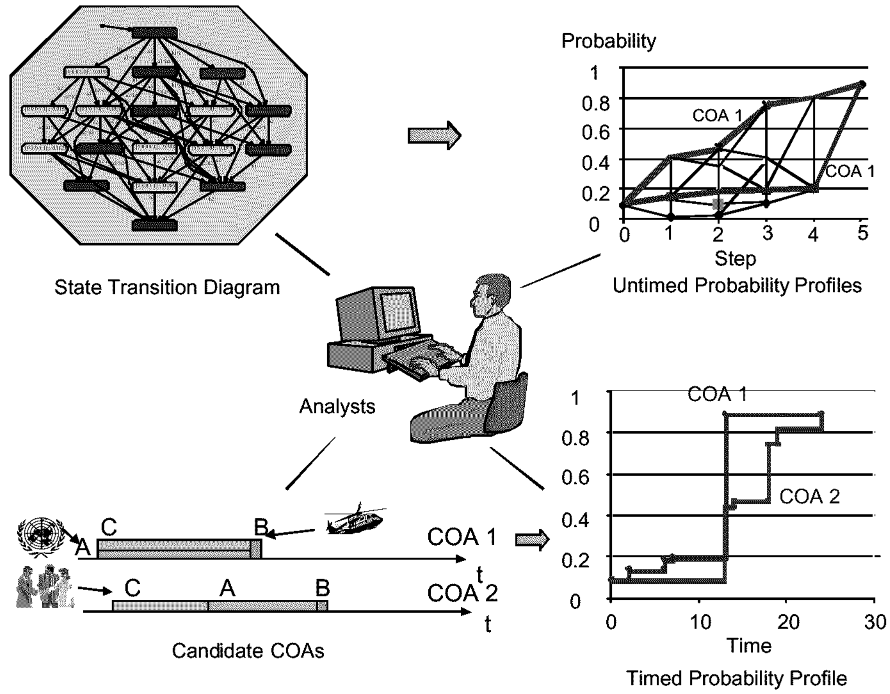

Figure 8 Decision support for COA selection

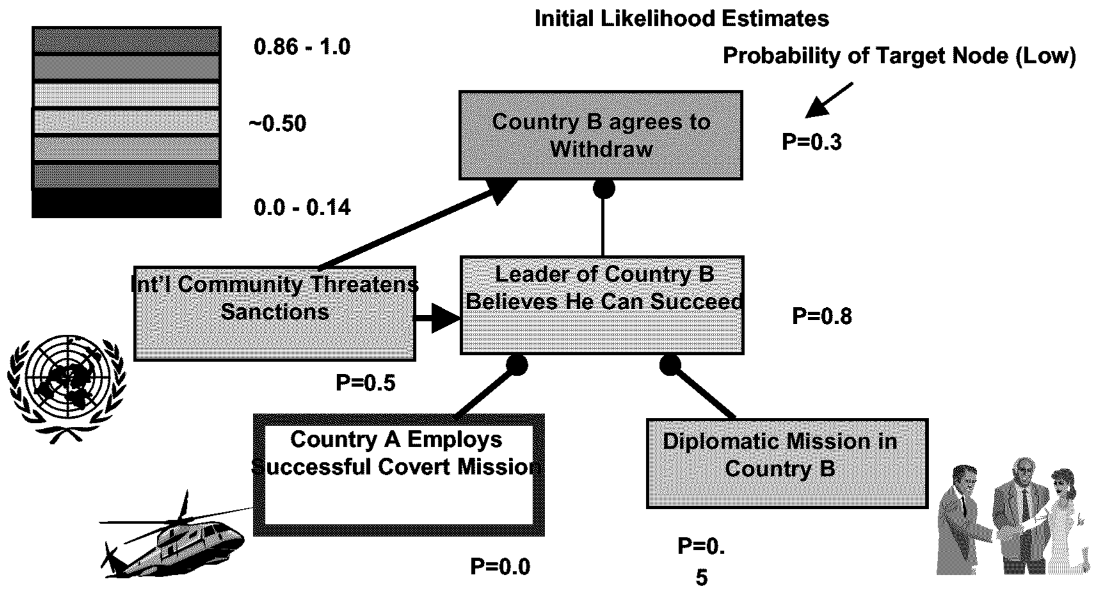

Figure 9 Influence net of example

Having selected a COA, a detailed executable plan is developed in the third activity of Figure 2. The existence of the executable model (structured in an object oriented manner so that it can be instantiated at different levels of abstraction) gives the opportunity to test the plans in simulation mode and *also to monitor their execution by inserting actual event as they occur.* This is a required capability for dynamic planning; the state of the system must be known in order to insert new tasks, eliminate existing ones, or redirect ongoing ones.

