The Application of Modelling and Simulation in Support of the Operations Process

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ABSTRACT

Military interventions are aimed at influencing the complex, increasingly hybrid, dynamics of conflicts to create a transition to a desired end-state. To this end, a commander has to translate a desired end-state to tactical activities conducted by the units under his command. A difficult task lies in understanding the interactions between actors and factors that shape the conflict and how these can be influenced to shift the dynamics to a favourable, preferably self-regulating state. A commander will have to make inferences about effects and future behaviour while the current situation is deeply uncertain. Modelling and simulation (M&S) could serve as a capability to structure information and derive insights through simulation. However, M&S methods, such as System Dynamics' models, are not frequently used. This paper reports results from an on-going study conducted for the Netherlands Armed Forces that aims to assess if and how M&S could be applied as part of the operational decision making process. An example concerning military interventions is presented in which exploratory system dynamics modelling and analysis (ESDMA) is used to explore plausible futures under deep uncertainty. The study is linked to the subject of the current NATO-MSG-124 on "Developing Actionable Data Farming Decision Support for NATO".[1]

1.0 INTRODUCTION

From a 'systems perspective' most contemporary military operations are focussed on creating self-regulating dynamics in a system that create a stable situation in an area in which specific conditions (such as human rights and security) are met. A self-regulating state of the system is desirable as this would mean that the presence of the intervening force is no longer necessary. The objectives of such an operations are there for much broader than achieving a military end-state (ie. defeating the enemy), but includes shaping the behaviour of many different actors and factors in an attempt to achieve both a military as well as a strategic/political desired end state. To this end a 'comprehensive approach' is often favoured which focuses on Military, Political, Economic and Civil factors and can combine the efforts of a host of governmental and non-governmental organizations (NATO, 2010). Such operations are extremely challenging because they take places in highly complex and adaptive systems which are often far from a stable state.

During a mission a commander has to make decisions on how to deploy the resources at his (or her) disposal to carry out tactical activities in order to achieve the strategic objectives that were set. This is referred to as the operational level of decision making. Operational decision making is an on-going process of assessment of the situation, development and assessment of potential courses of action, decision-making and execution

[1] Sections of this paper have appeared in an earlier conference draft: Veldhuis GA, de Reus N, Logtens T, Pallaske G and Carnohan S. 2016. The application of modelling and simulation in support of operational decision making during land operations. Proceedings of the 34th International Conference of the System Dynamics Society, Delft, The Netherlands, July 17 – July 21, 2016

of a selected course of action. Often this process is managed according to fixed process steps such as the NATO Comprehensive Operations Planning Directive (COPD) (NATO, 2010).

Modelling and simulation (M&S) could serve as a capability for a commander during the decision-making process. Benefits may include: structuring available information, deriving insight in the dynamics of the situation and a-priori impact assessment of different courses of action. Within the Netherlands armed forces, qualitative techniques, such as Causal Loop Diagrams and problem structuring methods such as MARVEL are used to this end (Barros & Monsuur, 2011; Heesmans, 2008; Veldhuis et al. 2015). However, the simulation capabilities of M&S methods (such as stock-and-flow models) are normally not used within the operational decision making process. This paper discusses some results from an on-going study being conducted for the Netherlands armed forces that aims to assess how M&S, specifically Exploratory System Dynamics Modelling and Analysis, can be used within the operational decision making process.

This paper is structured as follows. First, the potential of M&S in operational decision making is discussed based on the result of workshops with project stakeholders. Secondly, we discuss a small example application to learn more about how M&S could offer support in practice. The case includes a demonstrator model of a counter-insurgency type conflict that was developed using participatory model building sessions known as group model building (Vennix, 1996). Several courses of action were analysed using the Exploratory modelling and analysis approach (Kwakkel & Pruyt, 2013). The paper concludes with lessons learned and a way ahead.

2.0 OPERATIONAL LEVEL DECISION MAKING AND MODELLING AND SIMULATION

A series of brainstorm sessions was organised with military stakeholders to identify which aspects of the operations process might benefit most from M&S support. The Design, Planning and Assessment processes (see Figure 1) were identified as showing the most potential. In these processes a need exists for in-depth analyses of relevant actors and factors. Such an analysis is complex in comprehensive operations since it requires the integration of many military and non-military factors in decision-making. During the workshops it was concluded that the effects of manoeuvre/kinetic warfare can be assessed more confidently by the military subject matter experts (although simulation is not currently used during operations) while determining the effects of comprehensive interventions is perceived to be more difficult. The stakeholders concluded that M&S could offer much needed assistance in this challenge. From this starting point it was investigated how the application of M&S could fit within the existing organization (see Figure 1).

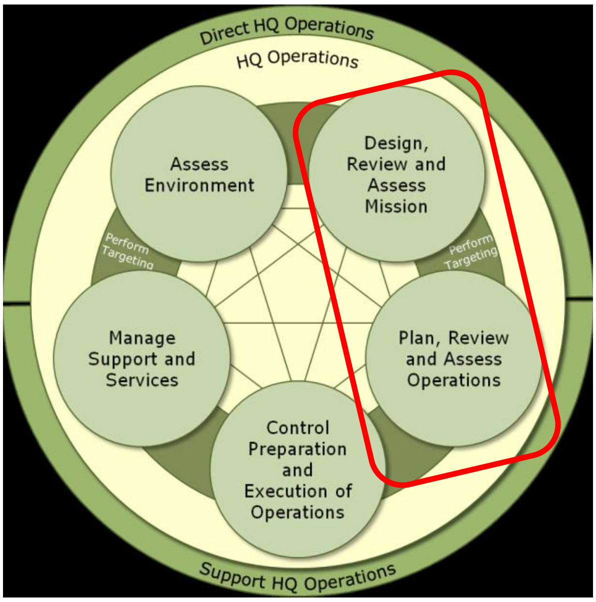

Figure 1 The headquarter' Operations process (KL, 2014)

2.1 Operational processes

In this section we will discuss the operational processes and the possible role of M&S. In the remainder of the paper we will refer to the combination of Design, Planning and Assessment as operational decision making.

Design

The aim of mission design is to identify mission objectives and relevant players and a develop a concept for realization of the objectives, planning of the operation and guidance of subordinate commanders. This is called a concept of operations (ConOps). It is part of the commander's operations plan (OPLAN) which describes the intended course of the mission and what operations are required and which capacities are required to reach the foreseen objectives, in concert with other actors. The criteria for success are defined as Measures Of Effectiveness (MOEs) and Measures Of Performance (MOPs) are defined for to assess the effectiveness of operations.

Planning

Within Netherlands Armed Forces one of the important planning processes for land operations is the so-called the Tactical Decision-making Model globally shown in the **Error! Reference source not found.**. On a process level the TBM is similar to the NATO Operational Planning Process or the UN Integrated Missions Planning Process (see KL, 2011; MoD 2013). Staff members in a so-called 'plans cell' execute the TBM in order to plan operations and direct the activities of the subordinate units in order to reach the desired objectives. The plans cell is supported by analyses from staff members in the 'environment cell'.

