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Simulating the Interrelationships of Military Plan Activities[1]

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Simulating the Interrelationships of Military Plan Activities

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Abstract

Support tools can be used to facilitate the planning process of military plans, one example of which is the operations analysis tool CSMT developed at the Swedish Defence Research Agency. Input to the CSMT consists of a cross-impact matrix (CIM) which is populated by values describing the relationships between a plan's components. Instead of using subject matter experts to assign the CIM values this paper proposes using simulation to generate the impacts in hope of increasing traceability and consistency. Preliminary results indicate that the proposed method is practicable and beneficial in terms of its suggested advantages but needs further examination.

1. Introduction

Military decision-makers of today are facing new challenges, such as more asymmetric warfare and irregular forces, which yield new demands on their support tools. During the development of a plan there is a need for a more comprehensive understanding beyond only the military perspective that includes all potential effects and consequences. This knowledge can then be used as feedback in a continuing planning process. Decision support that is providing this feedback can produce plans less likely to contain unknown inconsistencies. Thus, detection of potential unwanted outcomes becomes easier, and hence they are easier to avoid [1].

An example of a tool that facilitates feedback of a more holistic picture is the Collaborative Synchronization Management Tool (CSMT) [2] developed at the Swedish Defence Research Agency. CSMT was developed to enable the analysis of stability of plans and detection of possible inconsistencies within a plan, as well as comparing plan alternatives [3]. The methods of this operations analysis tool have been developed within the framework of Effects-Based Planning (EBP), which constitutes a part of an Effects-Based Approach to Operations (EBAO).

CSMT

The operations analysis tool CSMT [2, 4] was developed for finding any possible inconsistencies within plans and for the assessment of plans during execution. This is done for EBP within the framework of EBAO. The plans are described in the EBAO concept as a set of effects and actions that together will reach the desired end state. The overall objective is to contribute to the planning process under the EBAO concept and to become more efficient through the use of relevant decision support tools. With this tool it should be possible to see which plans lead to the desired effects.

Morphological methods for analyzing activities, evaluating, and refining plans are developed, as well as sensitivity based methods for finding the decisive influences. CSMT can be used early on to analyze the plans using morphological analysis in order to find any inconsistencies in the plans. By clicking on different tabs in the GUI (figure 1), the user is given the possibility of performing different kinds of numerical analyses, such as analyses of stability and consistency [3]. CSMT can be used in the following way:

1. CSMT finds any inconsistencies in the plan which can be managed directly,
2. CSMT finds plan strengths and weaknesses that should be monitored during execution,
3. CSMT will follow up on the plan during execution.

