# 15.

# Morphological Refinement of Effect-Based Planning[1]

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## Abstract

In this paper we present how a cross impact matrix may be used in effect-based planning for plan evaluation, plan refinement and generation of alternative plans. The purpose of using a cross impact matrix is to find inconsistencies in plans developed within the effect based planning process. The cross impact matrix consists of all activities, supporting effects, decisive conditions and the military end state of the plan. We develop methods for analyzing activities and evaluating and refining plans within effect based planning. In addition we use a Dempster-Shafer theory based sensitivity analysis to find decisive influences within the plan.

## Introduction

A *cross impact matrix* (CIM) [3, 4] can be used for *morphological analysis* [10] on the operational command level by the staff of a joint task force headquarter in an *Effects Based Approach to Operations* (EBAO) [2] during planning,

[1] A short version of this study was presented at the Third International Conference on Military Technology (MilTech3) in Stockholm, Sweden [6].



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National Defence College, 2008.

execution and assessment of an operation. In morphological analysis we break down the plan into essential sub-concepts, each concept representing a dimension in the CIM. The purpose of using morphological analysis is to find inconsistencies in plans developed within the *effect based planning* (EBP) [9] process. The CIM consists of all *activities* (A), *supporting effects* (SE), *decisive conditions* (DC) and *military end state* (MES) of the plan. It is created by a broad working group which must assess how each activity impacts every other activity and supporting effect, how each supporting effect impacts every decisive condition (and possibly other supporting effects), and how every decisive condition impacts the military end state (and possibly other decisive conditions). In this paper we present how a CIM may be used in EBP for plan evaluation, plan refinement and generation of alternative plans. We develop methods for analyzing activities and evaluating and refining plans within EBP.

The cross impact will aid the planning staff to find and exploit synergies by making all identified relationships between planned activities and their impact upon the supporting effects, etc. explicit. The values entered in the CIM during planning 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 supporting effects have on the decisive conditions and what impact all decisive conditions have on the military end state.

## The creation of the cross impact matrix

The cross impact matrix will initially be created during the planning process. It should be created by a working group containing key subject matter experts as required by the type of operation planned. The working group will first need to enter all planned activities into the CIM, and it is important that all activities are well defined. They will then have to decide which positive or negative impact each activity will have on every other activity. It is important to note that even if activity $A_1$ has a positive impact on activity $A_2$ then $A_2$ could have a negative impact on $A_1$. In the next step the working group must decide what impact all activities have on the supporting effects, what impact all supporting effects have on the decisive conditions and what impact the decisive conditions have on the military end state. In this paper we use British concepts [5].

It is important to note that the CIM will not be able to handle the effects of synergy. If the combined effect of performing activities $A_1$, $A_2$ and $A_3$ simultaneously is higher than the sum of performing each one separately, this can not be modeled within standard CIM analysis. However, it can be managed if $A_1$, $A_2$ and $A_3$ are combined into one activity with several alternatives.

## Tasks

The CIM can be introduced in EBP and used for evaluation of the plan and generation of alternative plans. The work with CIM in EBP may be conducted using the following tasks.

### *Form a plan*

Before the CIM is constructed, a plan must be formed according to EBP, see Figure 1.

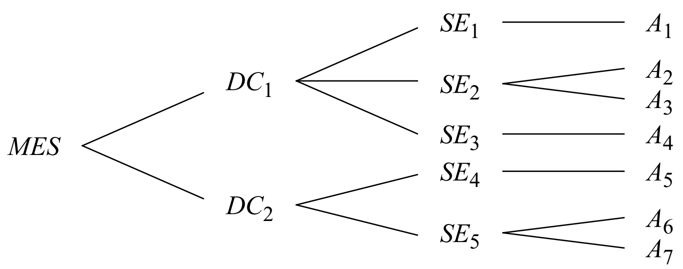


Figure 1. Effect based planning: *MES* = military end state, *DC* = decisive condition, *SE* = supporting effect, *A* = activity.