Assessment

The commander wants to know the status of the mission and which guidance he should give to his staff. Assessment takes place at different levels within the staff processes, namely at mission level and operations level.

- At mission level the commander judges the progress of the operations plan (OPLAN), either periodically or when unforeseen changes in the situation occur. The aim of assessment is to look into possible changes of the (high level) mission design in order to exploit positive factors or mitigate negative factors. This might result in starting additional planning activities.
- Operation assessment is minimally done after each operation within a mission in order to judge if the operation was successful, for longer term operations, assessment can be done more frequently.

Figure 2 shows the different steps in the operations process. As can be seen two planning levels are distinguished: conceptual planning and detailed planning. Conceptual planning deals with strategic choices like architectural/functional design of a mission while detailed planning is concerned with filling in the details and answering questions 'how to' performs the operation.

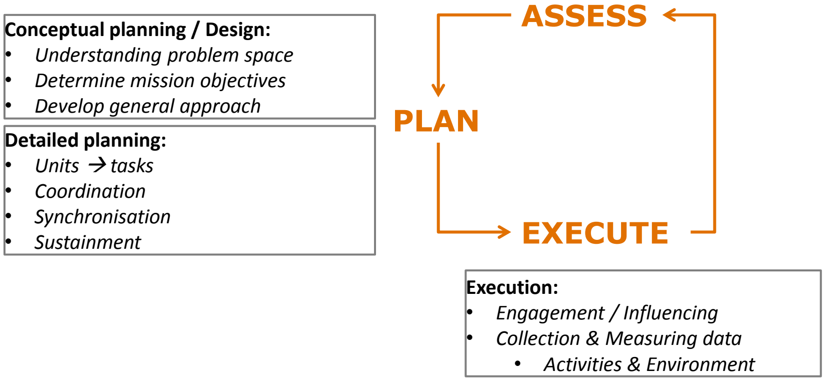

Figure 2 the operations cycle

2.2 Possibilities for M&S

During a follow up brainstorm it was concluded that the same types of support could be identified for the processes Design, Planning and Assessment. The differences are mainly in the level (mission vs operation and preparatory mission design vs operations planning).

Summarising, the main categories of possible M&S-based support are:

- Giving insight into factors and actors in the mission area and their interrelations. These should consist of the Human Terrain and Information terrain as well as the Physical Terrain and are usually summarized under the term PMESII-PT (Political, Military, Economic, Social, Infrastructural, Information, Physical Environment and Time).
- Enabling reviewing the impact of possible own interventions (COAs), usually summarised under the term DIME (Diplomatic, Information, Military, Economic) interventions on the PMESII-PT factors.

We gathered initial thoughts on implementing M&S for the two categories described above. A key point from the discussion that followed can be summarized by the phrase is *'all models are wrong, but some are useful'* (Box, 1979). The output of any (simulation) model should be viewed with some degree of caution especially if human behaviour is involved in the simulation. It is important that users do not view model outcomes as predictions but as investigations of plausible futures that can serve as an aid to their thinking. The usefulness of such models lies in the fact that they can help objectify the ideas (or mental models) of human decision makers. This does require that a model is not used 'off-the-shelve' but that the decision maker's staff is involved in the process of building and using the model. This will mean that a successful application of M&S will need to be integrated within the existing organization of a HQ staff organization and processes. In the next section we will describe a high level design on what this integration might look like.

2.3 A decision support environment

In order to support the ideas stated in the previous section, a M&S-based decision support environment is proposed. Such an environment should facilitate developing and using models as an integrated aspect of the operational process. This means knowledge of the operational environment and mission accumulates within simulation models and can be called upon to assist decision-making when needed. Our case study decision support environment is named MEMPHIS (Military Environment Modelling with Physical and Human terrain Information Services). See Figure 3.

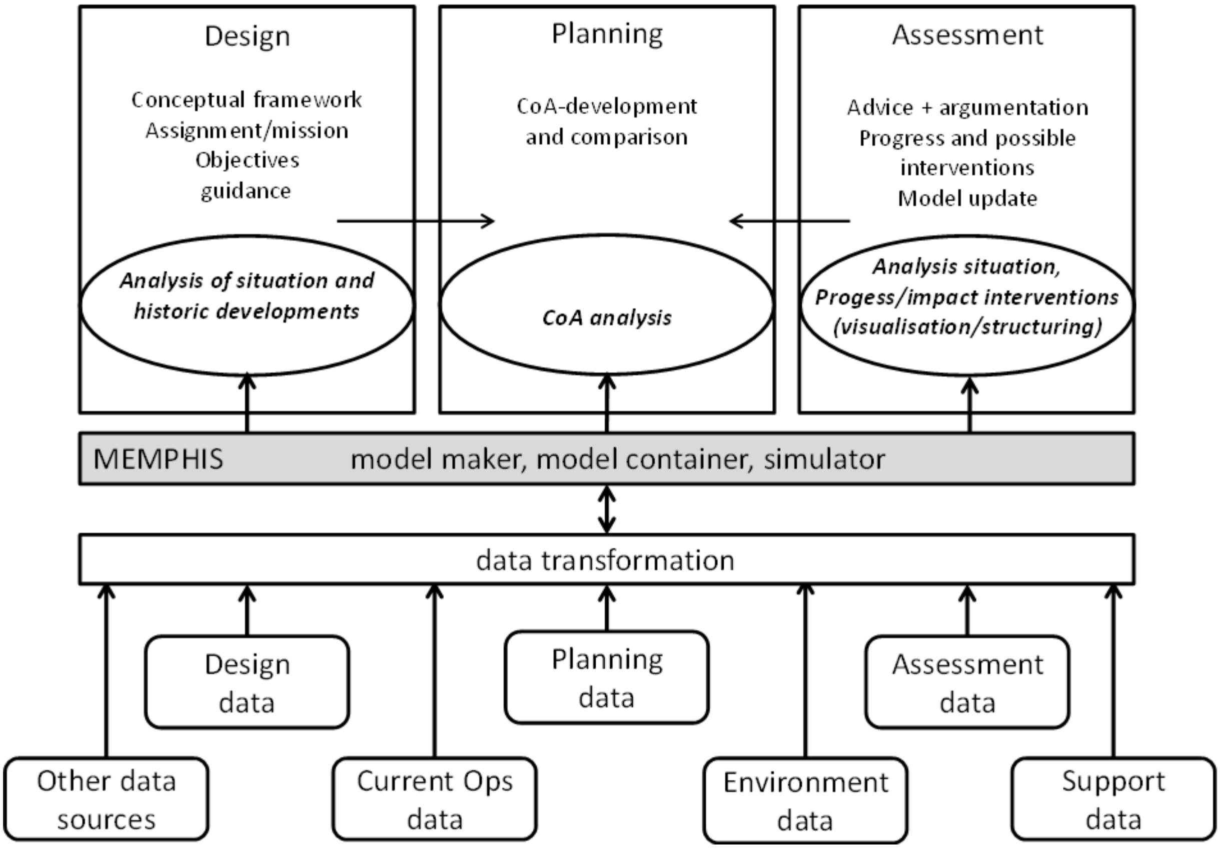

Figure 3 the MEMPHIS concept visualized

A fully developed MEMPHIS environment should enable military analysts to:

- Integrate information from existing processes and products within the HQ.
- Build models, either based on existing building block models for PMESII-PT/DIME, or newly developed structure.
- Define and run experiments

- Store and retrieve simulation results
- Provide access to model structure and simulation results in the form of analytics and visualizations at different levels of complexity and at different stages in the operational process.

