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Collaborative Synchronization Management Tool

Final Report

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Collaborative Synchronization Management Tool

Final Report

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Sammanfattning

I denna rapport presenterar vi hur en korspåverkansmatris (CIM) kan användas i planeringsprocessen av en effektbaserad syn på operationer (EBAO) för konceptutveckling och utveckling av handlingsalternativ. Syftet med att använda en CIM inom planeringsprocessen är att hitta inkonsistenser i planen samt att finna planens avgörande påverkan under fasen med konceptutveckling och utveckling av handlingsalternativ. CIMen representerar all påverkan mellan planens aktiviteter, effekter, avgörande villkor och det eftersökta sluttillståndet. Vi utvecklar morfologiska metoder för att analysera aktiviteter och utvärdera och förfina planer under planeringsprocessen med hjälp av CIMen. Vi visar också hur man kan hitta de avgörande influenserna från planens aktiviteter med hjälp av känslighetsanalys. Genom att göra både och, kan vi hitta alla svagheter och styrkor för planens alla handlingsalternativ så som den beskrivs av CIMen innan planen genomförs. Dessutom utvecklar vi en bedömningsmetod för att göra subjektiva bedömningar av planer och planelement inom EBAO. Vi visar att sådana subjektiva bedömningar kan utföras för alla effekter, avgörande villkor och sluttillståndet genom att utgå från människans subjektiva bedömningar om aktiviteter som indata och utvidga dessa bedömningar till att omfatta alla andra planelement med hjälp av CIMen. Korspåverkan kommer att stödja planerarna att hitta och utnyttja synergier genom att göra alla identifierade relationer mellan planerade aktiviteter och deras påverkan på effekter m.m. explicita. De värden som matas in i CIMen under konceptutvecklingen kan kontinuerligt uppdateras under genomförandet av planen allteftersom planerarna ökar sin kunskap om den aktuella operativa miljön. Tillsammans med annan information om operationen kan de explicita värdena i CIMen stödja olika beslutsfattare att få en gemensam förståelse av situationen som kan leda till förbättrade beslut. CIMen kan också användas vid bedömningen av operationen då den bör innehålla den mest aktuella synen av hur alla effekter påverkar de avgörande villkoren och hur alla avgörande villkor påverkar sluttillståndet. Genom att acceptera människors subjektiva bedömningar om möjlig framgång för planens aktiviteter, kan vi använda påverkan mellan planelement så som beskrivits av CIMen för att beräkna liknande subjektiva bedömningar av alla önskade effekter, avgörande villkor och sluttillstånd. Med användningen av den här metoden får vi en tidig bedömning av alla planelement under genomförandet och kan på ett tidigt stadium iaktta om aktiviteter och önskade effekter utvecklas enligt plan. Genom att också iaktta förändringen över tiden av dessa subjektiva bedömningar av effekter och avgörande villkor allteftersom bedömningar av aktiviteter uppdateras, märker vi om trender går i rätt riktning allteftersom ytterligare aktiviteter i planen genomförs. Vi anser att de metoder som har utvecklats framförallt är användbara på operativ nivå tidigt under konceptutveckling och utvecklingen av handlingsalternativ vid Joint Forces Command i fas 4a av NATO:s Allied Command Operations Comprehensive Operations Planning Directive (COPD). Metoderna är implementerade i ett verktyg för gemensam synkroniserad planering (CSMT).

Nyckelord: CSMT, korspåverkansmatris, effektbaserad syn på operationer, EBAO, planering, subjektiv bedömning, genomförande, Allied Command Operations Comprehensive Operations Planning Directive, COPD.

Summary

In this report we present how a cross impact matrix (CIM) may be used in the planning process of an Effects-based Approach to Operations (EBAO) for concept development and courses of action development. The purpose of using a CIM within the planning process is to find inconsistencies and decisive influences during concept and courses of action development. The CIM represents the impact between all actions, effects, decisive conditions, and end state of the plan. We develop morphological methods for analyzing actions and evaluating and refining plans, within the planning process using the CIM. We show that we can find the decisive influences from actions by using sensitivity analysis. By doing both we can find any weaknesses and all strengths of alternative courses of action as described by the CIM before the execution phase. We furthermore develop a subjective assessment method for making subjective assessment of plans and plan elements within EBAO. We show that such subjective assessments can be performed with regard to all effects, decisive conditions and the end state by taking human subjective assessments about actions as input and extending those assessments to all other plan elements using the CIM. The cross impact will aid the planning staff to find and exploit synergies by making all identified relationships between planned actions and their impact upon the effects, etc., explicit. The values entered in the CIM during concept development can be continuously updated during execution of the plan as the staff increases its knowledge of the current operational environment. Together with other information about the operation the explicit values in the CIM can therefore aid decision makers in gaining a more similar understanding of the situation, possibly leading to better decisions. The CIM can also be used during assessment of the operation as it should contain the most current view of what impact all effects have on the decisive conditions and what impact all decisive conditions have on the end state. Accepting human subjective assessments regarding the successful outcome of activities of the plan, we can use the impacts between plan elements as described by the CIM to calculate similar subjective assessments of all desired effects, decisive conditions and the end state. Using this methodology we get an early assessment of all plan elements during execution and may early on observe if actions and desired effects are developing according to plan. By observing the change over time of these subjective assessments of effects and decisive conditions as assessments of actions are updated, we notice if trends are moving in the right direction as more actions are further executed. We believe that the methods developed are primarily useful at the operational level early during concept development and courses of action development at Joint Forces Command in Phase 4a of NATOs Allied Command Operations Comprehensive Operations Planning Directive (COPD). The methods are implemented in a Collaboration Synchronization Management Tool (CSMT).

Keywords: CSMT, cross impact matrix, CIM, morphological analysis, Effects-Based Approach to Operations, EBAO, Planning, Subjective Assessment, Execution, Allied Command Operations Comprehensive Operations Planning Directive, COPD.

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Read also:

This current report is a methodology report intended for engineers. Previously we wrote a user's guide for CSMT intended for military officers [1]:

Hörling, P., Schubert, J. and Walter, J. (2009), Collaborative Synchronization Management Tool – A User's Guide. FOI-R--2706--SE, Swedish Defence Research Agency, Stockholm.
[Online] http://www.foi.se/upload/projects/fusion/FOI-R--2706--SE.pdf


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Collaborative Synchronization
Management Tool
A User's Guide

PONTUS HÖRLING, JOHAN SCHUBERT, JOHAN WALTER

CSMT

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1 Introduction

A cross impact matrix (CIM) [2][3] may be used for morphological [4] and statistical analysis on the operational command level by the staff at Joint Forces Command HQ within an Effects-based Approach to Operations (EBAO) [5] for concept development and courses of action development. In morphological analysis we break down the plan into essential sub-concepts, each concept representing a dimension in the CIM. The purpose of using a CIM is to find inconsistencies and decisive influences during concept and courses of action development. The CIM represents the impact between all actions, effects, decisive conditions, and end state of the plan. It is created by a broad working group which must assess how each action impacts every other action and all sought after effects, how each effect impacts every decisive condition, and how all decisive conditions impact the end state. We develop morphological methods for analyzing actions, and evaluating and refining plans within the planning process using the CIM.

The Collaborative Synchronization Management Tool (CSMT) described in this report has been developed at the Swedish Defence Research Agency [6]. It is used to analyze the cross impact or mutual influence between actions in large scale plans. Plans for large projects, let it be enterprise projects or large scale military missions, are complex and it is often difficult to get an overview of how the different actions in such a plan support or counteract each other when there might be hundreds of actions. A carefully designed plan is set up of actions that try to support each other. The simplest case is a plan with actions that are executed serially where the result of one action is the necessary initial state of the next action, something that easily can be depicted in the well known Gantt diagram. A bit more complex are temporally parallel actions where actions later in time might depend on several earlier or parallel actions; here the Gantt diagram is even more usable to get the necessary temporal overview.