### *Construct the CIM based on the plan*

The plan consists of a military end state, decisive conditions, supporting effects and activities. The number of these elements is denoted $n$. Construct a CIM with $n$-1 rows and $n$ columns. Listing these elements, except the military end state, to the left of the CIM and list the elements, including the military end state, above the CIM, see Figure 2. The CIM consists of values ranging from -9 to 9, where -9 denotes large negative influence, 0 means no influence and 9 denotes high positive influence. For example, an impact value of 8, i.e., “high positive influence”, might be assigned between the activity of “securing an area” and the activity of “transporting through that area”. How much the element of row $i$ influences the element of column $j$ is stored in $cell(i, j)$ in the CIM (for example the activity $A_2$ influence the activity $A_4$ in a positive way with a factor 2, but $A_4$ influence $A_2$ in a negative way by a factor of -2).

It is important to separate between direct and indirect influence. Only direct influence should be stated in the CIM. Also, one should be very careful not to

| | Military End State | $DC_1$ | $DC_2$ | $SE_1$ | $SE_2$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|---|---|---|---|---|
| $DC_1$ | 5 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 |
| $DC_2$ | 8 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $SE_1$ | 0 | 5 | 2 | 0 | 0 | 0 | 0 | 0 | -3 |
| $SE_2$ | 0 | 5 | 8 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_1$ | 0 | 0 | 0 | 3 | 3 | 0 | 4 | -2 | -3 |
| $A_2$ | 0 | 0 | 0 | 3 | -2 | 3 | 0 | 0 | 2 |
| $A_3$ | 0 | 0 | 0 | 3 | 6 | 0 | 8 | 0 | 0 |
| $A_4$ | 0 | 0 | 0 | 4 | -2 | -7 | -2 | 0 | 0 |

Figure 2. The CIM contains military end state, decisive conditions, supporting effects and activities (dark gray cells always contain zeros).

assign any direct influences between two activities if these more properly concern influences between each of the two activities and the supporting effect.

At this initial stage of the construction of the CIM we include the basic elements of the plan meaning that each element usually has only one alternative. Thus, all activities should be performed and all supporting effects and decisive conditions should be reached. In Figure 3 an implementation of the CIM is shown.

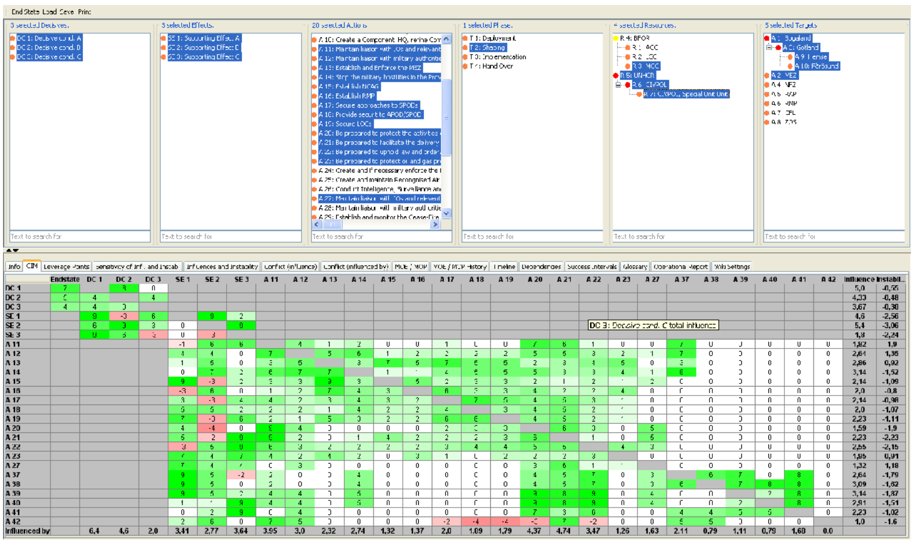

Figure 3. A complete CIM with activities, supporting effects, decisive conditions and military end state.

### *Opportunities: Create new alternatives*

It may be possible to state some alternative decisive conditions, supporting effects or activities. For instance, we may have two different activities we have to decide between. They could describe different things to do, or they could do the same thing at different times or places. Then we would have two different instances of the plan.