Approaches similar to MEMPHIS have been described in literature. Examples are (1) a former DARPA program on Conflict Modelling, Planning, and Outcomes Exploration (COMPOEX) (Kott et al., 2010) and (2) an ARL project resulting in the NOEM model (National Operational Environment model) (Salerno et al). However, such environments are not freely accessible and the underlying models would be difficult to harness since they often include tens of thousands of variables. The MEMPHIS approach favours smaller models that are more easy to build, share and comprehend. For this reason a demonstrator is being developed at TNO where as a first approach System Dynamics, Exploratory Modelling and Analysis and Group model building are combined. The MEMPHIS idea however doesn't depend on the type of modelling method, instead of SD also agent based or multi-modelling could have been used.

An approach as MEMPHIS depends on various prerequisites. It requires domain experts and data about the environment and about a units own actions to be available. In practise, such data might not be readily available and might be stored in ways which makes retrieval difficult (e.g. powerpoint slides). Furthermore, The use of an approach as MEMPHIS requires skills and knowledge (e.g. about M&S) which are not commonly available within the staff. These and other aspects should be considered at a future date.

2.4 Using models under deeply uncertain conditions

'War is the realm of uncertainty; three quarters of the factors on which action is based are wrapped in a fog of greater or lesser uncertainty.'

- Carl van Clausewitz (1873)

Military operations are executed in an environment with many uncertainties. Or better described by Betros (1991) as: "No one can define how a human enemy will reason or react, nor is it possible to master every fact pertaining to the physical environment. Changing situations introduce added uncertainty that may confound the effort to see through the fog of war. The environment of wartime uncertainty leaves commanders but one choice: they must structure their organizations to cope with incomplete information; those who excel at it improve their chances of success in battle." Considering this statement, M&S for operational decision-making should be able to deal with the deeply uncertain conditions common to military operations. Military operations can be defined as being deeply uncertain: "a situation where analysts do not know, or the parties to a decision cannot agree on: i) the appropriate conceptual models that describe the relationships among the key driving forces that will shape the long-term future, ii) the probability distributions used to represent uncertainty about key variables and parameters in the mathematical representations of these conceptual models, and/or how to value the desirability of alternative outcomes." (Lempert, 2003). This description of deep uncertainty is especially applicable to non-conventional military operations that influence or are influenced by population behaviours and decisions (e.g. Hybrid warfare, Irregular Warfare, Counter-Insurgency and other Peace Support Operations).

Bankes (1993) defined Exploratory Modelling and Analysis (EMA) as a modification to traditional sensitivity analysis to cope with deep uncertainty in (policy) problems. EMA is used with System Dynamics models, creating Exploratory System Dynamics Modeling and Analysis (ESDMA) (Pruyt & Kwakkel, 2014). EMA aims to explore plausible futures using a large scenario analysis combined with an extensive sensitivity analysis, leading to a large amount (called an ensemble) of plausible futures that have to be analysed. This characteristic distinguishes it from traditional uncertainty analysis; the model output is an ensemble of plausible futures and not a probability distribution. This means that EMA is not a prediction nor estimation of likeliness: All model runs are plausible and should be analysed with equal interest, whereas traditional uncertainty analysis tries to define confidence intervals of the output.

3. EXAMPLE CASE: AN OPERATIONAL VIEW ON THE SYSTEM DYNAMICS OF COUNTER-INSURGENCY

In order to make a start with the proof of concept of the MEMPHIS approach an example case was developed. We developed a SD model that describes relevant PMESII-PT system parameters and DIME type interventions for a counter-insurgency (COIN) type operation. To create illustrative examples we focused on COA analysis (see Figure 3). By using a case based approach we were able to experiment with and refine some aspects of the MEMPHIS approach. In total, three exploratory interviews, two facilitated workgroups (so-called 'group model building sessions') and an evaluation session were held. The lead time and available man-hours were limited for this project, this meant that that our aim was to construct a model which reflected the data gathered but did not aim to provide a fully validated and calibrated model. Specifically our goal was to:

- Experiment with developing a generic SD model of a mission type suitable for conceptual planning at the operational level.
- Evaluate developing a SD model based on knowledge available within an operational unit using the participatory GMB approach. To this end project stakeholders were invited that currently or in the past served as Operational analyst, Intelligence analyst, Staff chief or Soldier.
- Use the model as a testbed to develop and evaluate EMA techniques;
- Develop example case to demonstrate the added value of the approach. Demonstrate the added value of the approach to project stakeholders and receive feedback in an early stage of development.

For a more thorough discussion of the example case, the model and the process we kindly refer the reader to an earlier paper: Veldhuis GA, de Reus N, Logtens T, Pallaske G and Carnohan S. 2016. The application of modelling and simulation in support of operational decision making during land operations. Proceedings of the 34th International Conference of the System Dynamics Society, Delft, The Netherlands, July 17 – July 21, 2016.

The final results of the example case were briefed to the stakeholders involved in the GMB sessions followed by a discussion on usefulness and way ahead. We will discuss their response in the next section.

3.1 The example model: 'faction dynamics'

We used Ventana systems Vensim DSS to develop the model. The interaction amongst 5 different actors is modelled ('agents'): Three factions, a coalition (representing a foreign intervention force) and a regime. Several key dynamics are included in the model: Economic development, Basic needs fulfilment, Satisfaction with other actors, Mobilization, Violence, Collateral damage and Refugees. In the model the factions make their own decision in response to the user input. The user controls the decisions made by the regime and coalition. The paper does not aim to present a dynamic theory on COIN, therefor we will only briefly discuss some aspects of the model.

The three factions are modelled identically. Each faction consist of a number of stock variables that create the internal dynamics of the faction and its interaction with other actors. Each faction has a population that uses privately owned resources and public services provided by the regime to generate an income. This income fulfils the needs of the population to a certain extent. The population is split into civilians, (Part-time) combatants and, optionally, refugees. The civilians work to generate income. Combatants can engage in fighting with other actor and seize resources from other factions. Combatants are mobilized from the civilian population if the faction identifies another faction as a target or if they feel threatened by any of the other actors (Figure 4).