One action can support another simply by providing the necessary start state for the other one (necessary condition), or make preparations that simplify the execution of the other one (advantageous condition) in some sense. Actions can compete for resources which mean that they are in conflict with each other; if one action needs some resources for its execution and gets priority for those resources, the other action is impacted in a negative way; it becomes more difficult for it to obtain its goal. If some third, resource providing action, fails, both actions get negative impact because of lacking resources, etc.

For a large plan it is difficult to estimate the total influence on the success of the whole plan by all these cross couplings of supporting or conflicting dependencies between the actions in the plan. Here, CSMT comes onto the scene. A user manual for CSMT has been produced earlier [1], and only small extensions of the tool has been done since then, mainly for the Compare Plans (see Chapter 3.4) and Subjective Assessment (see Chapter 3.5) functions, as well as changes of the naming of some concepts. The last is due to the replacement of the earlier NATO Guidelines for Operational Planning (GOP) with the new NATO Comprehensive Operations Planning Directive (COPD)

[7], which has been adjusted to Swedish conditions by the Swedish Armed Forces [8].

The base in CSMT is the CIM, which will be discussed more closely in chapter 2. It is a matrix containing estimates of the influence of any action on all other actions. It also contains the influence of actions on higher level goals, called effects and, further up, how effects influence decisive conditions, and how these affect each other. From this, an estimate of the success of the whole plan (that is, to obtain its goal, the end state) can be given, see Figure 1.

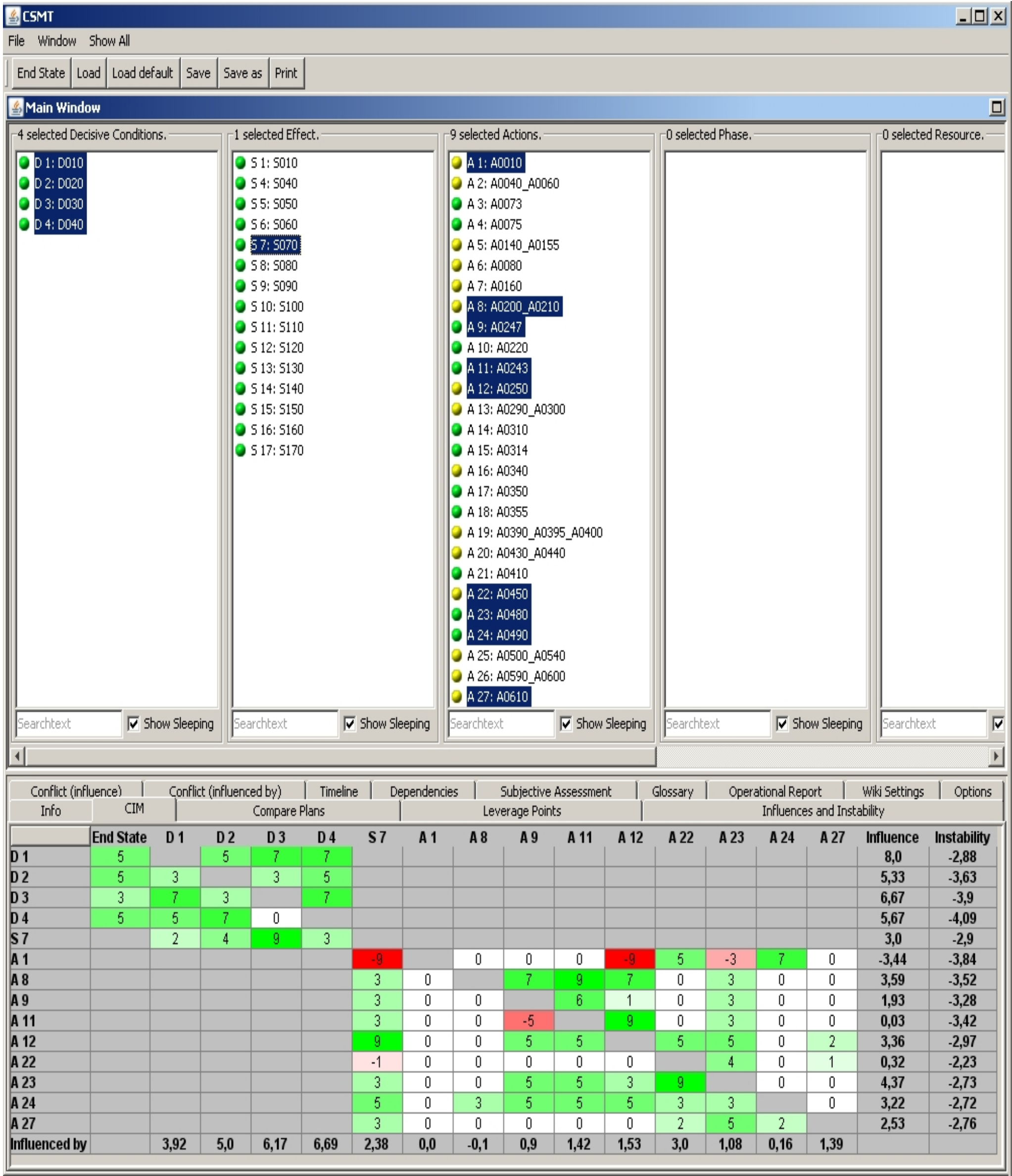

Figure 1. The interface of CSMT. The upper panels contain planning objects. Below is the CIM.

This report describes the most important analysis methods in CSMT. Several other publications on CSMT have been presented at scientific conferences and in journals. Detailed results and algorithms for performing morphological and statistical analysis of operational plans as described by the CIM are available in [1][6][9][10][11][12][13][14][15][16]. They are available online for easy download (see Chapter 4).

We believe that the methods developed and implemented in CSMT are primarily useful at the operational level early during concept development and courses of action development at Joint Forces Command (see NATOs COPD JFC Phase 4a [7]), see Figure 2.