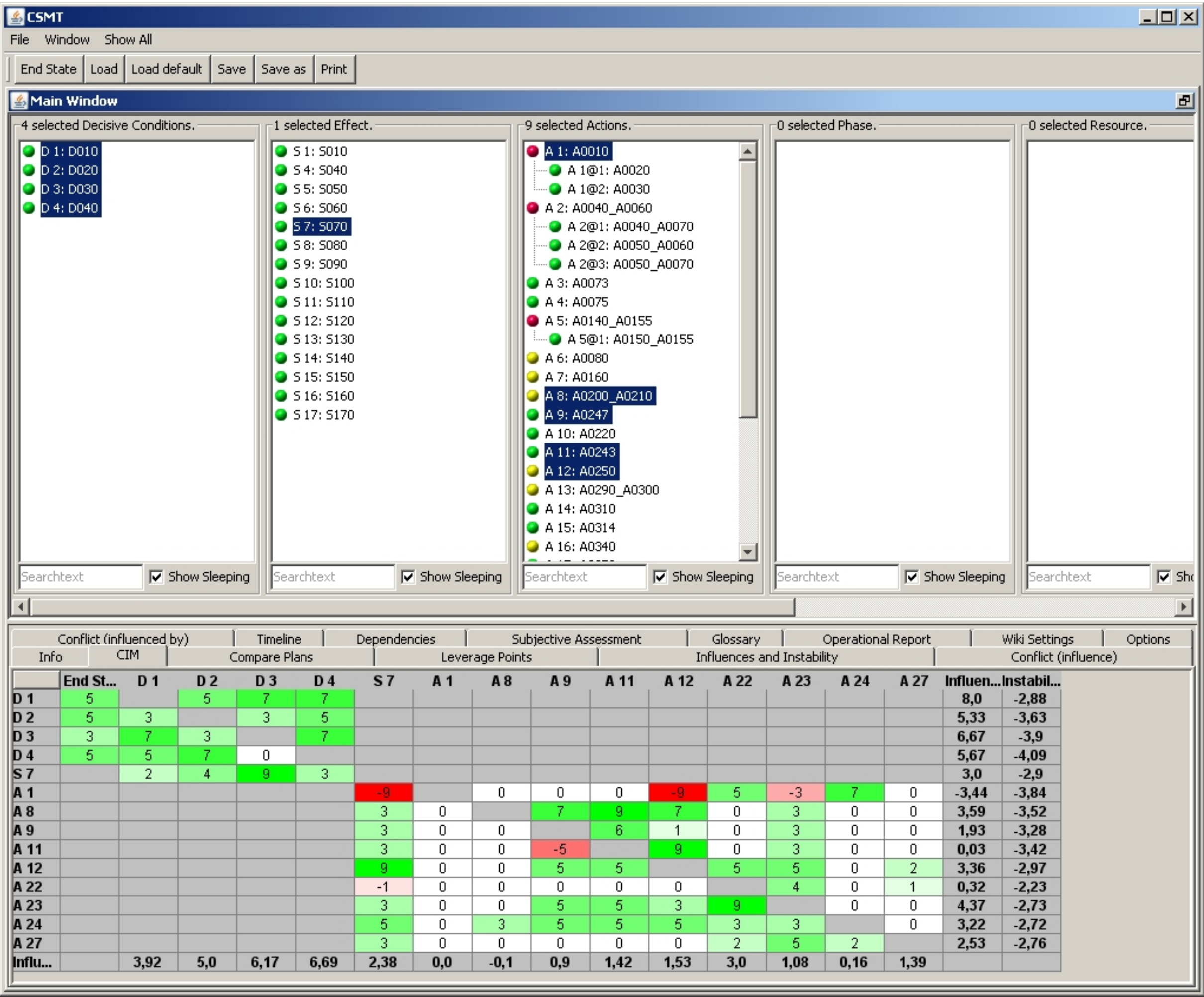

Figure 1. The CSMT user interface including a CIM.

Cross-Impact Matrix (CIM)

CSMT uses a qualitative Cross-Impact Matrix (CIM) which is a key component to the tool. The CIM is used within the EBP process in order to find inconsistencies and decisive influences within developed plans. We use the CIM to quantify knowledge about cross impacts between the components of a plan (the EBAO objects). The CIM consists of values describing how each pair of objects within a plan affect one another. The EBAO objects are the activities, supporting effects, decisive conditions, and the desired military end state of a plan.

The CIM is composed of integers displaying the interrelationships of planning elements, i.e., the EBAO objects. We say that the activities denote the actions that we carry out in order to eventually achieve some desired effect, whereas the supporting effects and the decisive conditions work as indicators of how a plan is developing from an end state viewpoint. The EBAO objects can be seen as different abstraction levels whose relationships are visualized in figure 2.

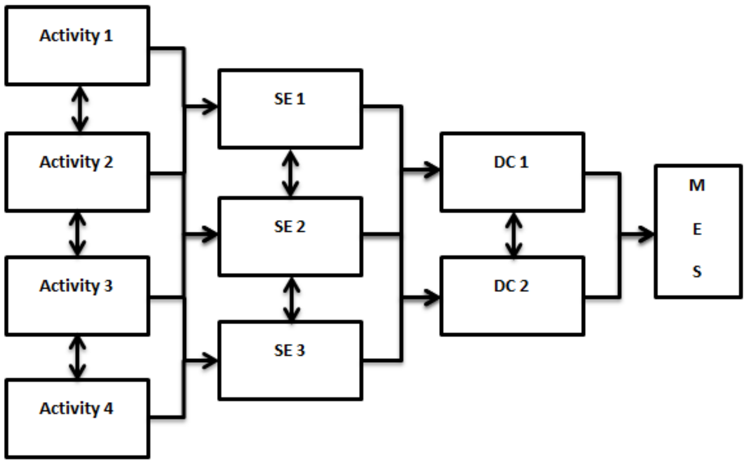

Figure 2. The possible paths of impact between EBAO objects in a CIM. The figure shows the connections between the EBAO objects; activities, supporting effects (SE), decisive conditions (DC), and military end state (MES).