We calculate consistency and stability for each element of the plan (activities, supporting effects and decisive conditions) relative all other elements. When calculating for each row we obtain how much each element influences other elements (by column how much it is influenced by other elements). For each row we have

$$\text{AltConsistency}(Alt_i) = \sum_j \text{impact}(i, j) \qquad (1)$$

were impact$(i, j)$ is the impact value in the CIM, $Alt_i \in \{DC_1, DC_2, SE_1, SE_2, A_1, A_2\ \ A_3, A_4\}$, Figure 4, and

$$\text{AltStability}(Alt_i) = \prod_j \frac{\min[\text{CV}(i, j), \text{CV}(j, i)]}{\max[\text{CV}(i, j), \text{CV}(j, i)]} \qquad (2)$$

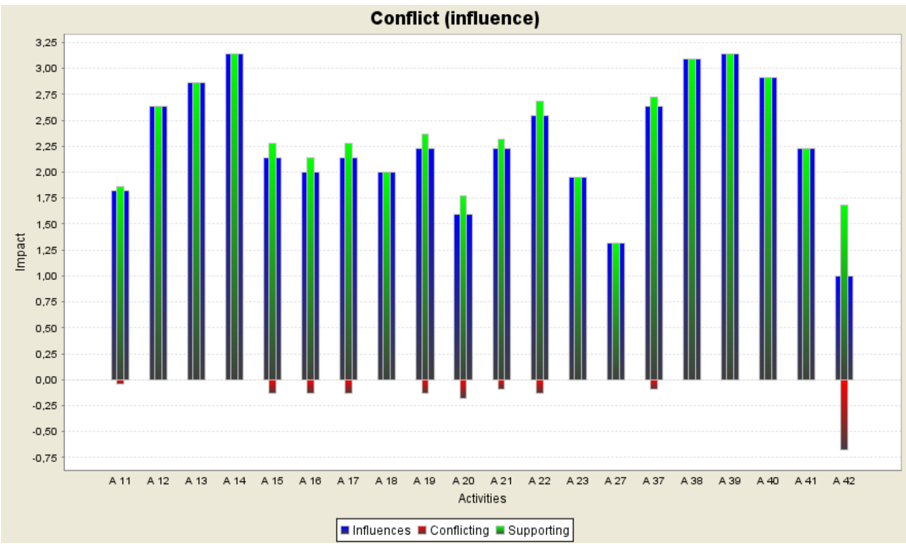


Figure 4. The figure shows how different activities influences other activities. For example, activity $A_{39}$ influence others strongly positive, while $A_{42}$ influence some in a positive manner (green) and other in a negative way (red). Average in blue.

where the coefficient value CV($i$, $j$) is calculated as

$$\mathrm{CV}(i,\ j) = \begin{cases} \mathrm{impact}(i,\ j) + 1, & \mathrm{impact}(i,\ j) \geq 0 \\ \dfrac{1}{1 - \mathrm{impact}(i,\ j)}, & \mathrm{impact}(i,\ j) < 0 \end{cases}. \tag{3}$$

For the sake of legibility we present the consistency values normalized and the stability values normalized and logarithmized according to

$$\mathrm{NormAltConsistency}(Alt_i) = \frac{\mathrm{AltConsistency}(Alt_i)}{\left|\{Alt_j \middle| \forall j\}\right|} \tag{4}$$

and

$$\mathrm{NormAltStability}(Alt_i) = 9\frac{\log_{10}[\mathrm{AltStability}(Alt_i)]}{2[\left|\{Alt_j \middle| \forall j\}\right| - 1]}. \tag{5}$$

In Figure 5 we observe the influence and stability for all activities.