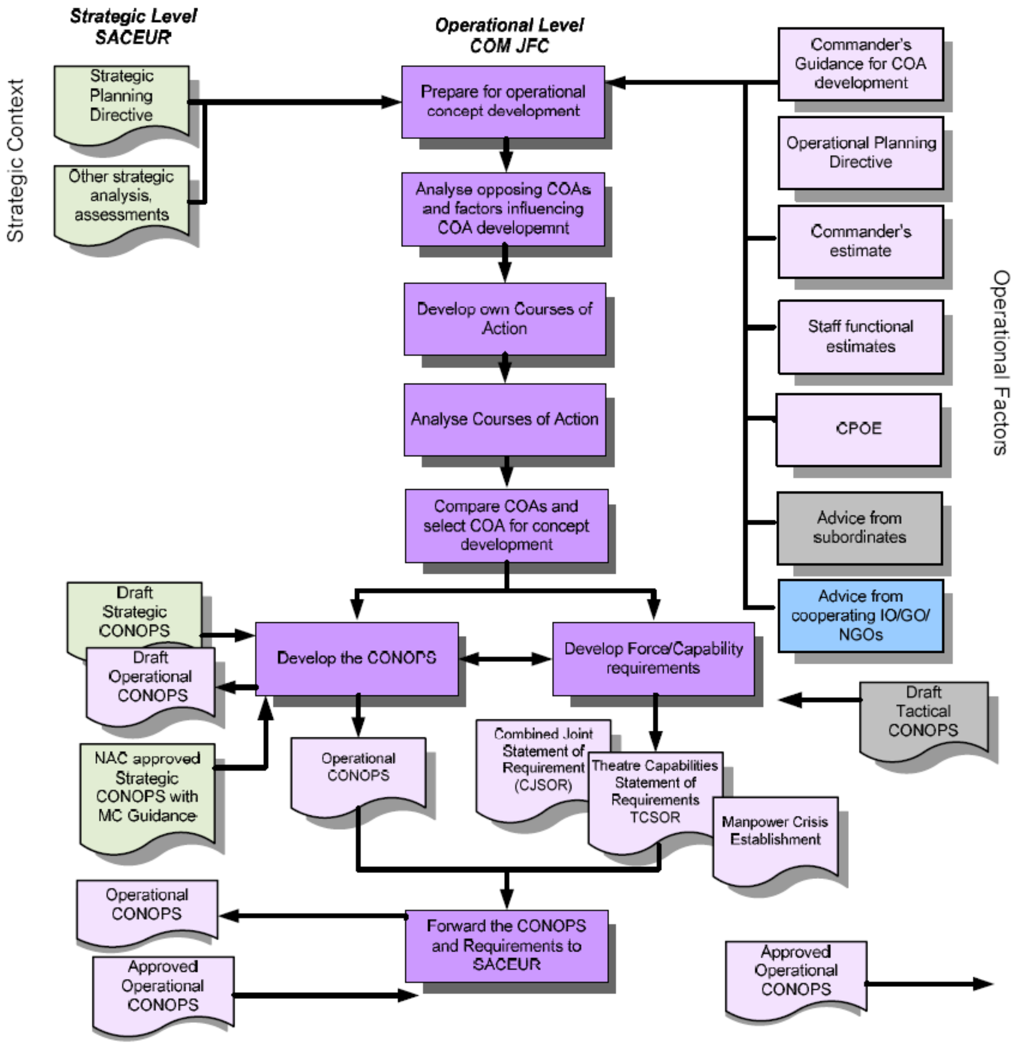

Figure 2. Operational Concept of Operation Development Main Activities.

2 The Cross Impact Matrix

The CIM in CSMT is a matrix in which the influence (negative or positive) of some action in a plan on some other action is given with an integer: from -9 (maximum conflict) via 0 (no cross impact) to +9 (maximum support). It is up to subject matter experts (SMEs) to judge, for all combinations where it can be meaningful, the value of the cross impact, and enter that value into the CIM, together with some motivation. With 100 actions there are 10 000 impact values to be assigned, although many are zero when there is no impact between actions, simply because an activity cannot affect an activity that has already been executed earlier (causally "disconnected" actions) and activities that are executed in very different geographical areas are often not affecting each other (spatially "disconnected").

There is always some goal (or end state, *ES*) one wants to obtain by executing the actions in a plan. The way to the goal can often be characterized by a set of advantageous states to be realized, and when all states are realized, the goal is reached. In CSMT these states are divided in two levels: The decisive conditions[1] (*DC*) on a higher level of abstraction, and the effects (*E*) on lower level of abstraction. The actions (*A*) are the activities that are executed in real life to obtain these states; the states as such do not constitute physical activities. *ES*, *DC*, *E* and *A* are altogether referred to as *planning objects*, see Figure 3.

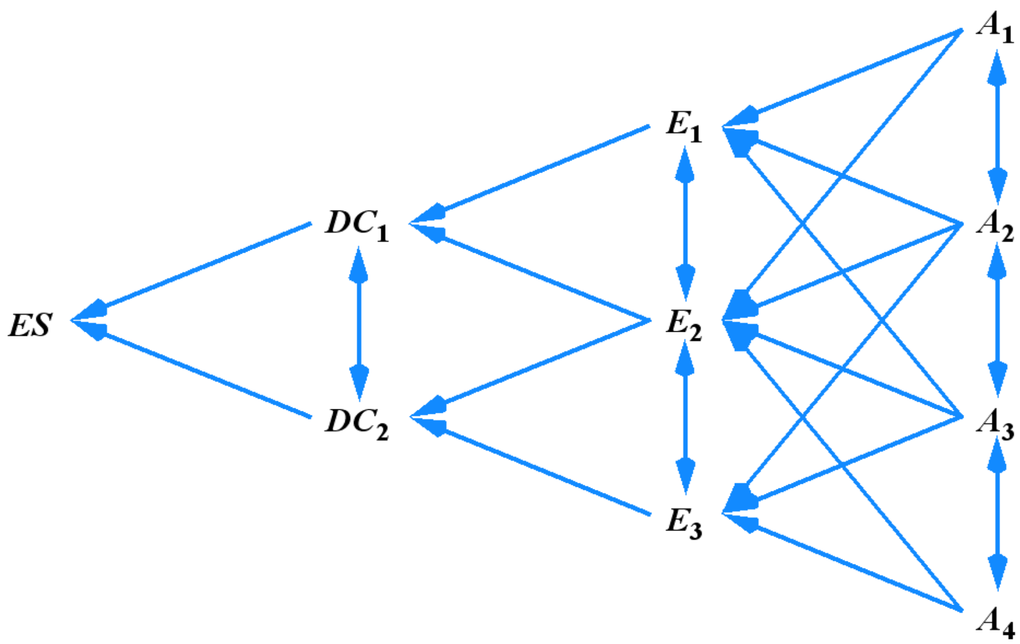

Figure 3. The influence chain from actions via more abstract state descriptions to the end state.

In CSMT the means by which the actions affect the end state is through these states: The success of a set of *A* affects the success of other *A* as well as the success of one or more *E*. These *E* affect the success of other *E* as well as the

[1] These concepts are from [8], page 27. There, for the decisive conditions, there is actually a subdivision in decisive points and decisive conditions (in CSMT, both are merged into the name decisive conditions), a decisive condition being slightly more abstract in its description than a decisive point.

success of one or more *DC*. Finally, these *DC* affect the success of other *DC* as well as the success of the *ES*. In the CIM, the planning objects are lined up along the left vertical axis and the upper horizontal axis, each planning object occupying one row and one column. The cross impact value of a certain planning object PO_1 onto another planning object PO_2 is entered in the matrix at row PO_1 and column PO_2.

It is important to note that the CIM is only used to state the first order (one step) influences between planning objects. If there is an influence chain between actions like the three step influence $A_1 \rightarrow A_2 \rightarrow A_3$, this should not result in a (indirect) cross impact of A_1 on A_3 to be entered in the CIM simply because it is meant to be mediated through the success or failure of A_2. Similarly, no analysis of "self-influencing loops" like $A_1 \rightarrow A_2 \rightarrow A_3 \rightarrow A_1$ is supposed to be done in CSMT.

In the planning process, there is often a need for setting up alternative ways for the execution of certain actions, or definitions of higher planning objects (*E*, *DC*). Eventually a certain combination of alternatives will (hopefully) be the way one chooses to execute the plan. Effectively, this means that all combinations of alternatives constitute different plans; the more different a plan is from some other plan, the more of its alternatives will differ. The combination of plan alternatives under analysis in CSMT is called the active plan, and is normally the plan for which the CIM is shown. One can choose to show the CIM for all alternative planning objects, but when there are many of these, the CIM will be very large and difficult to overview.

In CSMT, the CIM is displayed by pressing the CIM tab, see Figure 4.