EBAO

EBAO [5] is a military approach to the management and implementation of efforts at the operational level. According to the United States Joint Forces Command (USJFCOM) EBAO are "operations that are planned, executed, assessed, and adapted based on a holistic understanding of the operational environment in order to influence or change system behavior or capabilities using the integrated application of selected instruments of power to achieve directed policy aims" [6]. Smith [7] explains: "The cognitive domain is the real focus of any effects-based operation", which may be interpreted as if the purpose of military operations is always to influence other players' perceptions and behaviors. To reach the politically desired effects far more resources other than arms or violent means of power must be used. We must carefully analyze the effects we want to achieve before selecting the objectives and means for their strategic action. The process of EBAO consists of four connected parts: EBP for developing plans, Effects-Based Execution (EBE) for carrying out said plans, Effects-Based Assessment (EBA) to follow-up on the plan execution, and knowledge support providing the other three processes with background knowledge [8].

EBP

Within the framework of EBAO, EBP is a method for developing objectives and effects to be achieved through a series of synchronized actions starting from a desired end state and a control theory model [9] is shown in figure 3. As input we have the required situation R_s which is compared with the current situation C_s received from assessment. The first process is an end state analysis (ESA), followed by effects development (ED). Initially when there is no operation the military end state defines the goal of the operation. Later when a campaign assessment is carried out, the comparison between R_s and C_s may require further analysis in ESA. The output from ED is the required effects R_e which is compared with the current effects C_e, also received from assessment. The next process is action development and resource matching (ADRM) followed by synchronization and plan refinement (SPR). All processes take inputs from red-green activity (RG). The output from SPR is a plan to be executed by EBE. Campaign assessment C_s is received from a qualitative campaign assessment and current effects C_e is received by measure of effectiveness and measure of performance analysis in EBA [8].

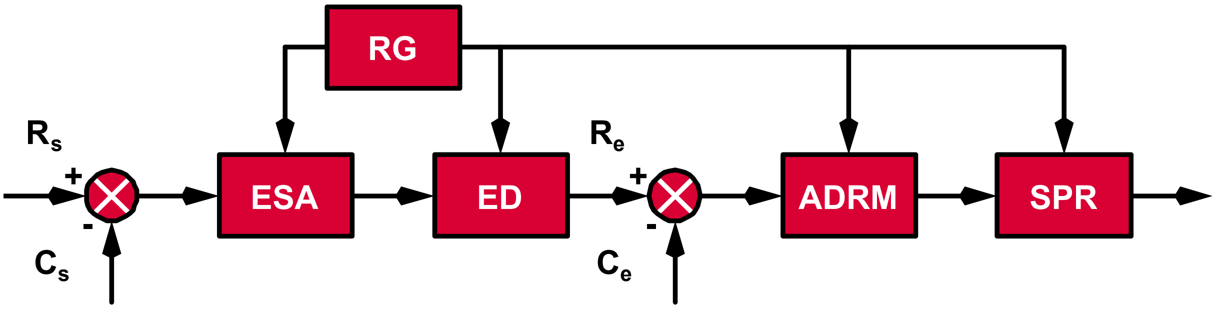

Figure 3. The processes of EBP.

Within the scope of this paper the focus will be on the supporting effects, which are defined through the specification of desired states of plan entities. The effect that each pair of activities can have on one another is calculated numerically. A high positive indicates a positive impact on the other activity (and on supporting effects), whereas a negative value indicates a counteractive relationship. The assigned impacts can take any integer values between -9 and 9, where the limits represent a strong negative or positive influence [1].