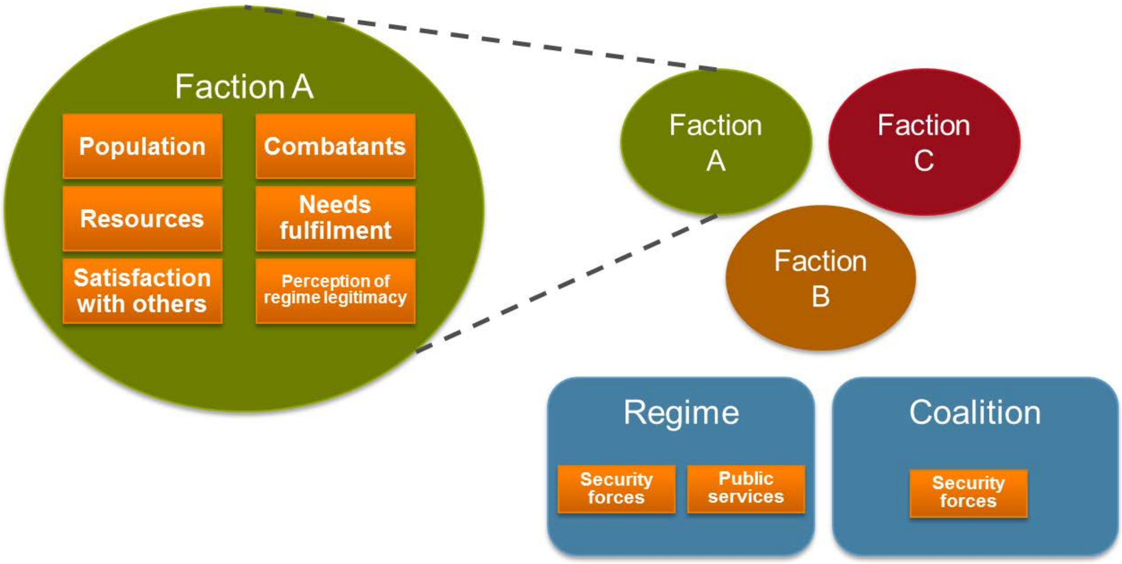

Figure 4 Overview of different actor in the model and their most important variables

Each faction forms an opinion of the other two factions and state actors. The attitude towards another faction is based on economic motives (the relative income position) and grievances (past violent acts against the faction). In addition, each faction forms an opinion of the regime and coalition. Issues such as violence (limited security), limited public services and forced migration due to basic needs not being met will cause the faction to perceive a regime as less legitimate.

If a faction is dissatisfied with an actor or if they perceive the regime to be illegitimate they can decide to commit violent acts. Violent acts are committed by the combatants of the faction. Violent acts amongst factions can be used to seize resource from one another and thus expand the economic power of a faction. A violent act has a number of secondary effects: loss of life on both sides, collateral damage to both private and public resources and an increase in grievances (Figure 6). The outcome of a violent act is based on the number of combatants on the defending side and the offensive side (‘the force ratio’). Violence of a faction towards the regime or coalition is modelled in a similar way, although resources are not seized from the regime or coalition.

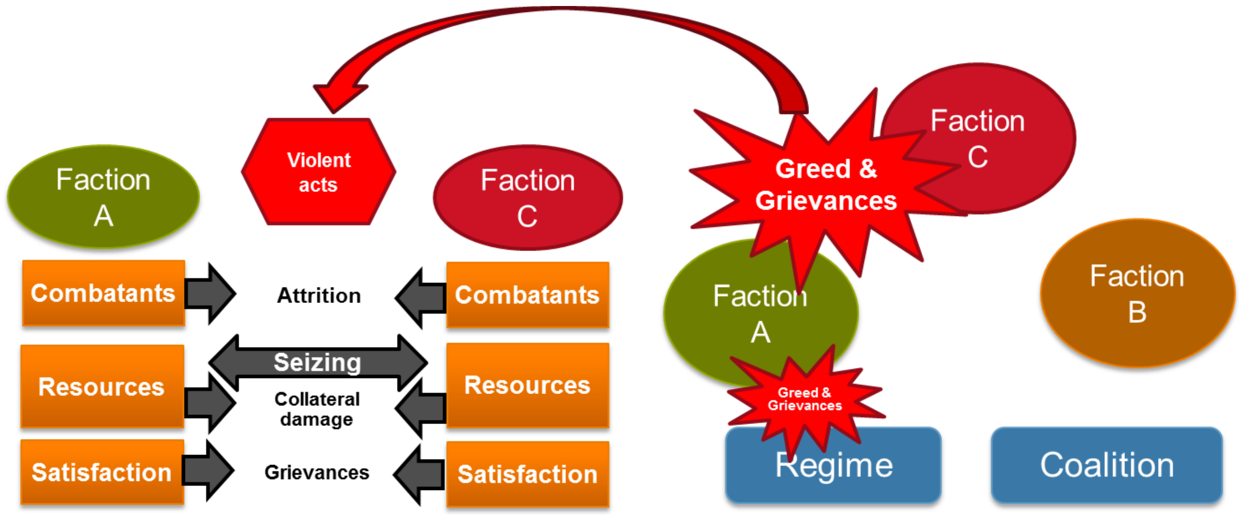

Figure 5 Violent acts between two factions

To be able to experiment with the model we have included policies based on the input collected during the GMB sessions. The following policies were included across DIME categories:

- **D**iplomatic
  - **Reconciliation** – reduces the dissatisfaction of factions with other factions.
- **I**nformation
  - **Controlling the narrative** – reduces to what extent the regime and coalition are blamed for events occurring, such as violence or refugees.
- **M**ilitary
  - **Force size** – the number of troops available
    - **Policing** – the fraction of the force dedicated to policing operations.
    - **Offensive** (‘Combat’) – the fraction of the force dedicated to offensive combat operations
      - **Target** – The faction(s) that is(are) targeted by the offensive operations of the regime or coalition.
- **E**conomic
  - **Economic development** (e.g. Provincial reconstruction teams)
    - Force size – the size of the force that can provide economic assistance by creating resources
      - **Focus on public service resources** - the fraction of the PRT focused on creating public service resources.
      - **Focus on privately owned resources** – the fraction of the provincial reconstruction team focused on creating privately owned resources.
        - **Target** – The faction(s) that benefit from the PRT work focused on privately owned resources.

3.2 Analysis using EMA

Establishing which model structures are valid and which parameter values are accurate might be very challenging for military analyst during a COIN mission. Available information about the dynamics might be limited, especially during an early phase of the deployment. Furthermore, it might be difficult to measure various 'soft' factors. Intelligence assets which could assist in obtaining this sort of information might be scarce. The type of conflicts and the military response is constantly evolving, for this reason the interventions used can be novel (such as the deployment of PRT's in Afghanistan), adding to the uncertainty about their effect. Using ESDMA can help avoid these difficulties. It can also keep focus on what the model is: a means to explore plausible futures and derive implications of policies not a 'crystal ball' that can predict the result of future events. However, analysing the large amounts of data generated by applying EMA can be complex to perform but also communicate. We focus on visualization over other analytical techniques since visualization can make insights accessible to a much larger audience. More sophisticated techniques are useful in the analysis process, such as: clustering, screening analysis, partition trees and discriminant analysis.