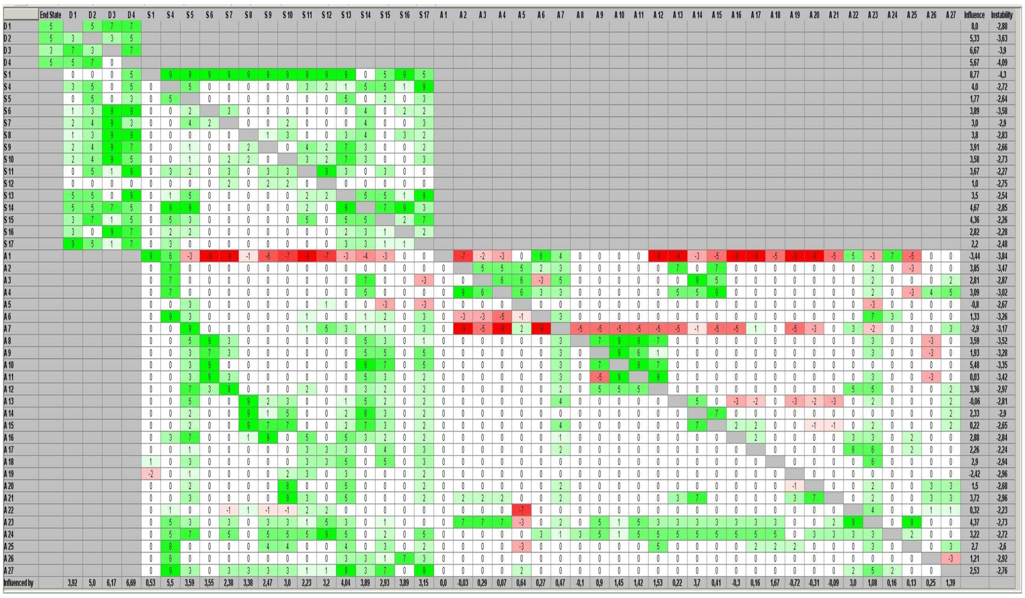

Figure 4. The cross impact matrix. The influence chain from actions via more abstract state descriptions to the end state.

With large scale plans the CIM might be so large that it becomes difficult for SMEs to manually fill it in with all impact values. In this situation it may be advantageous to simulate actions in the plan to derive impact values semi-automatically [17]. This process would be monitored by SMEs and operational analysts.

3 Methods for Analyzing the Cross Impact Matrix

Several methods exist for analyzing the CIM, which will hereby be described. When analyzing large plans with many planning elements, one can always choose to look only at sub portions of the plan by choosing only parts of the planning elements in the upper tree view in the CSMT GUI.

3.1 Conflict and Influence Analysis

In CSMT, there are two important measures that can be defined for a plan; the Consistency and the Stability which will both be described in the following. In developing a plan, one should try to optimize the consistency with highest priority. When choosing among several alternatives with similar consistency, it is preferable to choose the one with highest stability.

The consistency is a measure of how much the planning objects in a plan support each other (with high positive cross impact values). High consistency is good, low consistency is bad. In CSMT, one can show two views of this measure for each action; how much an action *influences* all others, see Figure 5, and how much it is *influenced by* all others. Both plots are available as tabs in the lower part of the CSMT GUI.

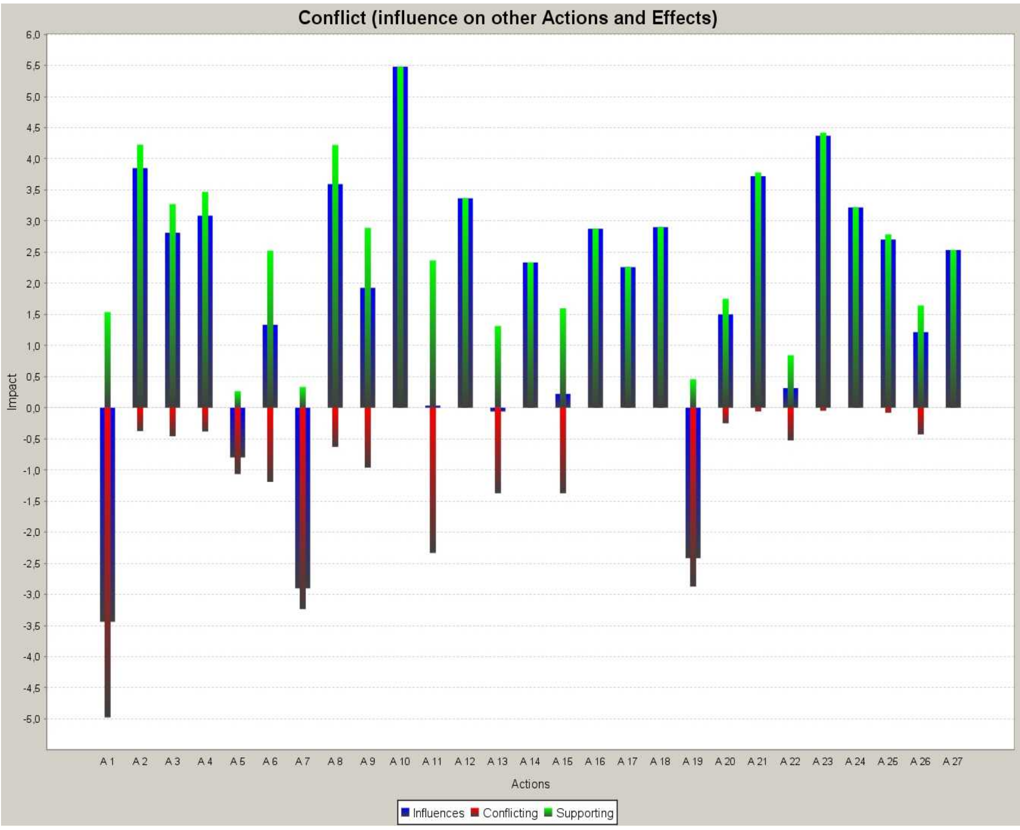

Figure 5. The figure shows how different actions influence other actions. For example, action A_{10} influence others strongly positive, while A_{11} influence some in a positive manner (green) and others in a negative way (red). Average in blue.

3.2 Influence and Stability Analysis

A third tab in the CSMT GUI also includes the stability. The stability is a measure of to which degree the planning objects support each other *equally* (positive or negative). High stability is safe, low stability is dangerous. In Figure 6, the average influences in both directions described in the previous subsection are spanned by the X- and Y-axes, respectively. The stability is depicted by the inverted size of the blue circle, each representing an activity. The larger the circle is, the more instable is the activity. Activities represented by small circles far up to the right are both consistent and stable.