Method problematization and proposed alternative

The most commonly used method of populating the CIM is through assumptions and estimated probabilities [10], and up until now CSMT has been populated by subject matter experts – a method that poses traceability and consistency issues and is very time-consuming for large problem sizes. Subjectivity amongst the experts also constitutes a cause for concern since proper documentation becomes more difficult, and it can also cause inconsistencies due to experts' differing mental models of the analyzed system. Furthermore, validation becomes a difficult, if not impossible, task to perform.

This paper presents the possibility of using simulation to generate impact values and hence increase traceability and consistency by limiting subjective approximations. After an initial phase of model development it will also become a much faster process. In short, the proposed method for generating input data to CSMT would involve the modeling of a scenario and then simulating a plan to identify relationships and measure the effects between the plan activities. The aim is to use models as simple as possible without losing too much accuracy in the results. Scalability and reusability of the models are also key aspects that influence the design process [11].

Preliminary results indicate that the proposed method is practicable and beneficial in terms of its suggested advantages. However, creating the necessary models constitutes a costly initial phase, and this effort must be taken into consideration.

In Section 2 we will introduce the methodology. We will describe our models, how the EBAO objects are all connected, our method for impact calculation and our simulation process. Our scenario and test case are then described in Section 3, and our results are also presented. Finally, in Section 4 conclusions are drawn.

2. Methodology

We develop a program that simulates the models at hand. Plans, activities, effects, and end state are all established concepts within EBAO. A plan is defined as a sequence of activities executed by a military force intended to lead to a desired end state.

2.1. Models

Activities are carried out in an environment containing *actors* and *environmental objects* (for example religious buildings and schools), and it is the states of these entities that collectively make up the *simulation state*. The simulation state determines the conditions under which the activities will be executed, and an activity can also impact its surrounding because of the effects that result from its execution. Thus we can also say that activities affect the simulation state. Consequently, when the simulation state changes, it brings about altered conditions for any forthcoming activities, and we say that activities can impact other activities. This is illustrated in figure 4.

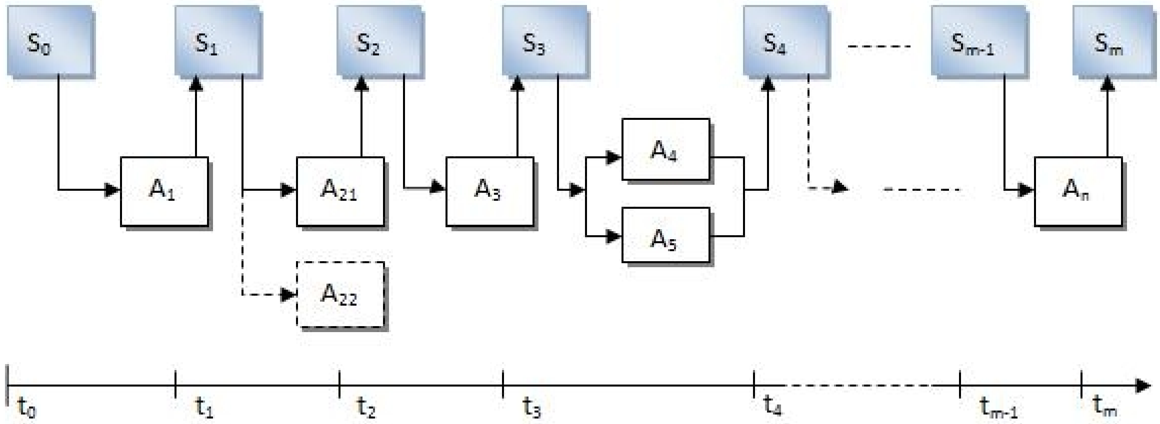

Figure 4. The relationship between activities and simulation state

We see that the activities (A) can have *alternatives* (see A_{22} and A_{21}), be *parallel* (as A_4 and A_5 depicts) or *sequential* as represented by the remaining activities. The activities impact the plan – thus creating new simulation states (S).