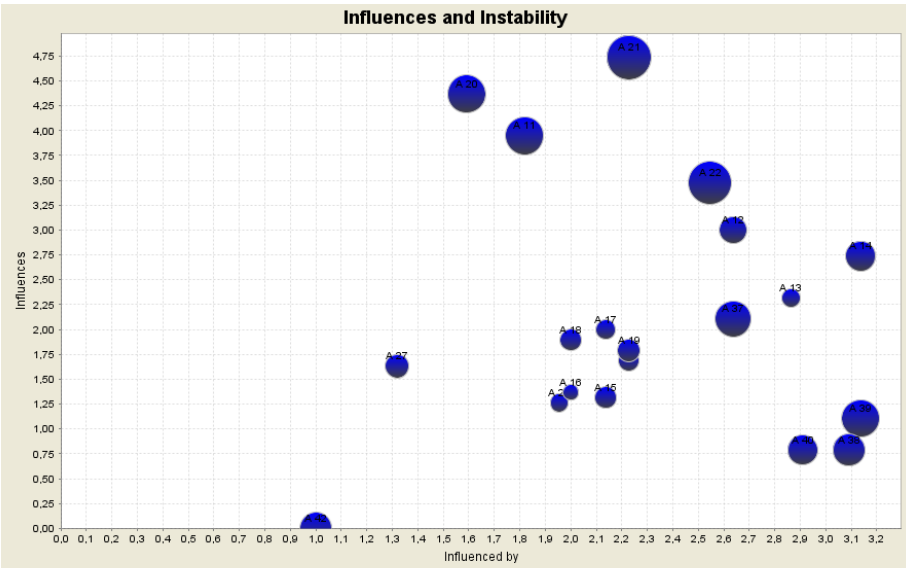


Figure 5. Top view contains all elements of the plan. Bottom view contains all activities ranked by how much they influence and are influenced by other activities. Ellipse size correspond to instability (large ellipse implies high instability).

We may now create new alternatives, mostly alternative activities to realize some supporting effect, but it is also possible to consider new alternative supporting effects or decisive conditions to reach the intended military end state. For each new alternative it is important to note which activity, supporting effect or decisive condition it belongs to, *i.e.*, which other alternatives is this an alternative for.

These new alternative are introduced into the CIM and all new matrix values must be assigned. After this is done new consistency and stabilities can be calculated. This procedure can be repeated until satisfaction is reached and a suitable set of alternatives are at hand. If a new alternative gives good consistency and stability for some element of the plan this may be found satisfying and work may continue on finding new alternatives for other elements. However, if the new alternative gives poor values we must try to find further alternatives for the same element. When this process has been repeated until satisfaction is reached for all elements of the plan, we have a CIM with several alternatives for many of the activities, supporting effects and decisive conditions, Figure 6.

The CIM is now expanded with several alternatives activities, supporting effects and decisive conditions (*e.g.*, $A_{12}$, $SE_{12}$ and $DC_{12}$). The alternative activity may for example be a change in timing or intensity of an activity in order to improve on the plan. When this is done we may evaluate the plan with different alternative activities.

| | | Military End State | $DC_1$ | | $DC_2$ | $SE_1$ | | $SE_2$ | $A_1$ | | $A_2$ | $A_3$ | $A_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $DC_{11}$ | $DC_{12}$ | | $SE_{11}$ | $SE_{12}$ | | $A_{11}$ | $A_{12}$ | | | |
| $DC_1$ | $DC_{11}$ | 5 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | $DC_{12}$ | 6 | 0 | 0 | 6 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $DC_2$ | | 8 | 6 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $SE_1$ | $SE_{11}$ | 0 | 5 | 4 | 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -3 |
| | $SE_{12}$ | 0 | 6 | 3 | 2 | 0 | 0 | 2 | 0 | 0 | 0 | 0 | 2 |
| $SE_2$ | | 0 | 5 | 5 | 8 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| $A_1$ | $A_{11}$ | 0 | 0 | 0 | 0 | 3 | 8 | 3 | 0 | 0 | 4 | -2 | -3 |
| | $A_{12}$ | 0 | 0 | 0 | 0 | 7 | 9 | 1 | 0 | 0 | 2 | 2 | 3 |
| $A_2$ | | 0 | 0 | 0 | 0 | 3 | 1 | -2 | 3 | 1 | 0 | 0 | 2 |
| $A_3$ | | 0 | 0 | 0 | 0 | 3 | 5 | 6 | 0 | 0 | 8 | 0 | 0 |
| $A_4$ | | 0 | 0 | 0 | 0 | 4 | 7 | -2 | -7 | -1 | -2 | 0 | 0 |

Figure 6. Note that the CIM now also contains alternatives for many decisive conditions, supporting effects and activities.