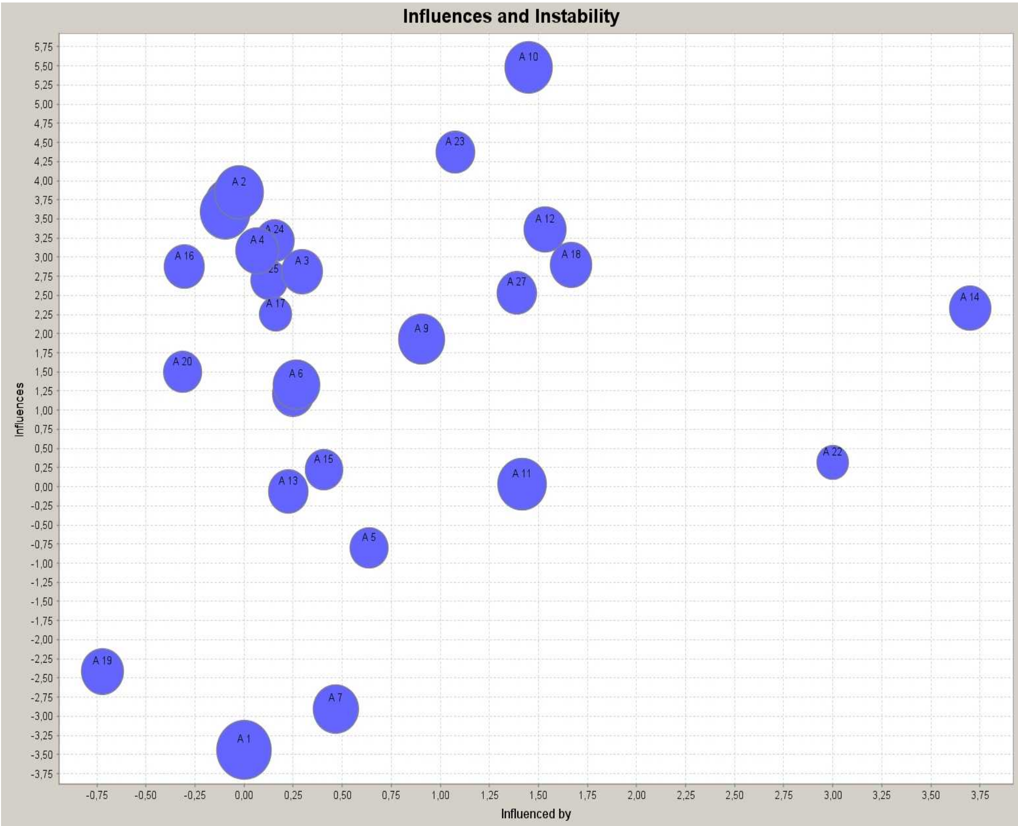

Figure 6. All actions ranked by how much they influence and are influenced by other activities. Circle size correspond to instability (large circles implies high instability).

The consistency and stability values (for all planning elements) are found also when displaying the CIM (pressing the CIM tab in the CSMT GUI), along the bottom row and rightmost two columns, see Figure 1.

3.3 Leverage Points Analysis

We can calculate which actions provide a decisive influence on a particular effect, decisive condition or on the end state by performing a sensitivity analysis. In this analysis we assume a simple event space Θ for each effect, decisive condition and the end state with only two possible outcomes, $\Theta = \{AdP, \neg AdP\}$ on each hierarchical level of the plan, where AdP means an Adequate Plan, and ¬AdP means not an Adequate Plan. Either the desired effect, decisive condition or the end state is achieved or it is not.

The calculation is made by first, for a certain action A_k, calculating the support for the requested effect m_{E_j} (AdP), decisive condition m_{DC_j} (AdP) or end state m_{ES}(AdP) assuming 100% success for every action m_{A_i} (AdP) = 1 $\forall i$ and then recalculating the same with 99% probability of success for a particular action A_k, i.e., m_{A_k} (AdP) = 0.99 and m_{A_i} (AdP) = 1 $\forall i \neq k$, to observe the changes. Here, m_{A_i} (¬AdP) = 0 $\forall i$. By selecting these assessments as input data we will be able to perform numerical differentiation of all effects, decisive conditions and the end state with respect to each individual action. The value of these derivatives shows the influence of the individual actions on these effects, conditions and end state.

If we are only interested in which actions have a decisive influence on some particular effect or decisive condition then we may choose to calculate only these values, but if we are interested in which actions have a decisive influence on the plan at large, then we must perform the calculation for the end state level.

Before combining the assessments we discount them using the impact values of the CIM. This ensures that each action influences the effect to its proper degree as specified by the impact values of the CIM. We have

$$m_{A_i}^{\alpha_{kj}}(X) = \begin{cases} \alpha_{kj} m_{A_i}(\text{AdP}), & X = \text{AdP} \\ \alpha_{kj} m_{A_i}(\neg\text{AdP}), & X = \neg\text{AdP} \\ 1 - \alpha_{kj} m_{A_i}(\text{AdP}) - \alpha_{kj} m_{A_i}(\neg\text{AdP}), & X = \Theta \end{cases} \tag{1}$$

with discounting factors

$$\alpha_{kj} = \frac{\text{impact}(k, j)}{10} \,. \tag{2}$$

Here discounting factors may assume values less than 0, i.e., α_{kj}= {–0.9, –0.8, –0.7, ..., 0.9}. These discounted assessments are combined using Dempster's rule within Dempster-Shafer theory [18][19].

For each action A_k and every effect E_j we can calculate

$$\text{DecisiveInfluence}(A_k \rightarrow E_j) = \left\{ \left[m_{E_j}(\text{AdP}) \middle| \begin{matrix} m_{A_j}(\text{AdP}) = 1 & \forall i \\ m_{A_j}(\neg\text{AdP}) = 0 & \forall i \end{matrix} \right] - \left[m_{E_j}(\text{AdP}) \middle| \begin{matrix} m_{A_k}(\text{AdP}) = 0.99 & \\ m_{A_j}(\text{AdP}) = 1 & \forall i \neq k \\ m_{A_j}(\neg\text{AdP}) = 0 & \forall i \end{matrix} \right] \right\} \tag{3}$$

where

$$m_{E_j}(\text{AdP}) = \max\left\{ 0,\ \ 1 - \prod_k \left[1 - \frac{\text{impact}(k, j)}{10} . m_{A_k}(\text{AdP}) \right] \right\} \tag{4}$$

and $0 \leq m_{E_j}$ (AdP) ≤ 1. We have chosen to cap the value of m_{E_j} (AdP) ≥ 0 and not handle the case where m_{E_j} (AdP) < 0.

By substituting $\{ m_{E_j} \rightarrow m_{DC_j} \}$ in Eq. (3) we may calculate for each action A_k which influence it has on every decisive condition DC_j, DecisiveInfluence($A_k \rightarrow DC_j$). However, most interesting is perhaps the influences the different actions have on the plan at large, i.e., the end state. By substituting $\{m_{E_j} \rightarrow m_{ES}\}$ in Eq. (3) we calculate for each action which influence it has on the end state, DecisiveInfluence($A_k \rightarrow ES$). Since we only have one end state we get one value for each action and may thus rank these by the calculated impact.

An example of action influence on the end state is shown in Figure 7.