The fourth activity involves the continual assessment of the execution of the actionable events, the assessment of their effects and the impact they have on achieving the goal. The three loops correspond, very approximately, to measures of performance, measures of Effectiveness, and Measures of Force Effectiveness. The models of the Common Planning Problem can be used in the assessments associated with each feedback loop. During the execution of a plan, there are two major factors that can impact the expected effectiveness of that plan. First, the timing of the actionable events may change as the resources perform the tasks in the plan. The impact of these timing changes in terms of the timed probability profile can be quickly examined using the executable model of the Common Planning Problem. If anticipated timing changes have an adverse effect on the probability profile, adjustments to the timing can be determined that will bring the profile within acceptable levels. The second type of changes involves the occurrence or non-occurrence of anticipated events in the influence net. In the planning mode, events were assumed to occur with some probability; in the assessment mode, events occur with probability one or zero – depending on whether they occurred or not. This changes substantially the computational model incorporated in the Colored Petri Net but not the structure of the model. The impact of these observations on the timed probability profiles can be observed by updating the elements of the Common Planning Problem.

All parts of this process have been prototyped and executed using the suite of tools called CAESAR (Computer Aided Evaluation of System Architectures.) Several case studies have been run and demonstrated, ranging from a small influence net that illustrates the concepts, to a large influence net (about 100 nodes) representing a complex situation. The next section contains the a description of the small illustrative example.

EXAMPLE

The operation of CAESAR II/EB is illustrated through a hypothetical "day in the life" of such a system. Assume that a crisis emerges. Country B has invaded a neighboring country and a key issue is whether the leader of the country believes that he can succeed in this undertaking. The crisis action team is constituted and begins to evaluate the situation and consider options. An existing influence net that describes the decision making process of Country B is retrieved from the library of models and the analyst modifies it directly to reflect the specifics of the crisis. There are many actionable events ranging from diplomatic efforts by country A all the way to declaring war by a coalition of nations. The analyst carries out a sensitivity analysis of these alternative actionable events and determines that three particular actionable events may be sufficient at this stage, namely, diplomatic mission by country A to country B; sanctions by the international community (through the United Nations) and a covert mission by country A that causes severe damage to the leader's arsenal. The influence net with initial values of probability of occurrence of the actionable events 0.5, 0.5, and 0.0, respectively is shown in Fig. 9. The result of the analysis, the probability that country B will withdraw is only 0.3. However, if all three actions take place with probability 1, then the probability of the outcome rises to 0.9, which is the highest value that can be attained in this influence net.

The influence net is then converted automatically by CAESAR II/EB into a Colored Petri net, as shown in Fig. 10. However, temporal information must be entered. This information is of two types: First, the temporal characteristics of the system as represented by the influence net such as communication delays, procedural delays, etc. The second type is the time sequencing of the actionable events. Even though there are only three events here, there is a large number of alternatives since we allow concurrency of events. Using the analyst's and planner's experience, the number of event sequences can be reduced substantially. Given that the outcome of the sensitivity analysis was to carry out all three actions and given that the covert action should follow the diplomatic efforts, two sequences were chosen as the alternative courses of action: (a) the incremental approach: first country A's diplomatic mission; then the international sanctions, and finally the covert action; and (b) the forceful approach: concurrent diplomatic efforts followed by covert action if diplomacy is not successful.

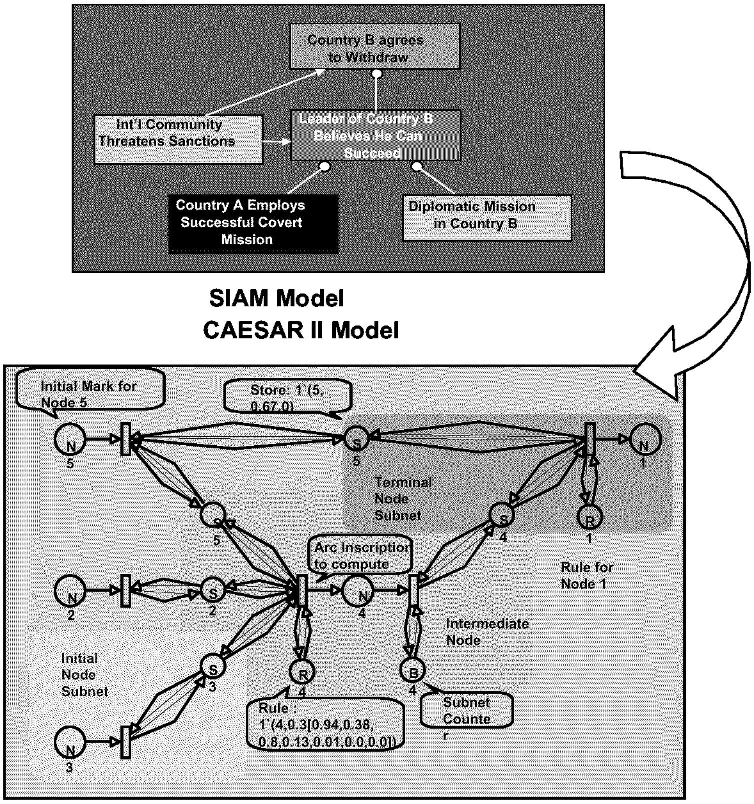

Figure 10 Influence net to Petrinet conversion

The Colored Petri net (Fig. 11) is used in the simulation mode to produce the two probability profiles shown in Fig. 12. Clearly, approach (b) is preferable; it shows a substantially higher probability of achieving the goal without ever resorting to the covert mission.