*Leverage Points: Decisive influence from activities*

We can calculate which activities that provide a decisive influence on a particular supporting effect, decisive condition or on the military end state by performing a sensitivity analysis using Dempster-Shafer theory [1] [7]. In this analysis we assume simple frames of discernment for each supporting effect, decisive condition and the military end state with only two possible outcomes, $\Theta = \{\mathbf{Good}, \mathbf{Bad}\}$. Either the desired supporting effect, decisive condition or the military end state is achieved or it is not. The calculation is made by first, for a certain activity $A_k$, calculating the support for the requested $m_{SE_j}(\mathbf{Good})$, $m_{DC_j}(\mathbf{Good})$ or $m_{MES}(\mathbf{Good})$ with $m_{A_i}(\mathbf{Good}) = 1 \ \ \forall i$ and then recalculating the same with $m_{A_k}(\mathbf{Good}) = 0.99$ and $m_{A_i}(\mathbf{Good}) = 1 \ \ \forall i \neq k$. Here, $m_{A_i}(\mathbf{Bad}) = 0 \ \ \forall i$. By selecting these mass functions as input data we will be able to perform numerical differentiation of all supporting effects, decisive conditions and the military end state with respect to each individual activity. The value of these derivatives show the influence of the individual activities on these effects, conditions and end state.

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

Before combining the mass functions we discount them using the impact values of the CIM. This ensures that each activity influences the supporting effect to its proper degree. We have

$$m_{A_i}^{\alpha_{kj}}(X) : \begin{cases} \alpha_{kj} m_{A_i}(\mathbf{Good}), & X = \mathbf{Good} \\ \alpha_{kj} m_{A_i}(\mathbf{Bad}), & X = \mathbf{Bad} \\ 1 - \alpha_{kj} m_{A_i}(\mathbf{Good}) - \alpha_{kj} m_{A_i}(\mathbf{Bad}), & X = \Theta \end{cases} \tag{6}$$

where the discounting factor

$$\alpha_{kj} = \frac{\text{impact}(k, j)}{10}. \tag{7}$$

This is a generalization where discounting factors may assume values less than 0, i.e., $\alpha_{kj} = \{-0.9, -0.8, -0.7, \ldots, 0.9\}$.

These discounted mass functions are combined using Dempster's rule. For every supporting effect $m_{SE_j}$ we have

$$m_{SE_j}(\mathbf{Good}) = \max\left[0, \frac{m^*_{SE_j}(\mathbf{Good})}{m^*_{SE_j}(\mathbf{Good}) + m^*_{SE_j}(\mathbf{Bad}) + m^*_{SE_j}(\Theta)}\right]$$
$$m_{SE_j}(\mathbf{Bad}) = \max\left[0, \frac{m^*_{SE_j}(\mathbf{Bad})}{m^*_{SE_j}(\mathbf{Good}) + m^*_{SE_j}(\mathbf{Bad}) + m^*_{SE_j}(\Theta)}\right] \tag{8}$$

where

$$m^*_{SE_j}(\mathbf{Good}) = \prod_i \left[1 - \frac{\text{impact}(i, j)}{10} m_{A_i}(\mathbf{Bad})\right]$$
$$- \prod_k \left[1 - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Good}) - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Bad})\right]$$
$$m^*_{SE_j}(\mathbf{Bad}) = \prod_i \left[1 - \frac{\text{impact}(i, j)}{10} m_{A_i}(\mathbf{Good})\right] \tag{9}$$
$$- \prod_k \left[1 - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Good}) - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Bad})\right]$$
$$m^*_{SE_j}(\Theta) = \prod_k \left[1 - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Good}) - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Bad})\right]$$