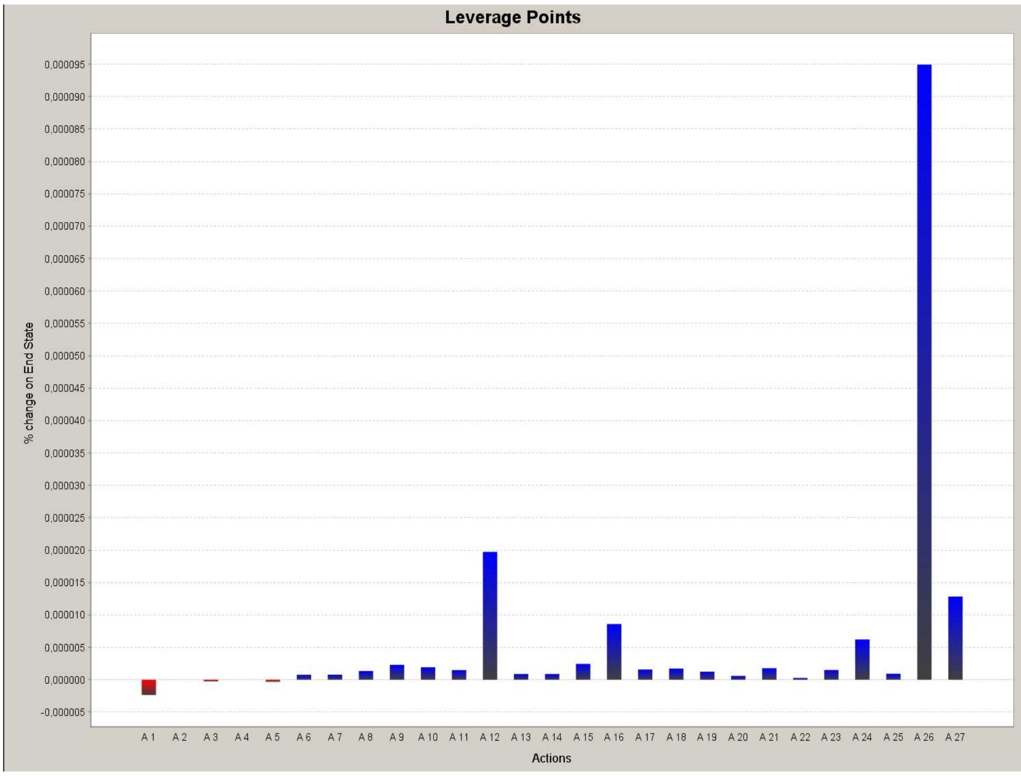

Figure 7. Leverage points show the impact of success of each action on the success of the end state. The possible success of action A_{26} would have a high impact on the possible success of the end state.

3.4 Compare Plans Analysis

One of the most important steps in plan development is to develop alternative plans and compare their probability of success. In CSMT this is done by combining all permutations of alternative planning elements; each combination constituting a separate plan. Then the consistencies for each plan are computed and compared with the others. For instance, assume that a plan has 10 actions, where action 2 has 2 alternative ways to be executed, action 5 has 6 alternatives and action 8 has 4 alternatives, then if all actions in the plan should be executed, this means that there will be 2 x 6 x 4 = 48 ways to combine the alternatives of actions 2, 5 and 8. The remaining actions without alternatives are always executed, and do not add extra alternatives. In CSMT, one can also define alternatives for higher planning elements like *E* and *DC* where an *E* or *DC* can be formulated differently in each alternative (with different cross impact from the actions), but below we only discuss actions.

If the planning problem is large with perhaps up to one hundred actions or more, where many of the actions can have many alternatives, the number of permutations of all these alternatives can grow very large, resulting in a number of possible plans that can easily reach billions, trillions, or even more. In an earlier version of CSMT, a table with all plans that resulted from this permutation was shown which is of course not possible for many normal planning problems. In the present version, if the number of plans exceed a certain constant, an A^*-search algorithm is used that searches through the tree-like planning space where each plan represents a unique path from one alternative in the root (first action) along a specific set of alternatives of each action to an alternative of the last action. If the A^*-algorithm is tuned correctly for an example planning problem based on a Bogaland scenario, which resulted in 1 120 403 456 permutations in total, a list of around 500 permutations is presented within a few seconds. This list is very close to the list of best plans.

A bar chart can be used to present the best plans found, see Figure 8 where the consistencies of the 150 best plans found in the Bogaland scenario are shown.

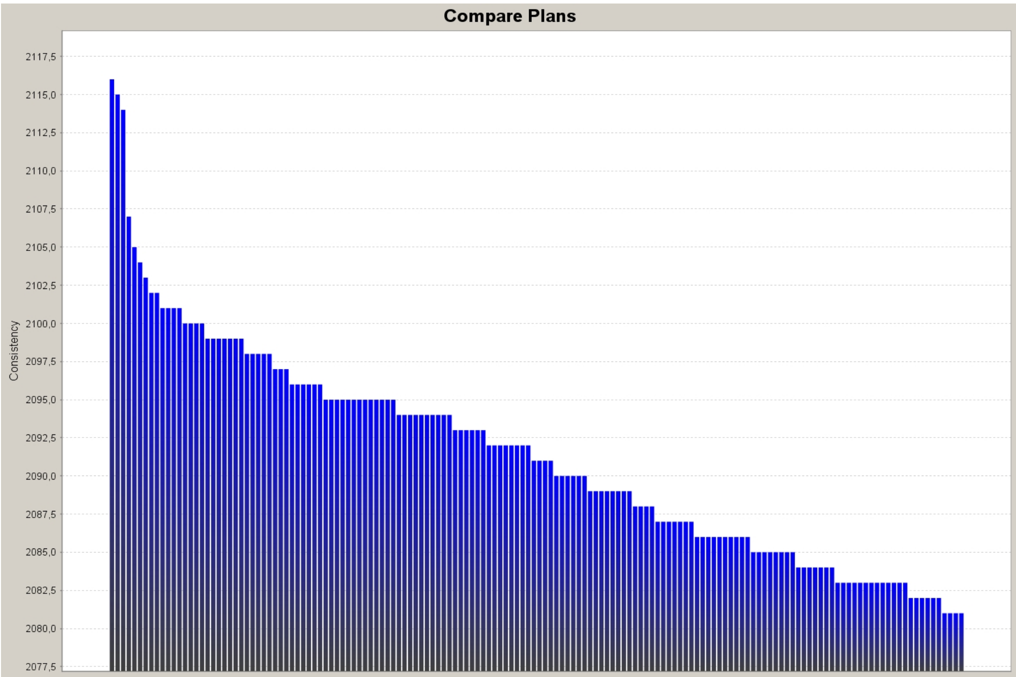

Figure 8. Bar chart showing the consistency of the 150 best plans found. Here the three the plans to the left seem to be the clearly best ones found.

It is also possible to choose only a subset of all actions; then the list will only contain the plans for the possible permutations of the selected actions. However, the consistency is still computed over all actions within each plan, but only the alternatives of selected actions are used in plan generation.

As mentioned above the way to build alternative plans goes via creating actions with alternatives, and then compare the consistency of their resulting combinations. Another way would be to build plans that differ concerning number of actions to be executed. One could think of a more advanced set-up of alternatives to an action where for example one has to choose between 2 alternatives or a pairwise combination of 2 sub-actions, each having 2 alternatives. This results in 1 + 1 + 2 x 2 = 6 alternatives, like in Figure 9.

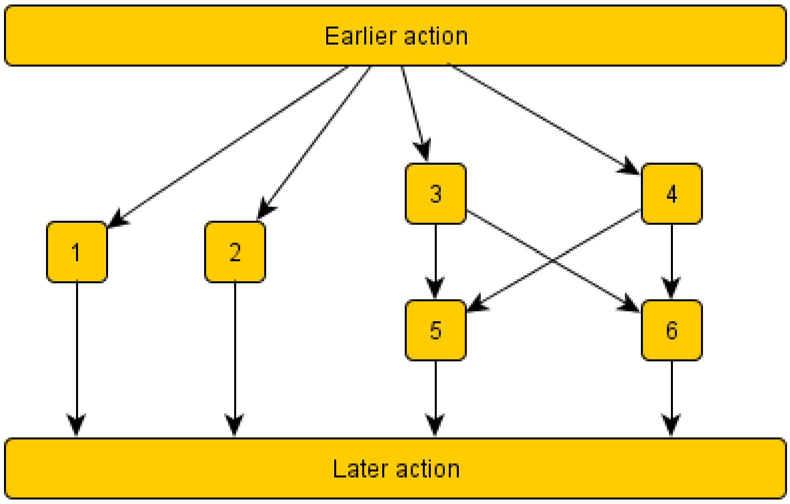

Figure 9. Different ways to construct plan alternatives. Today in CSMT, an action can have one to many singe alternatives (like 1 and 2 constitutes 2 alternatives). Another way would be to let an action be built as two sub-actions executed serially or in parallel like any of the 4 combinations 3–5 or 3–6 or 4–5 or 4–6. Or both 1 or 2 or 3–5 or 3–6 or 4–5 or 4–6 as described in the text.