For this demonstration we decided to simulate[2] as if was the conflict is already on-going but sill in an escalating phase. Especially 'Faction A' is in dispute with the regime, 'Faction B' is displeased both with the regime and 'Faction B', 'Faction C' is a fence sitter (see **Figure 4** and **Figure 5**).

Together with the policies we have defined uncertainty ranges for 25 of the most important variables across different sectors of the model. In this experiment we used the model structure described in the previous chapter. We have not used alternative model structures, although changing some of the parameters severely influences the activity of certain feedback loops. We will provide an example analysis of the base case and the policy options. The results presented here are strictly intended as a demonstration and not as an actual analysis of COIN operations.

3.2.1 Base case analysis

We start our EMA analysis by reviewing the 'Base case' behaviour of the model. This is the situation in which no intervention will take place. By analysing the base case we can develop a better understanding of the model dynamics under deep uncertainty and identify drivers of desirable and undesirable behaviour. These insights can help formulate policies.

Figure 7 displays the output for two important variables: The total violent acts per month (top) and the fraction of the population that is lost (bottom). The fraction of population lost aggregates the amount of people who left the area as refugees or who were killed during violent acts. The variable violent act describes how many violent incidences occurred between factions and between factions and the regime. Figure 6 shows that a wide range of outcomes is possible under deep uncertainty. Although some plausible futures exists in which the conflict does not escalate, in most cases the conflict develops with an initial escalation over the course of about 30 months after which the region slowly stabilizes. Over this period the loss of population can be sever, as much as 70% and on average around 10% of the population (Figure 6 bottom right). The observation that a broad range of plausible futures leads to escalation and severe loss of life can be a motivation to intervene. The timing of the escalation, in most cases within a few months, can serve as an indication that timely deployment of an intervention is necessary.

[2] To perform the simulations we used Ventana Systems VENSIM in combination with the TUDelft EMA workbench: http://simulation.tbm.tudelft.nl/ema-workbench/contents.html. Analysis was done with SAS JMP.

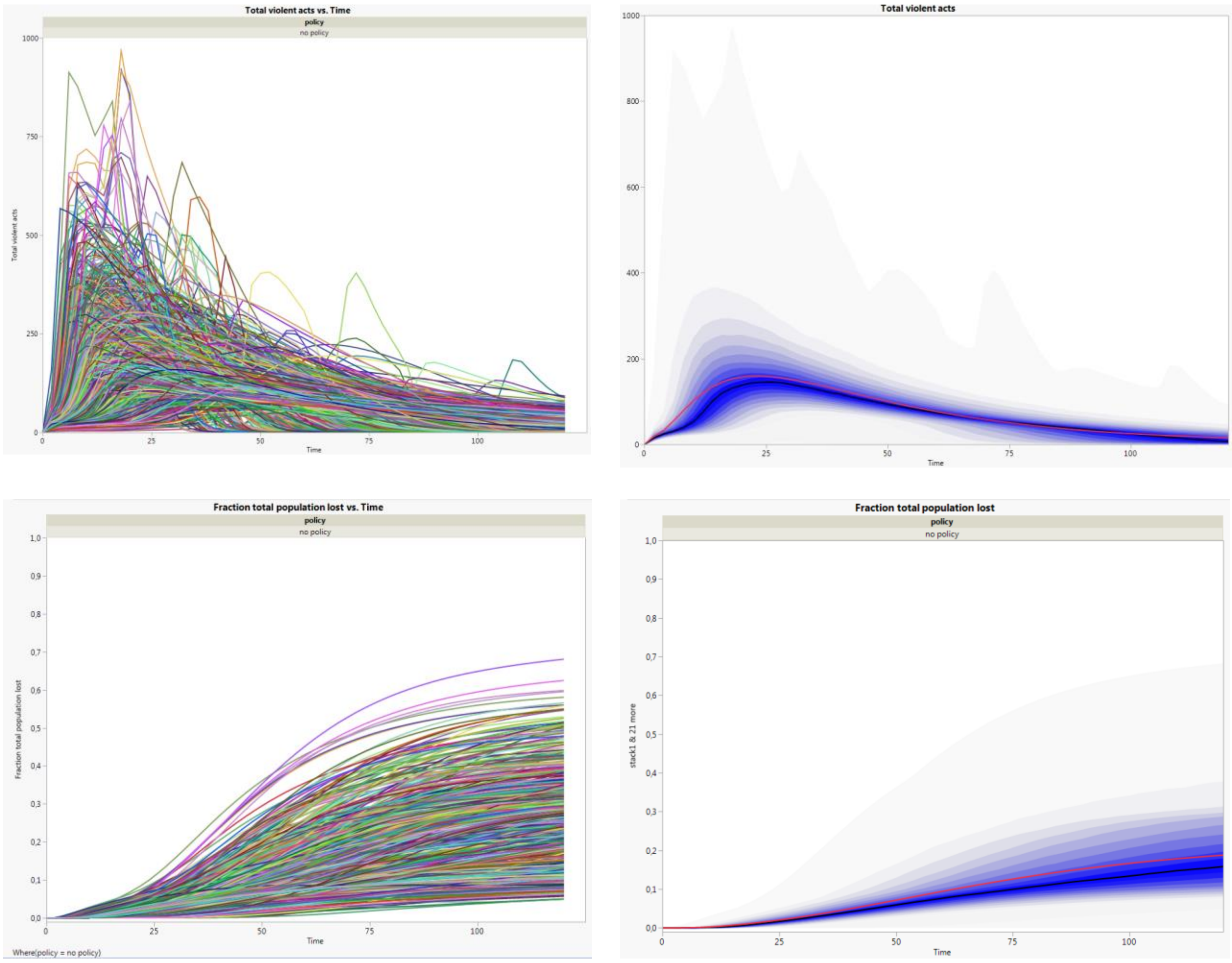

Figure 6 Simulation results for the 'no policy' situation. Top: The total violent acts in the area per month. Bottom: The total fraction of the population lost either due to people becoming a refugee or due to loss of life. The two figures on the left display the results for each individual run (as is commonly done in ESDMA literature), the two figures on the right aggregate the results per time step and display them as a distribution, the median is shown in black and the mean in red. Note that in common EMA practice the distribution of results is not considered to be an indication for probability.

We can further investigate the base case behaviour by clustering behaviour patterns. In this way we can group plausible futures in categories that appear to develop in a similar manner. These clusters can then be used to review the influence of uncertainties. Figure 7 displays the behaviour of the variable 'Total population lost' after Ward's-clustering was used to create 9 clusters. The bottom half of the figure displays the outcomes of two variables: The total combatants lost and the total population lost for each replication in the cluster. We can see that different patterns emerge leading to different outcomes. For example, cluster 3 appears to be a favourable outcome since loss of civilians is minimized to below 10% (Figure 7 bottom right), while combatant losses are roughly average (Figure 7 bottom left). Cluster 9 appears very unfavourable, all replications in this cluster lead to very high population losses.