where $m_{A_k}(\mathbf{Bad}) = 0$. We get

$$m_{SE_j}(\mathbf{Good}) = \max\left\{0, 1 - \prod_k \left[1 - \frac{\text{impact}(k, j)}{10} \cdot m_{A_k}(\mathbf{Good})\right]\right\}$$
$$m_{SE_j}(\mathbf{Bad}) = 0 \tag{10}$$

where

$$m_{SE_j}(\mathbf{Unknown}) = 1 - m_{SE_j}(\mathbf{Good}), \tag{11}$$

and $0 \le m_{SE_j}(\mathbf{Good}) \le 1$, $0 \le m_{SE_j}(\mathbf{Bad}) \le 1$ and $m_{SE_j}(\mathbf{Good}) + m_{SE_j}(\mathbf{Bad}) \le 1$.

We have chosen to cap the value of $m_{SE_j}(\mathbf{Good}) \ge 0$ and not handle the case where $m_{SE_j}(\mathbf{Good}) < 0$. Such negative mass functions are called inverse simple support functions [8]. While it is possible to include them in the analysis we have chosen not to do so here.

By substituting $\{m_{A_k} \to m_{SE_j}\}$ in Eq. (9) and $\{m^*_{SE_j} \to m^*_{DC_j}\}$ in Eqs. (6,7) and $\{m_{SE_j} \to m_{DC_j}\}$ in Eq. (8) we may calculate $m_{DC_j}(\mathbf{Good})$ and $m_{DC_l}(\mathbf{Bad})$. Furthermore, by substituting $\{m_{A_k} \to m_{DC_j}\}$ in Eq. (9) and $\{m^*_{SE_j} \to m^*_{MES}\}$ in Eqs. (6,7) and $\{m_{SE_j} \to m_{MES}\}$ in Eq. (8) we may calculate $m_{MES}(\mathbf{Good})$ and $m_{MES}(\mathbf{Bad})$. We get

$$m_{DC_j}(\mathbf{Good}) = \max\left\{0,\ 1 - \prod_k \left[1 - \frac{\text{impact}(k,\ j)}{10} \cdot m_{SE_k}(\mathbf{Good})\right]\right\}$$
$$m_{DC_j}(\mathbf{Bad}) = 0 \tag{12}$$

and

$$m_{MES}(\mathbf{Good}) = \max\left\{0,\ 1 - \prod_k \left[1 - \frac{\text{impact}(k,\ j)}{10} \cdot m_{DC_k}(\mathbf{Good})\right]\right\}$$
$$m_{MES}(\mathbf{Bad}) = 0. \tag{13}$$

When these calculations are performed we may directly calculate which activities are of decisive influence for a particular supporting effect, decisive condition or for the military end state.

For each activity $A_k$ and every supporting effect $SE_j$ we can calculate

$$\text{DecisiveInfluence}(A_k \to SE_j)$$

$$= \left\{\left[m_{SE_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_i}(\mathbf{Good}) = 1 & \forall i \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right] - \left[m_{SE_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_k}(\mathbf{Good}) = 0.99 & \\ m_{A_i}(\mathbf{Good}) = 1 & \forall i \neq k \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right]\right\}. \tag{14}$$

By substituting $\{m_{SE_j} \to m_{DC_j}\}$ in Eq. (14) we calculate for each activity $A_k$ and each decisive condition $DC_j$ which influence this activity has on this decisive condition,

$$\text{DecisiveInfluence}(A_k \to DC_j)$$

$$= \left\{\left[m_{DC_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_i}(\mathbf{Good}) = 1 & \forall i \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right] - \left[m_{DC_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_k}(\mathbf{Good}) = 0.99 & \\ m_{A_i}(\mathbf{Good}) = 1 & \forall i \neq k \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right]\right\}. \tag{15}$$