So far, CSMT only offers the possibility to use one or several single alternatives to an action, choosing one alternative for a specific plan. This forces all possible plans to have the same number of actions which makes them easy to compare. Plans with different number of actions would introduce a normalization problem which could make them more difficult to compare on an equal footing.

3.5 Subjective Assessment Analysis

The CIM is a model of influence between elements of the plan. In assessment, our interest is on the impact between actions on the lowest level and effects on the next level, and so forth. During action execution we receive subjective assessments regarding the success of actions as user input. These are in the form of assessments that express support for and against the success of that action, encoded as AdP and ¬AdP, respectively.

For assessment m_i we have,

$$m_i(A) = \begin{cases} m_i(\mathrm{AdP}), & A = \mathrm{AdP} \\ m_i(\neg\mathrm{AdP}), & A = \neg\mathrm{AdP} \\ 1 - m_i(\mathrm{AdP}) - m_i(\neg\mathrm{AdP}), & A = \Theta \end{cases} \tag{5}$$

The CIM contains all information regarding the impact of each action on all effects. When the impact on a particular effect E_j is less than full we discount the assessment m_i in relation to its degree of impact on E_j

$$m_i^{\alpha_{ij}}(A) = \begin{cases} \alpha_{ij} m_i(\text{AdP}), & A = \text{AdP} \\ \alpha_{ij} m_i(\neg\text{AdP}), & A = \neg\text{AdP} \\ 1 - \alpha_{ij} m_i(\text{AdP}) - \alpha_{ij} m_i(\neg\text{AdP}), & A = \Theta \end{cases} \quad (6)$$

Combining all $m_i^{\alpha_{ij}}$, we get

$$m^{\alpha_{ij}}_{\oplus\{m_i\}_{i=1}^n}(A) = \begin{cases} K\left\{\prod_i [1 - \alpha_{ij} m_i(\neg\text{AdP})] - \prod_i [1 - \alpha_{ij} m_i(\text{AdP}) - \alpha_{ij} m_i(\neg\text{AdP})]\right\}, & A = \text{AdP} \\ K\left\{\prod_i [1 - \alpha_{ij} m_i(\text{AdP})] - \prod_i [1 - \alpha_{ij} m_i(\text{AdP}) - \alpha_{ij} m_i(\neg\text{AdP})]\right\}, & A = \neg\text{AdP} \\ K\prod_i [1 - \alpha_{ij} m_i(\text{AdP}) - \alpha_{ij} m_i(\neg\text{AdP})], & A = \Theta \end{cases} \quad (7)$$

where

$$m^{\alpha_{ij}}_{\oplus\{m_i\}_{i=1}^n}(\text{AdP}) + m^{\alpha_{ij}}_{\oplus\{m_i\}_{i=1}^n}(\neg\text{AdP}) + m^{\alpha_{ij}}_{\oplus\{m_i\}_{i=1}^n}(\Theta) = 1 \quad . \quad (8)$$

Thus, Eq. (7) becomes the subjective assessment of E_j as calculated using the subjective input assessments of all actions A_i that impact upon E_j.

What is calculated for effects from subjective assessment of actions can in a second phase be calculated for decisive conditions using the newly calculated assessments of effects. In the same way we can calculate the subjective assessment of the end state from the assessment of decisive conditions.

With these calculations we have all pieces of a subjective assessment algorithm:

Subjective Assessment Algorithm

- For all E_j calculate: $m_{E_j}(\text{AdP})$, $m_{E_j}(\neg\text{AdP})$, $m_{E_j}(\Theta)$.
- For all DC_j calculate: $m_{DC_j}(\text{AdP})$, $m_{DC_j}(\neg\text{AdP})$, $m_{DC_j}(\Theta)$.
- Calculate: $m_{ES}(\text{AdP})$, $m_{ES}(\neg\text{AdP})$, $m_{ES}(\Theta)$.

In Figure 10 the calculated values are presented in the upper part labeled “Impact”, together with the initial subjective assessments in the lower part labeled “Input” within CSMT. Obviously, $m(\text{AdP})$ is indicated by green, $m(\neg\text{AdP})$ by red and the uncommitted part $m(\Theta)$ by gray.

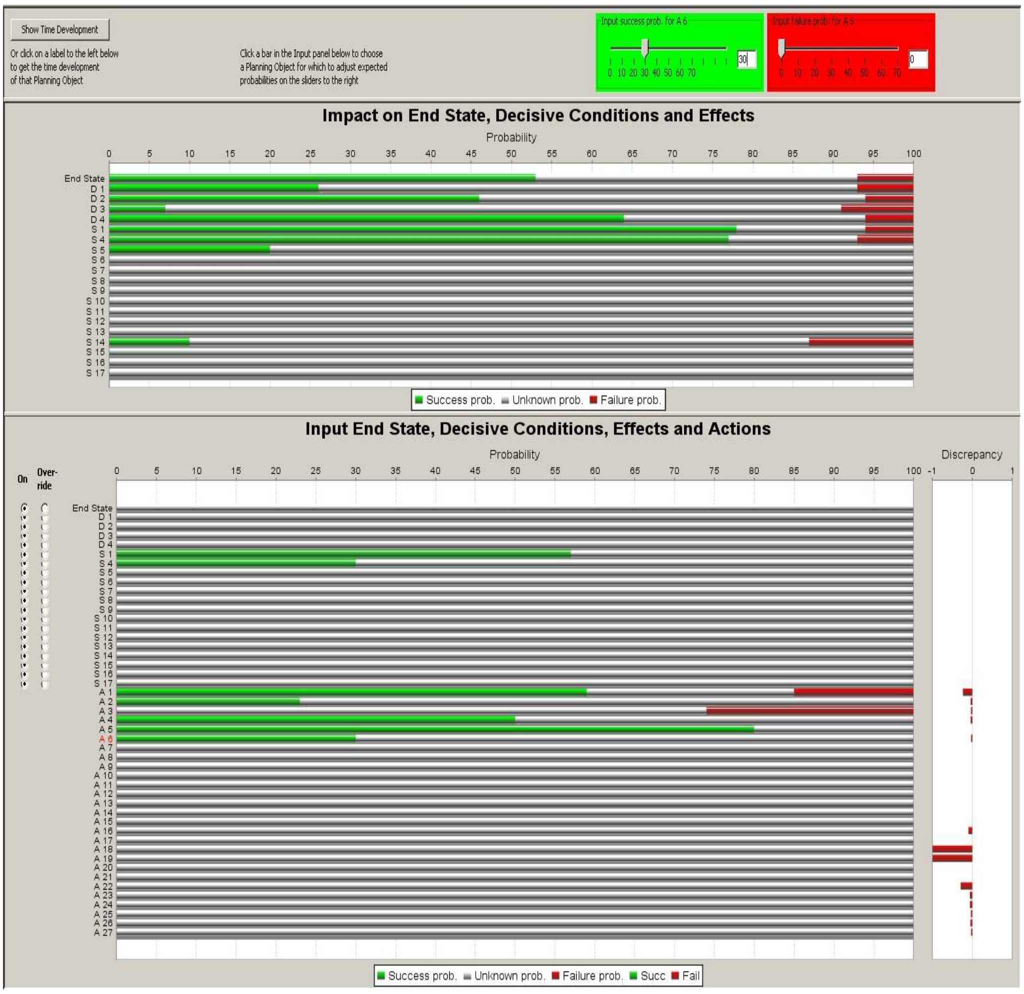

Figure 10. Subjective assessment in CSMT. A snap-shot where a few assessments at the action and effects level are available (lower part). Impact on the effects levels are shown in top part.