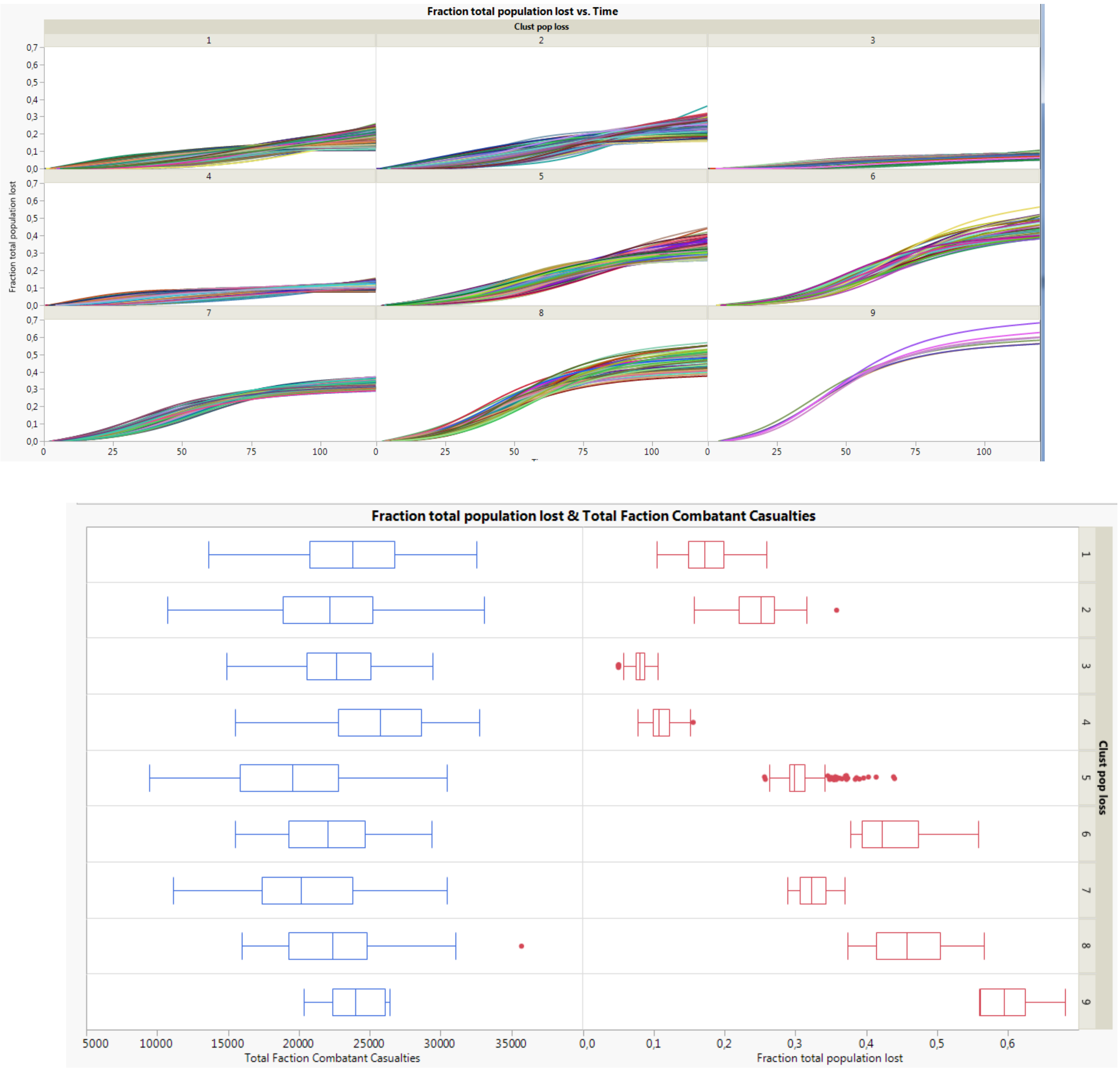

Figure 7 A different set of clusters based on the fraction of the total population lost (Civilian casualties and refugees). Cluster 3 appears most favorable, civilian losses are minimized (bottom right) while Combatant losses are average (bottom left)

Based on the clusters we can determine which uncertainties in the model drive the favourable (cluster 3) and unfavourable (cluster 9) behaviour. Figure 8 present a series of boxplots to perform this analysis. The boxplot shows which input parameter values were observed within the two clusters. Note that all parameters originally have a uniform distribution. If the parameter would not have an influence on the occurs of the behaviour in the cluster we would expect to find a uniform distribution. However, after clustering new distributions emerge for the input parameter, this signals that the behaviour observed in the cluster is related to some specific range of input values per parameter. For example, for cluster 9 (unfavourable) only the low end of input values for 'Planning delay' and 'Combatants needed per violent act' are observed and only high values for the variable 'Faction A willingness to engage'. Alternatively, the favourable behaviour (cluster 3) appears to contain more replications in which the 'collateral damage factor' was low, while the 'normal gain in resources' parameter was high. This indicates that outcomes will be more favourable if less economic resources are damaged and those resources that are damaged can recover faster. This indicates that an effective policy might need to include economic support, for example economic development programs as executed by provincial reconstruction teams (PRT).