2.1.1. Activities

An activity contains a list of involved actors, i.e., actors who are directly affected by the execution of the activity, and environmental objects. We also assign a starting and ending time of its execution, as well as a geographical reference to the area in which the activity will be carried out. The modeling aspiration is to capture as much of the "reality" as possible without the model becoming too complex. For example: at present we do not allow delays of activities – however, they could be incorporated in future development if the trade-off between output accuracy and model complexity is deemed reasonable. Different actors and environmental objects are of varying importance to an activity (e.g., the possibility of executing an activity could be completely dependent on the availability of a certain actor); an effect which is described by *activity weights* and *attribute weights*. While activity weights reflect the importance of the different actors (and more specifically their strengths) to the activity, attribute weights describe how attribute changes other than strength are important to the activity. Also included in each activity are the necessary resources (e.g., full logistic ability for some specific unit) and other conditions that are required for its execution, e.g., full logistic ability for some specific unit or maybe a bridge that needs to be intact.

2.1.2. Actors

Actors are also described by a number of parameters, and the parameterization of actors is a modification of previous work by Schubert and Moradi [8]. The aim for model simplicity excluded a few traits but in order to still capture the dynamics of the actor interactions we introduce the notion of *state of mind* and *strength*. An actor's state of mind can assume values such as "neutral" or "happy". It can serve as an indicator of how an actor will perceive, and react in, a given situation or context for example. Strength can in turn be viewed as a more general attribute that describes the actor's ability and capacity to successfully achieve their goals or agendas. Strength is an aggregated attribute based on the other actor attributes. *Actor weights* describe the degree of importance of different attributes to a specific actor and can assume values between 0 and 3. Strength is simply expressed as

$$S_i = \frac{1}{n}\sum_{j=1}^{n} r_j * w_j\,,$$

where *r* corresponds to the value of the attribute, and *w* to the attribute's weight. Future work could include a more detailed model where the weights are linked to the activity, thus making strengths unique to each activity. The effect of this improvement is deemed negligible within the scope of this paper and defined weights are held constant for all activities. Other examples of actor attributes include "arms strength", "logistic ability", and "size". Attributes can assume integer values between 0 and 3 which roughly corresponds to "non-existent", "low", "medium", and "high".

2.2. Object interrelations and state changes

2.2.1. The simulation state

The simulation state will be updated between each pair of activities, since we want the activity about to be executed to be affected by all state changes caused by previous activities. However, in the case of an activity not being allowed to execute due to lack of required resources, the lacking resources' values will be reset to adequate levels enabling the execution of the activity. Despite not reflecting a completely realistic course of development, we make this choice to ensure that we still generate impact relationships between all EBAO objects while still accounting for this negative impact by automatically setting the CIM value to -9.

2.2.2. Relationships between actors

In order to capture the effects that a state change may have on actors despite the simplified actor models we do not limit our study only to how actors that are "directly involved" in the activity are affected. We also study how other actors (i.e., not listed as directly involved but present in the plan) are affected. We look at the relationships between actors from two perspectives by asking ourselves the following questions:

- How will the change in strength of one actor affect the attributes of another actor?
- How will a value change in an attribute of one actor or environmental object affect the attributes of another actor?

This solution allows for both a more overall (general) approach to the relationship, as well as a more specific study focusing on related actors' attributes in a closer manner. It should be noted that while it is possible to have impact in the direction from strength to attribute, the opposite is not possible. Thus, strength can only be affected indirectly.

The relationships between actors are also influenced by their stance toward each other. For every activity the actors are assigned status reflecting whether the actor is an enemy (red), an ally (blue), neutral (green), or undecided (yellow). This status is important as it affects our expectations of the different actors. This in turn has a big influence on our ability to properly describe and predict the behavior of different actors in different contexts. For simplicity (remember we are interested in finding out how simple we can keep the models and still get usable output) reasons we say that the "color status" is local to the activity and begins and ends with the activity.

2.2.3. State changes

The simulation state changes as the plan entities are affected by the activities we execute. Our model attributes can assume integer values from 0 to 3 where, in the case of an actor's *state of mind*, 0 would correspond to "neutral" and 3 to "very happy". We will use a conditional approach to actor changes, meaning that the actual change depends on the type attribute in question as well as the current value of the attribute. In other words the actual impact after some change is contextual. If we look to state of mind again, it is easier to achieve a state transition from *neutral* to *content,* than from *happy* to *very happy*. We can also look at it as the step size being larger around zero and decreasing the closer you are to the edges of the interval.