In order to further enhance the usability it may be of value to include a diagram of changes over time for these assessments. In Figure 11 this is exemplified for the end state at different times.

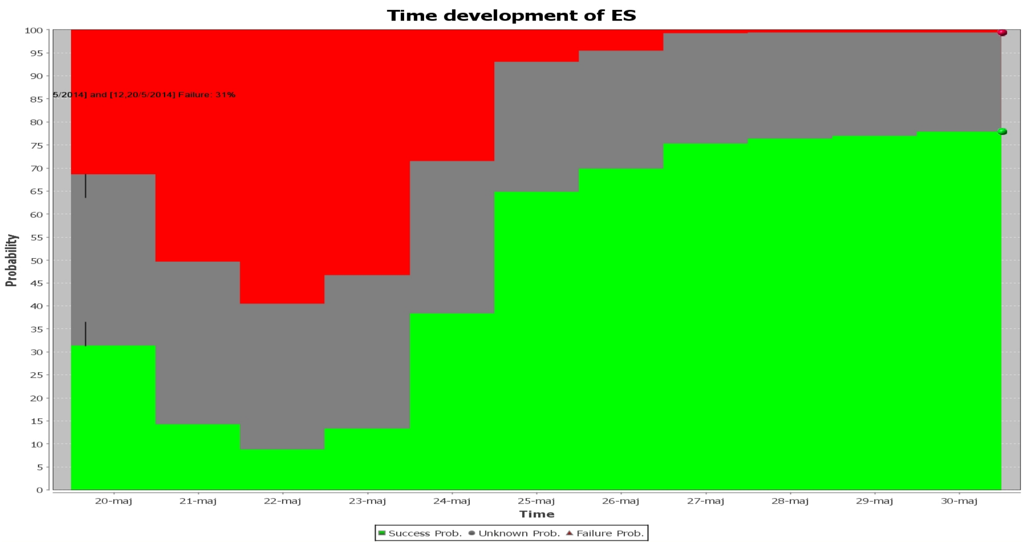

Figure 11. Subjective assessments over time of end state (*ES*).

4 References

[1] Hörling, P., Schubert, J. and Walter, J. (2009), Collaborative Synchronization Management Tool – A User's Guide. FOI-R--2706--SE, Swedish Defence Research Agency, Stockholm.
[Online] http://www.foi.se/upload/projects/fusion/FOI-R--2706--SE.pdf

[2] Glenn, J.C. and Gordon, T.J. (2003), Futures Research Methodology − Version 2.0. American Council for the United Nations University, Washington, DC.

[3] Gordon, T.J. and Hayward, H. (1968), Initial experiments with the cross-impact matrix method of forecasting, *Futures* **1**(2):100−116.

[4] Zwicky, F. (1969), *Discovery, invention, research through the morphological approach*. Macmillan, New York, NY.

[5] Smith, E.A. (2006), Complexity, networking, and effects-based approaches to operations. U.S. Department of Defense CCRP, Washington, DC.

[6] Schubert, J. (2010), Analysis and assessment of effects-based plans, in *Proceedings of the NATO Symposium on Analytical Support to Defence Transformation* (SAS-081), Sofia, Bulgaria, 26−28 April 2010. NATO Research and Technology Organisation, Neuilly-sur-Seine, France, 2010, Paper 33, pp. 1−18. (FOI-S--3395--SE, Swedish Defence Research Agency, Stockholm).
[Online] http://www.foi.se/upload/projects/fusion/fusion88.pdf

[7] Allied Command Operations Comprehensive Operations Planning Directive (COPD) Interim Version 1.0. Supreme Headquarters Allied Power Europe, North Atlantic Treaty Organization, Brussels, 2010.

[8] Swedish Armed Forces application of NATOs Comprehensive Operations Planning Directive (SWE COPD 1.5). Swedish Armed Forces, Stockholm, 2011.

[9] Wallén, M., Schubert, J. and Walter, J. (2007), Användning av Cross Impact Matrix (CIM) i Effects-Based Planning (EBP) och Effects-Based Assessment (EBA). FOI Memo 2070, Swedish Defence Research Agency, Stockholm. (In Swedish).

[10] Schubert, J., Wallén, M. and Walter, J. (2007), Morphological refinement of effect based planning, in *Proceedings of the Third International Conference on Military Technology* (MilTech3), Stockholm, Sweden, 14−15 June 2007, Paper Or21, pp. 1−8. (FOI-S--2578--SE, Swedish Defence Research Agency, Stockholm).
[Online] http://www.foi.se/upload/projects/fusion/fusion53.pdf

[11] Schubert, J., Wallén, M. and Walter, J. (2007), Analys och förfining av planer i effektbaserad planering. FOI-R--2307--SE, Swedish Defence Research Agency, Stockholm. (In Swedish).
[Online] http://www.foi.se/upload/projects/fusion/FOI-R--2307--SE.pdf

[12] Schubert, J., Wallén, M. and Walter, J. (2008), Morphological refinement of effect-based planning, in *Stockholm Contributions to Military-Technology 2007*, M. Norsell (Ed.). Swedish National Defence College, Stockholm, 2008, pp. 207−220. (FOI-S--2867--SE, Swedish Defence Research Agency, Stockholm).
[Online] http://www.foi.se/upload/projects/fusion/fusion60.pdf

[13] Schubert, J. (2008), Subjective effects-based assessment, in *Proceedings of the Eleventh International Conference on Information Fusion* (FUSION 2008), Cologne, Germany, 30 June−3 July 2008. IEEE, Piscataway, NJ, 2008, pp. 987−994. (FOI-S--2903--SE, Swedish Defence Research Agency, Stockholm).
[Online] http://www.foi.se/upload/projects/fusion/fusion63.pdf

[14] Schubert, J. and Wallén, M. (2008), Prognos och uppföljning av planer i effektbaserad utvärdering. FOI-R--2594--SE, Swedish Defence Research Agency, Stockholm). (In Swedish).
[Online] http://www.foi.se/upload/projects/fusion/FOI-R--2594--SE.pdf

[15] Schubert, J. (2010), Multi-level subjective effects-based assessment, in *Proceedings of the 13th International Conference on Information Fusion* (FUSION 2010), Edinburgh, UK, 26−29 July 2010. IEEE, Piscataway, NJ, 2010, Paper We3.4.1, pp. 1−8. (FOI-S--3463--SE, Swedish Defence Research Agency, Stockholm).
[Online] http://www.foi.se/upload/projects/fusion/fusion94.pdf

[16] Kylesten, B., Schubert, J. and Hörling, P. (2011), Användarförsök med CSMT – Ett operationsanalytiskt verktyg för att testa operativa planer. FOI Memo 3559, Swedish Defence Research Agency, Stockholm. (In Swedish).

[17] Harrysson, F. (2009), Simulation as a means of providing input to the CSMT. FOI-R--2932--SE, Swedish Defence Research Agency, Stockholm.
[Online] http://www.foi.se/upload/projects/fusion/FOI-R--2932--SE.pdf

[18] Dempster, A.P. (1968), A generalization of Bayesian inference, *Journal of the Royal Statistical Society Series B* **30**(2):205−247.

[19] Shafer, G. (1976), *A Mathematical Theory of Evidence*. Princeton University Press, Princeton, NJ.