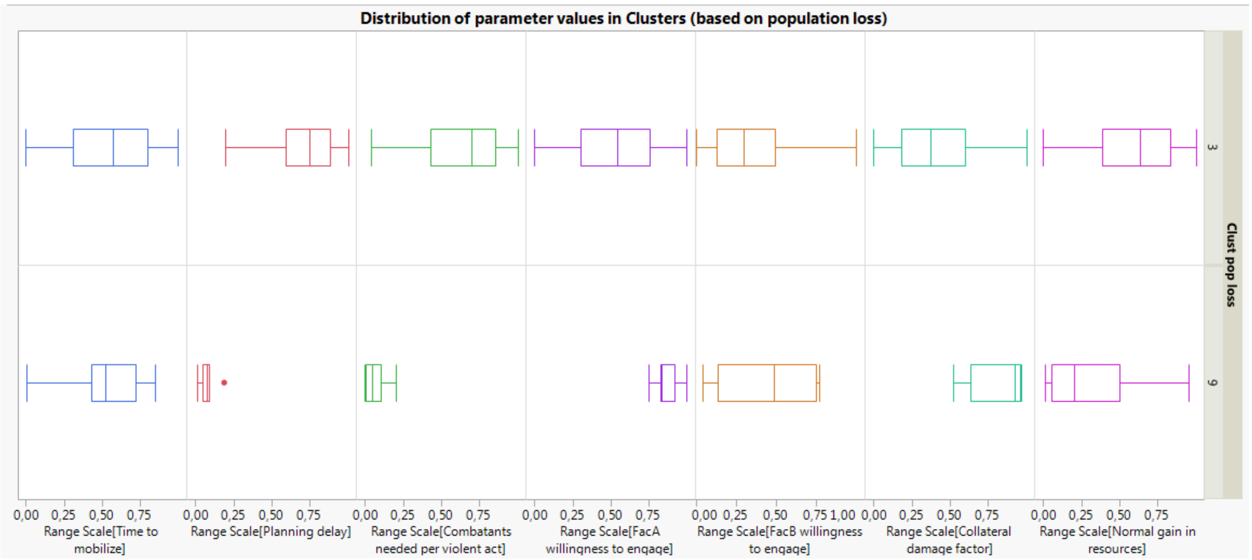

Figure 8 Analysis of the influence of parameters on clusters of population loss behaviour (see Figure 9). Only cluster 3 (favourable outcome) and 9 (unfavourable) are displayed. The distribution of the input parameters is displayed as a subset according to the cluster. Input parameters have been normalized to a 0-1 range.

3.2.2 Policy analysis

Six months into the conflict the simulated unit is instantly deployed in the area of conflict. We have conducted an EMA analysis in which we evaluate different policies composed of the DIME interventions from the previous section:

- Base case: 'None' Policy
- 'Combat' Policy
- 'Policing and PRT' Policy
- 'All with balanced focus' Policy

The MOE's the model calculates as output should reflect the mission objectives. In this case the objectives might be to restore the regime as a legitimate force while minimizing the loss of life. We have presented the results based on three MOE's: The loss of life of friendly forces, civilian population and perception of legitimacy of the government. Figure 9 displays the simulation results. The most favourable outcomes can be seen in the bottom right corner of the cube. From the 3-D scatterplot it becomes clear that the 'Combat' policy performs very poorly, barely leading to better performance than the 'No policy' option while more lives or lost on the friendly side (due to the unit being deployed and actively fighting the factions). The 'Policing and PRT' policy performs best, leading the lowest loss of friendly lives, while in many cases resulting in higher legitimacy and less population loss then the other policies or no policy option.

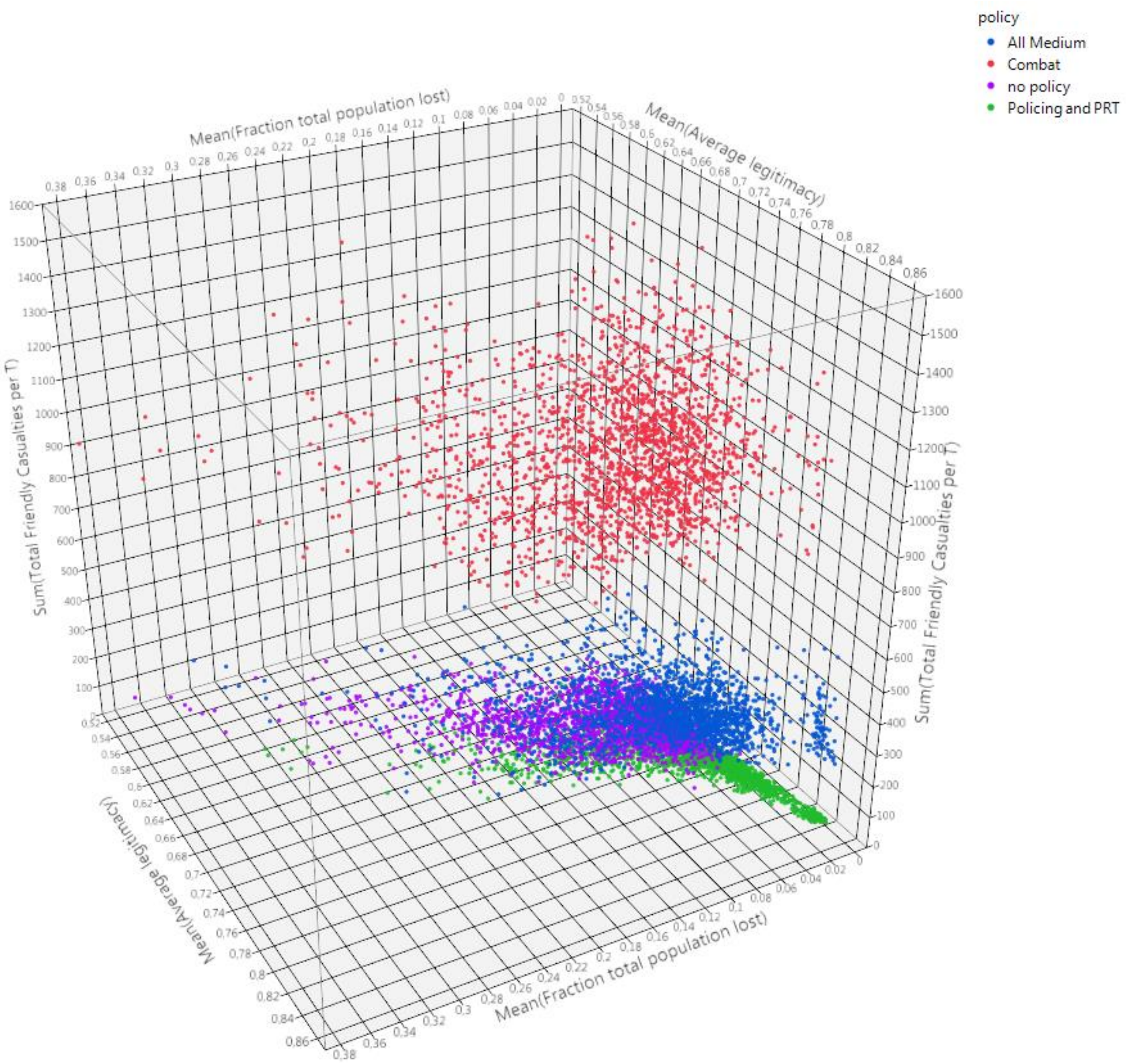

Figure 9 Comparison between policy outcomes based on three MOE: The fraction of civilian population lost, the average legitimacy of the government as perceived by all three factions and the total casualties suffered by friendly forces (regime and coalition)

4. LESSONS LEARNED

The paper documents the first steps in the process of conceptualizing the MEMPHIS approach and creating a demonstrator tool. We have described the place of MEMPHIS within an operational unit and have explored the application of some aspects of MEMPHIS with an example case. We have identified the following lessons learned, in part based on the feedback received from project stakeholders.

General appraisal:
The first example case results of the MEMPHIS approach was received very positively by project stakeholders. It is seen a natural next step following the introduction and use of qualitative modelling such as causal loop and MARVEL models within especially the planning and intelligence community. A desire was stated to not only use the approach for the operational level but also for the tactical level and also not only for PMESSI-PT / DIME factors using non-kinetic models but also for combat modelling. This however, would require other modelling approaches then System Dynamics to be included in the MEMPHIS

framework.