Actors can be impacted in two different ways – either by primary or secondary effects. Primary effects only affect actors and environmental objects listed as directly involved in the activity whereas other actors can be affected by secondary effects, i.e., effects generated from changes in the states of other actors and environmental objects. The availabilities of all activity resources (such as a troop with some specific capabilities) are reevaluated upon the end of an activity and availability statuses can be set to *available, consumed*, or *reduced capacity.*

After the activity has been executed the post-availability values are collected and the new value is assigned depending in the actor's troop size value pre-activity,

$$value_{new} = postAvailability * \frac{1}{3} * value_{old}.$$

Secondary effects are included to capture actors' (not directly involved) responses to changes in the simulation state. In order to include these effects it is necessary to model all actor interrelationships and define how a change in an attribute of one actor can affect attributes in another. This will catch any cascade effects and incorporate it into the simulation.

2.3. *Simulation Process*

2.3.1. Impact calculation

We have already described how an actor's strength is defined but how does the attribute come into play when we are interested in establishing the impact between two activities? Before we can make the actual calculation of impact we will establish whether the two activities are scheduled to occur parallel or sequential to one another. This is done in order to determine which simulation states to compare in order to evaluate the impact.

Two activities are defined as *parallel* if they have any kind of overlapping execution time; otherwise they are said to be *sequential*. In this context being parallel means that there is a two-way impact relationship to calculate as opposed to sequential activities where only the activity that occurs first affects the following one. Each activity is pair wise studied with all its parallel and subsequent activities, and the impact is evaluated for each pair. For parallel activities we compare *the pre-activity state* with the *state during activity* which constitutes the new conditions for the other activity. The state during activity is affected by, for instance, how long and when the activities overlap. These factors impact how we anticipate the effects to be carried out: e.g., a long overlap probably means that the affected activity experiences more of the other activity's effects than if the overlap is short and occurs early on. If two parallel activities share resources a longer overlap will also result in a higher impact than if they only overlap for a very short period of time. The kind of effect at hand is also important, since some effects might only be experienced in an all-or-nothing manner. For simplicity, we assume that effects that don't display that kind of quality are distributed in a uniform fashion. Thus, if an activity is executed over the course of four days then 25% of the total effect will be noticeable after day one; 50% after day two; 75% after day three, and the total effect will have been carried out by the end of day four. If the activities are sequential the simulation state is simply the post-activity state after all effects of the activity have been carried out.

The different aspects presented in section 2.2.1 are combined into a straightforward formula representing the conditions of the activity

$$C_k = \frac{1}{m}\sum_{i=1}^{m} s_i * v_i + \frac{1}{p}\sum_{j=1}^{p} t_j * a_j,$$

where s and v corresponds to the strength and weight of actor i (i.e., the activity weight), a and t corresponds to the value and weight of attribute j, and m and p to the number of key actors and key attributes important to the activity. In other words, C_k is a more aggregated description of conditions that are important to a certain activity, thus telling us if the circumstances are favorable or not.

The formula is used to calculate the conditions for each activity before (C_1) and after/during (C_2) an activity's execution. C_1 and C_2 can assume values between 0 and 6, and we compare the two by studying the difference C_2-C_1. This difference displays how the current conditions for the coming activity have changed due to the activity's execution, and if the conditions have improved or worsened. A positive difference implies a positive CIM value while a negative difference implies a negative CIM value. Since the CIM entry can assume a value of an integer between -9 and 9 we express the formula as

$$CIM\ value = 9 * \{\frac{C_2 - C_1}{6}\}.$$

The same procedure is followed when calculating the CIM value between activities and supporting effects, the only exception being that the conditions will be based on some preset states which, upon achievement, will attain the supporting effect. A supporting effect consists of conditions, such as actors' states, that are stated as beneficial to the end state. This way, the execution of each activity can be determined to either bring the supporting effect closer to, or further away from, being obtained.

2.3.2. Simulation Process

We develop and use a tool to enable the modeling of activities, actors, and environmental objects (and their relationships), in order to build our scenario. We then run the simulation, and after an activity has been executed we evaluate how the state changes impact the conditions for the other activities, as well as supporting effects.