However, most interesting is perhaps the influences the different activities have on the plan at large, *i.e.*, the military end state. By substituting $\{m_{SE_j} \to m_{MES}\}$ in Eq. (14) we calculate for each activity which influence it has on the military end state, $\text{DecisiveInfluence}(A_k \to MES)$. Since we only have one military end state we get one value for each activity and may thus rank these by the calculated

$$\text{DecisiveInfluence}(A_k \to MES)$$

$$= \left\{\left[m_{DC_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_i}(\mathbf{Good}) = 1 & \forall i \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right] - \left[m_{DC_j}(\mathbf{Good})\ \middle|\ \begin{matrix} m_{A_k}(\mathbf{Good}) = 0.99 & \\ m_{A_i}(\mathbf{Good}) = 1 & \forall i \neq k \\ m_{A_i}(\mathbf{Bad}) = 0 & \forall i \end{matrix}\right]\right\}. \tag{16}$$

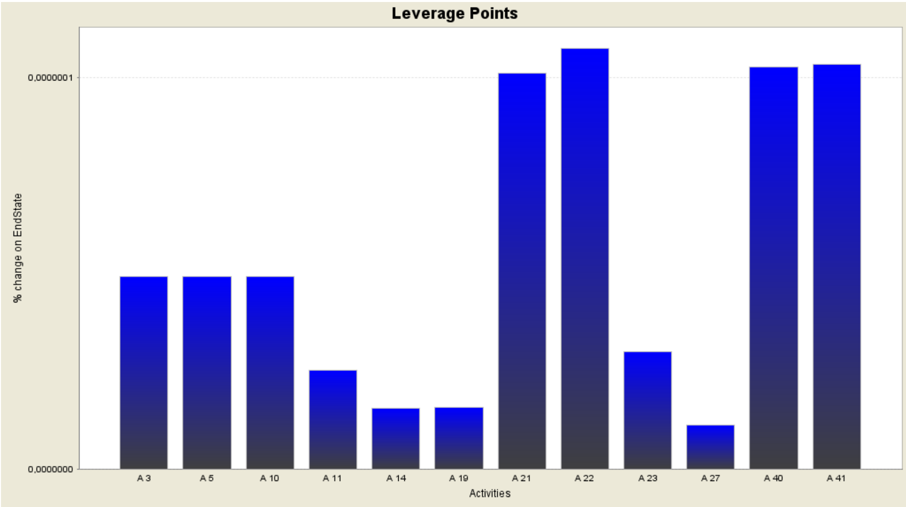


Figure 7. Leverage points show the impact of success of each activity on the success of the military end state. Activities $A_{21}$, $A_{22}$, $A_{40}$ and $A_{41}$ have high impact.

These calculations can be made both with the initial CIM where each activity has only one alternative and with the later CIM where some activities have two or more alternatives. If the calculations are made for the later CIM then we must carry out the calculation separately for each alternative $i$, *e.g.*, for activity $A_k$ and military end state

$$\forall i. \qquad \text{DecisiveInfluence}(A_{ki} \rightarrow MES) \tag{17}$$

after which the decisive influence by activity $A_k$ on the military end state is calculated as

$$\text{DecisiveInfluence}(A_k \rightarrow MES) = \max_i\{\text{DecisiveInfluence}(A_{ki} \rightarrow MES)\} . \tag{18}$$

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

### Plan refinement

We may now evaluate the current plan and propose incremental changes to the plan by performing a CIM analysis, or make a complete CIM analysis to obtain the optimal plan according to the given CIM. These alternative modes of procedure are based on the same analysis and only represent different ways to