A precondition that was mentioned as vital for the acceptability of the approach is the explainability of model results. Analysts should be able to make insights from the model accessible and be able to transfer confidence by clear explanation of results. Therefore the use of simple, relatively small models was recognized as important together with the use of participatory model building techniques that could involve member of the staff and potentially other organizations.

Phrasing
Stakeholder commented that the use of the word COA (Course Of Action Analysis) implies detailed planning while the approach was judged to be most suitable form conceptual planning. For this reason interventions in the model could best be phrased as ‘effects’. This can help signal that model is used to determine *what* to do rather than *how* to do it.

MEMPHIS modelling environment:
In order to be useful for the staff at the operational level a model must thus be tailored to their needs. In our COIN example case this required a higher degree of disaggregation then found in many published SD models, especially with regards to modelling different actors in the conflict (Coyle, 1985; Richardson et al., 2004; Maldonado, 2009; Anderson, 2011). Modelling and analysing the interaction between multiple agents within a SD model was challenging. The use of SD limits to what extent interaction can be modelled, for example with regards to the influence of networks or coalition forming. The MEMPHIS approach might thus benefit from a model building environment that facilitates the use of different modelling methods as well as multi-method models. Recently several commercial software packages have appeared that might help alleviate these shortcomings by integrating aspects of agent-based simulation and SD (e.g. Ventana Systems Ventity, Anylogic etc.)

Group model building and modelling experts:
We learned that group model building with intel and operational analysts is an effective process to develop a model, however it does require specialized model building skills / experts. Also, when building models for real missions, not only defence participants should be present but also participants with knowledge from the local environment like cultural advisers, civilians, NGOs, etc. The lead in the model building process could either come from the intel or from operational analysts. The current idea is that a viable way of work could be that the intel analysts should have the lead and the results should be validated by the operational analysts.

Stakeholders did comment that attempting to build ‘generic’ models is very difficult due to the vagueness in scope. It is expected that building models aimed at describing specific circumstances is more effective. This models could make use of ‘building blocks’ of certain generic aspects of a system such as an aging chain to model population cohorts.

A viable approach to using M&S in an operational context should anticipate that this expertise might not be present and needs to be developed through training and education before the start of a mission. Reach-back capability to external operational analysts can be useful but has its limitation since we feel most learning occurs during the development of a model.

Time aspects of modelling:
The so-called ‘Battle rhythm’ of a staff (ie. The daily/weekly cycle of planning, reporting, meetings etc.) can be fast paced, while developing and using models takes time. Developing a generic model might take weeks to months, modifying and calibrating the model to a specific operational scenario might take days to weeks, while simulating and analysing a scenario takes anywhere from hours to multiple days. However this might be more of a problem when dealing with tactical issues than with operational issues for which the approach is more likely to be used.

Future work should consider which questions of the staff a model could answer in a timely manner. Potentially, models or building blocks can be developed before a mission or used from previous missions. However, learning takes place when interaction occurs. It can therefore be expected that using models during deployment will mean a continuous process of model iterations and development of new problem specific models.

Exploratory Modelling and Analysis (EMA):
We found that the use of EMA facilitated the use of simulation within a deeply uncertain environment. Furthermore, we found that EMA could provide benefits beyond the commonly referenced benefit of identifying robust policy options. For example:

- Insight
  - Clustering for scenario identification
- Force structuring, commitment of resources
  - Which events (e.g. threat) can always/never be countered with a given set of capabilities?
  - Reducing which uncertainties (for example by tasking intelligence units) gives a maximum decrease in outcome uncertainty?
- Course of action
  - Which COA's are most effective under deep uncertainty, or in other words are the most robust for varying models?
  - Which assumptions must hold true for a policy to be effective?

Data visualisation:
The use of data visualisation offered an accessible way to find and present insights. However, for complex models with very large envelops of results data visualisation alone might not be sufficient. Advanced analytics techniques might be required to successfully harness the complexity of deeply uncertain situations and models that attempt to simulate them. Initial results of using partition trees, clustering techniques and discriminant analysis look promising.

Geographical mapping:
Since the military are 'map oriented', it was seen as vital for the MEMPHIS approach to somehow try to map the model results to geographical locations and show them on a map. Of course this only makes sense when the parameters under discussion can be placed in a geographical context. Although MEMPHIS is not limited to SD models, when using SD models which deal with aggregate parameters of a country this could be a problem since more detailed information that can be geographically pinpointed is usually not available in the model. A solution directions for this could be the use of SD models per region. However such more detailed aggregate level regional models should somehow be interlinked which greatly complicates the modelling. Another solution direction which was discussed was to use extra information from other sources to de-aggregate the SD model output in order to place it on a map. These approaches need to be investigated.

5. WAY AHEAD

We will proceed our project by presenting MEMPHIS to more stakeholders and refine its integration in the operational process. We will further develop an approach of how M&S can be used within the operational process. We distinguish different levels where the approach can be used in a headquarters, namely initially by the operational and intelligence analyst who have to use the results and prepare results for the planning/environment cells. These results should be at a lower level of detail and the planning/environment cells in their turn have to prepare a briefing for the commander which again requires less detail. In the figure below this is visualised. Aspects of MEMPHIS will be tested and demonstrated during an operational exercise later this year.

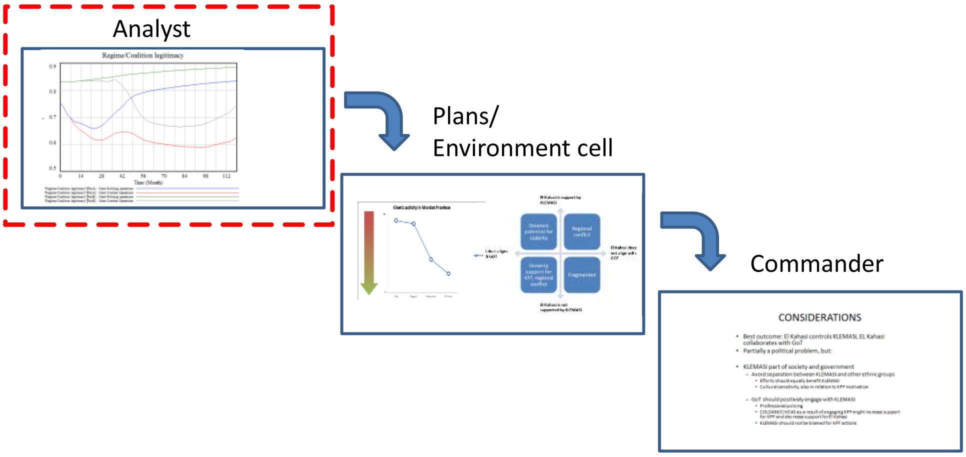

Figure 11 The MEMPHIS approach should support different levels of analysis. At the highest level detailed simulation results should be available for analysts while these should be translated to actionable insights that can be shared with a commander.

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