For each activity we identify stakeholders (actors) and their colors with regards to their role in the activity, and set their initial values. The execution of an activity during a simulation run can roughly be said to consist of three sub-processes:

- Collecting all necessary activity resources and other requirements that makes the execution possible and check if they are met,
- Collecting all changes associated with the execution,
- Collecting all secondary effects associated with each attribute state change.

If an activity's requirements are not fulfilled when it is scheduled to start, it will not be executed in that simulation state, and the CIM value is set to -9. However, since the remaining impact calculations require its execution we reset the insufficient values to the lowest required level. A new *pre-activity state* is created and we try to execute the activity again. For parallel activities the reasoning is a bit more complex; if some requirements are not fulfilled we will check what the post-activity status will be for the unfulfilled value. If the needed values will be obtained after the first activity's execution we look at how long the coming activity will be delayed, and how long the delay is in comparison to its whole execution time. The strength of the negative CIM value is then based on the quotient between delay and execution time, i.e., the smaller the quotient the smaller the negative CIM value and vice versa. The execution of an activity from a simulation viewpoint is presented in the figure 5.

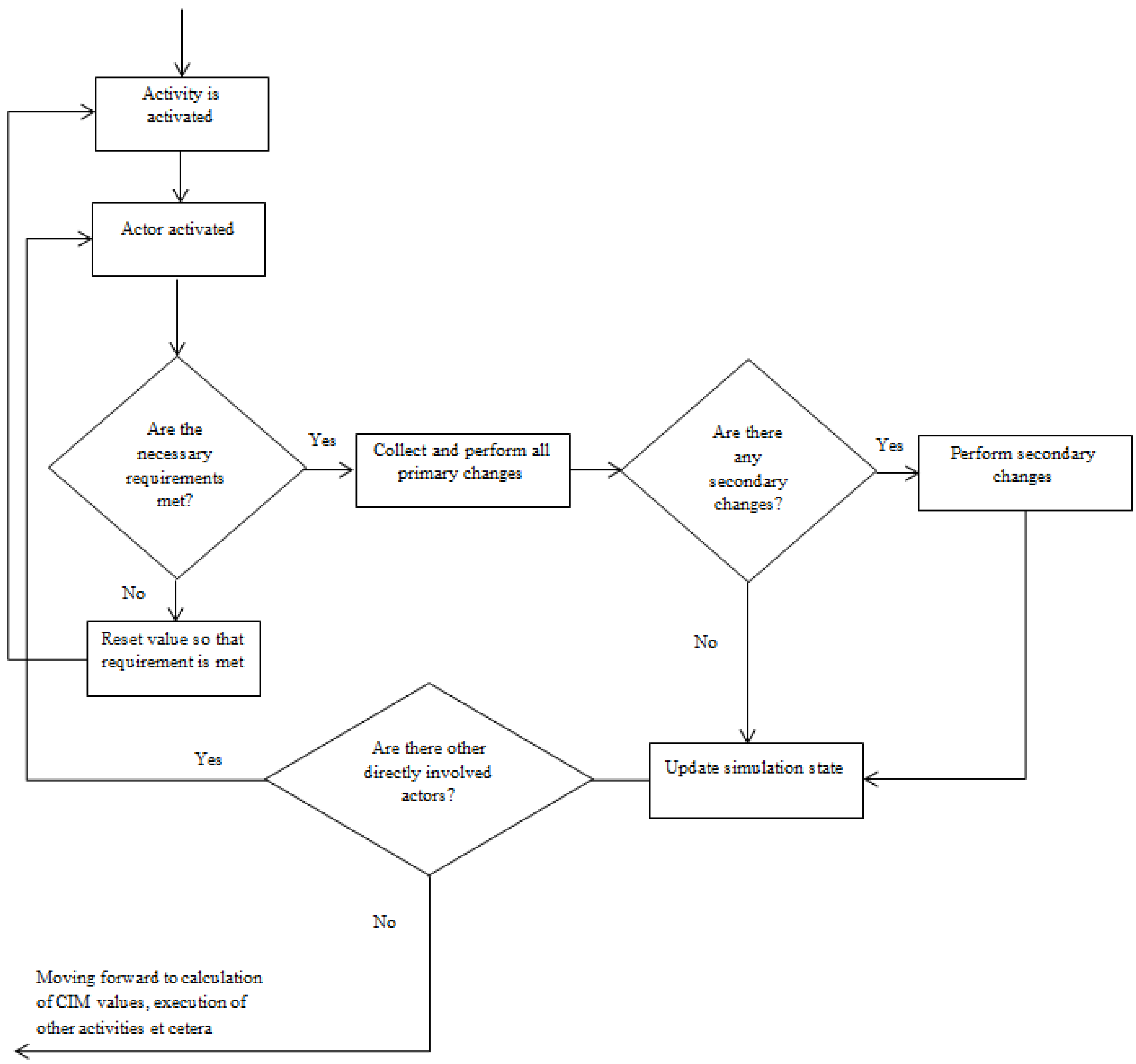

Figure 5. The course of events during the execution of an activity.

3. Case study

To test and evaluate our method we put up a test case based on the Bogaland scenario, which is often used as a military exercise scenario within the Swedish Armed Forces. Bogaland is a fictitious republic which is divided into two parts, Mida and Kasuria, and the whole scenario is useful since it is adjusted to reflect the kinds of conflicts and actors we see in the world at present. We have ongoing cultural as well as economic conflicts and actors include a wide range for example militia, war lords, and government. Our scenario includes ten actors in addition to the blue forces, two supporting effects, and a plan of nine activities.

The non-BFOR actors can be of the following types:

- influential single actor,
- neighboring country,
- irregular actor,
- international forces,
- local population.

The supporting effects that will help us achieve the MES are defined as "peacefulness in West Kasuria" and "peacefulness in East Kasuria", and the activities which we will carry out in order to achieve the supporting effects are for example

- establish area surveillance and identify key leaders of DSD (irregular actor),
- arrest DSD key leaders,
- handover civilian security to the UN.

3.1. Results

The scenario is challenging but definitely possible to model. When it came to the modeling and simulation of our actor models their states changed within the scope of expectation for each activity execution. The CIM-values however are almost consistently small in an absolute sense. This might be an indicator that the contextual conditions that determine the actual impact of change could be modeled in greater detail or that for example the number of different values attributes can assume should be increased.