| | $DC_1$ | $DC_2$ | $SE_1$ | $SE_2$ | $A_1$ | $A_2$ | $A_3$ | $A_4$ | Consis-tency | Stability |
|---|---|---|---|---|---|---|---|---|---|---|
| Plan 1 | $DC_{11}$ | $DC_2$ | $SE_{11}$ | $SE_2$ | $A_{11}$ | $A_2$ | $A_3$ | $A_4$ | 63 | -3,43 |
| Plan 2 | $DC_{11}$ | $DC_2$ | $SE_{11}$ | $SE_2$ | $A_{12}$ | $A_2$ | $A_3$ | $A_4$ | 77 | -3,47 |
| Plan 3 | $DC_{11}$ | $DC_2$ | $SE_{12}$ | $SE_2$ | $A_{11}$ | $A_2$ | $A_3$ | $A_4$ | 79 | -3,44 |
| Plan 4 | $DC_{11}$ | $DC_2$ | $SE_{12}$ | $SE_2$ | $A_{12}$ | $A_2$ | $A_3$ | $A_4$ | 90 | -3,34 |
| Plan 5 | $DC_{12}$ | $DC_2$ | $SE_{11}$ | $SE_2$ | $A_{11}$ | $A_2$ | $A_3$ | $A_4$ | 65 | -3,45 |
| Plan 6 | $DC_{12}$ | $DC_2$ | $SE_{11}$ | $SE_2$ | $A_{12}$ | $A_2$ | $A_3$ | $A_4$ | 79 | -3,50 |
| Plan 7 | $DC_{12}$ | $DC_2$ | $SE_{12}$ | $SE_2$ | $A_{11}$ | $A_2$ | $A_3$ | $A_4$ | 79 | -3,30 |
| Plan 8 | $DC_{12}$ | $DC_2$ | $SE_{12}$ | $SE_2$ | $A_{12}$ | $A_2$ | $A_3$ | $A_4$ | 90 | -3,20 |

Figure 8. A list over the plans with consistency och stability values. Both plan 4 and plan 8 have high consistency (= 90). However, plan 8 have the higher stability, making this the preferred plan. [The stability values are logarithmized and normalized (≤ 0,00); The elements are from the CIM in Figure 6].

sort evaluated instances ($I$) of the plan. In each mode of procedure a complete CIM analysis is performed.

The evaluation is performed by calculating consistency and stability for each possible instance of the plan, according to[2]

$$\text{Consistency}(I) = \sum_{i \in I} \sum_{j \in I} \text{impact}(i, j) \tag{19}$$

and

$$\text{Stability}(I) = \prod_{i \in I} \prod_{\substack{j \in I \\ j > i}} \frac{\min[\text{CV}(i, j), \text{CV}(j, i)]}{\max[\text{CV}(i, j), \text{CV}(j, i)]}. \tag{20}$$

In Figure 8 the eight alternative plans of Figure 6 are evaluated by consistency and stability.

## Conclusions

We have demonstrated that it is possible to evaluate and refine a plan within EBP using morphological analysis of the CIM. Furthermore, we show that we can find the decisive influences from activities by using Dempster-Shafer theory

[2]Eq. (19) and Eq. (20) were derived through reverse engineering by the first author in 1995 (unpublished at the time).

and sensitivity analysis. By doing both we can find any weaknesses and all strengths of the plan as described by the CIM before the effect based execution phase.

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## References

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

[2] Effects based approach to multinational operations, Concept of operations with implementation procedures. Version 1.0, United States Joint Forces Command, Suffolk, VA, USA, 31 July 2006.

[3] Jerome C. Glenn and Theodore J. Gordon. Futures Research Methodology – Version 2.0. American Council for the United Nations University, Washington, DC, USA, 2003.

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

[5] Incorporating and extending the UK military effects-based approach. Joint Doctrine Note (JDN 7/06), Development, Concepts and Doctrine Centre (DCDC), Ministry of Defence, Shrivenham, Swindon, Storbritannien, 2006.

[6] Johan Schubert, Mattias Wallén, and Johan Walter. Morphological refinement of effect based planning. In *Proceedings of the Third International Conference on Military Technology,* number Or21, Stockholm, Sweden, June 14–15, 2007.

[7] Glenn Shafer. *A Mathematical Theory of Evidence.* Princeton University Press, Princeton, NJ, 1976.

[8] Philippe Smets. The canonical decomposition of a weighted belief. In *Proceedings of the Fourteenth International Joint Conference on Artificial Intelligence,* vol. 2, pp. 1896–1901, Montréal, Canada, August 20–25 1995.

[9] Edward A. Smith. *Complexity, networking, and effects-based approaches to operations.* U.S. Department of Defense CCRP, Washington, DC, 2006.

[10] Fritz Zwicky. *Discovery, invention, research through the morphological approach*. Macmillan, New York, NY, 1969.