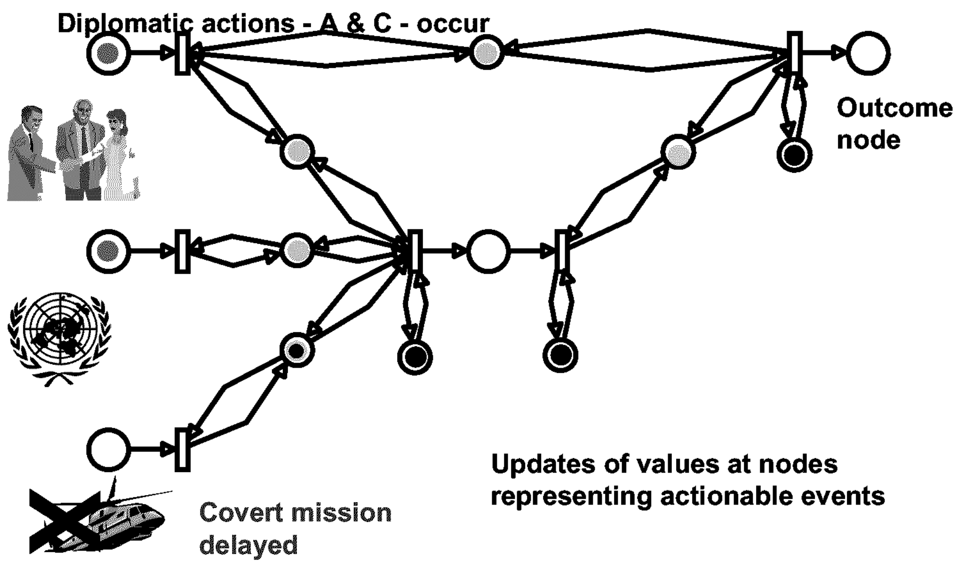

Figure 11 Petri net execution

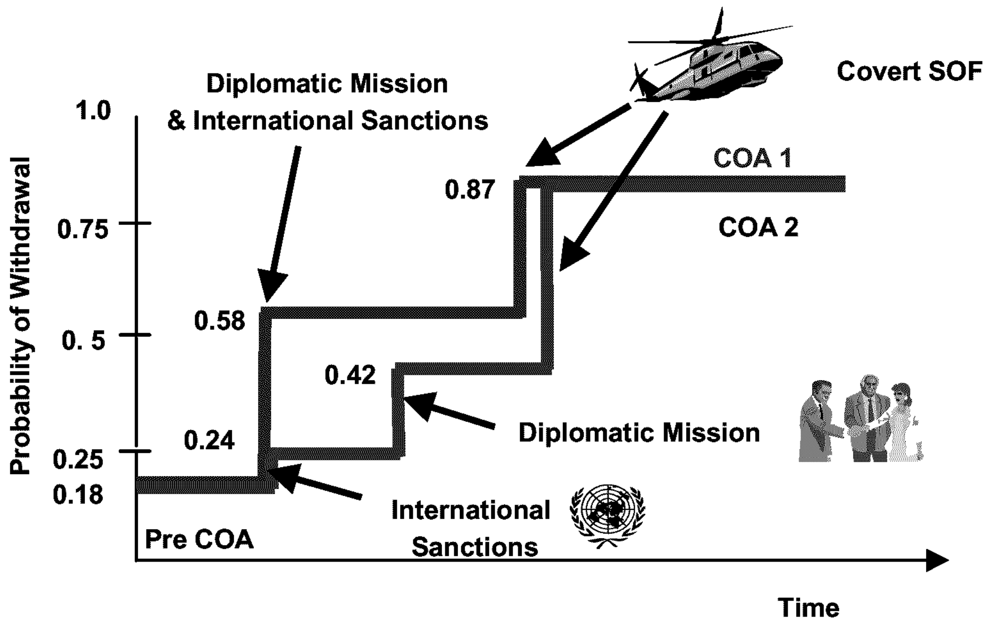

Figure 12 Comparison of COAs

CONCLUSION

An approach to Course of Action development and selection for effect based operations has been described and CAESAR II/EB, a decision support tool prototype, has been described and an example has been used to illustrate the operation.

ACKNOWLEDGEMENT

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