Validation is a challenge since we do not have any real data to compare the output with. The detail level of the case scenario turns out to be so low that it does not enable a subject matter expert to provide us with another set of CIM values for comparison – a subject matter expert needs more information to generate a useful CIM. Hence, this way of validating our results is not a possibility. Instead we use the scenario creator's prediction regarding the probable development of the actors' states as they are affected by the activities. This comparison generated encouraging results since the actors' strengths changed in a similar fashion. The changes also seem "logical" in the sense that they follow the direction of change that one can anticipate is plausible.

4. Conclusion

We choose to base our test case scenario on a set-up which is examined and approved by subject matter experts. In this set-up the actors' strengths are set before and after the execution of each activity. A complete validation is not possible to perform due to the nature of the test case, but since we also introduce our own strength attribute it enables a comparison between the relative increases / decreases in strength generated by our program to those of the original scenario set-up. The results are encouraging since the actors' strengths change in a similar fashion and can be considered plausible. However, the term strength referred to in the case scenario set-up should not be confused with our own aggregated term; they are different descriptions, but of the same type of concept so while the numbers may not be comparable in absolute terms a comparison between them is still useful as they are describing the same quality.

As for the practicality of the method, the test case scenario is challenging and time-costly, but still very much viable, to model. The states of the actors are changing within the scope of our expectations as the activities are executed, although the CIM values are almost consistently small. This could perhaps constitute an indicator that the contextual conditions that determine the actual impact of a change should be modeled in greater detail. Expanding the number of values that an attribute can assume could also be a possible alternative to try out.

Our results indicate that the method is practicable and beneficial due to its traceability and consistency, as well as to its advantages concerning time-saving. What needs to be examined and evaluated further is the costly process of creating the initial model templates necessary for using the proposed method. To be able to do this and to better validate present and future results, more work also needs to be invested in creating a suitable scenario of an appropriate aggregation level. Positive indications encourage further method experimentation but more experience is needed before a final assessment can be made.

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