The application of modelling and simulation in support of operational decision making during land operations

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Abstract

Contemporary military interventions are aimed to influence the complex dynamics of a conflict to create a stable situation in which further outside intervention is no longer necessary. To this end, an operational commander has to translate a desired end-state to tactical activities conducted by the units under his or her command, in coordination with other acting organizations. Modelling and simulation (M&S) could serve as a capability for a commander to structure available information and derive insight into the situation to assist decision making. 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 reports some 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. As part of this assessment, a small example concerning a counter-insurgency intervention is developed using group model building (GMB), system dynamics and exploratory modelling and analysis.

1. 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 (NATO, 2010) and can combine the efforts of a host of governmental and non-governmental organizations. 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 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. 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. Operational level decision making and modelling and simulation

A series of brainstorm sessions was organised with military stakeholders to identify which operational processes 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.

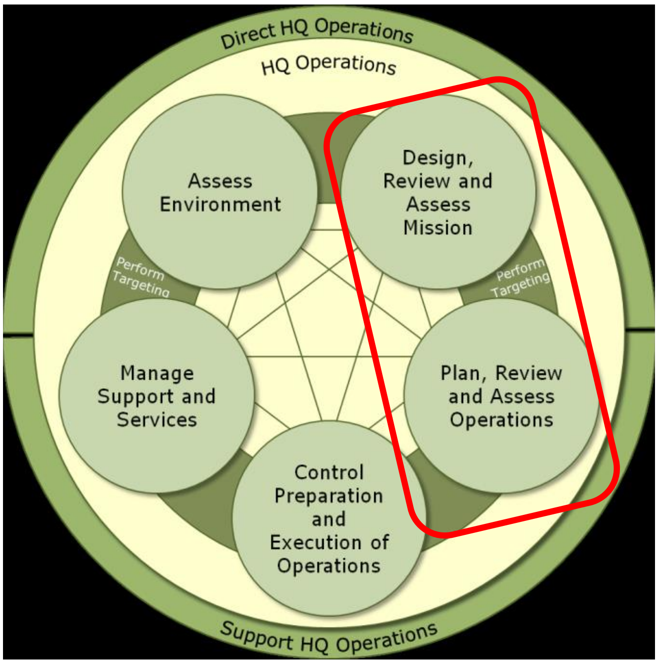

Figure 1 The headquarter' Operations process (KL, 2014)

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 Figure 2. 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'.

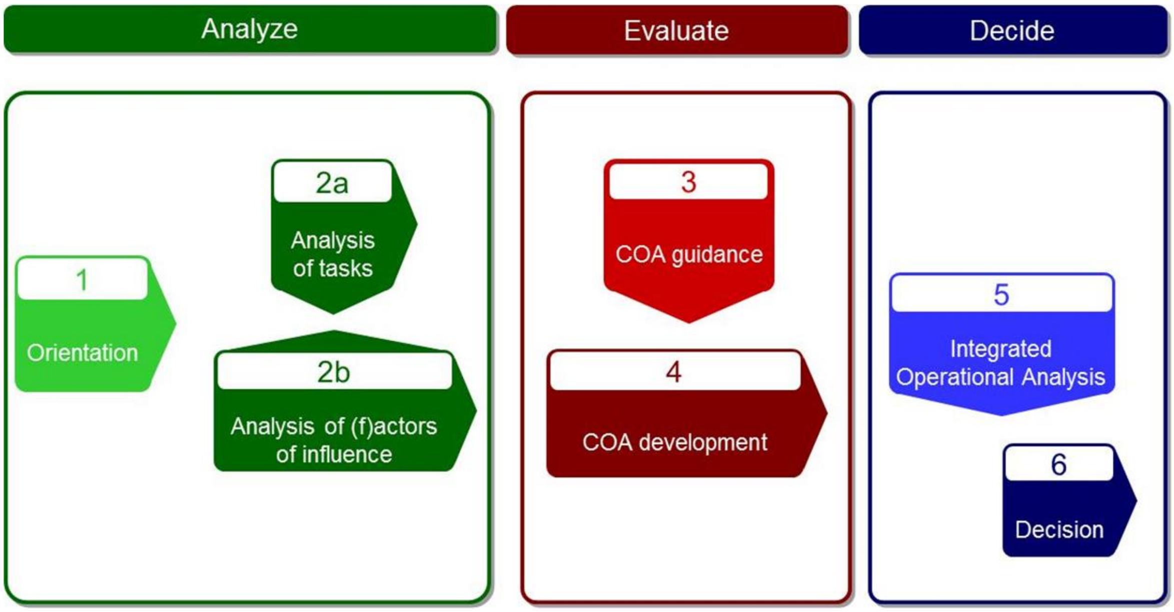

Figure 2 The Tactical decision making model (KL, 2011)

In this process the following steps are distinguished:

1. Orientation: Analysis of the deep cause of the problem and the actors and factors that are part of the problem.
2. (a) Task analysis: Gaining insight in the mission and operations within it, including the effects that need to be reached or mitigated.
   (b) Analysis of actors and factors of influence: Gaining insight into (1) the (f)actors in the operational environment influencing the mission and operations to be planned (local population, enemy(s), friendly actors, terrain, climate, etc.) and (2) own possibilities.
3. Guidance for Courses of Action (COAs): Determining guidance for the development of COAs in the next step.
4. COA development: Developing COAs including required coordinating measures and conditions.
5. Integral operational analysis: the COAs are related to (activities) of other actors in the mission area and the concept of operations is refined. Activities are placed in time and the benefits and drawbacks, chances and risks of the COAs are elaborated. This forms the basis for detailed operations planning.
6. Decision: The commander selects the COA on which the operation will be based. This is put into a warning order as a basis for writing the operations order.

In summary , a commander asks his or her staff, containing operational analysts and members of the planning cell and environment cell the following.

- Analysis of factors and actors of influence.
- A set of roughly sketched own possibilities (COAs) that enable reaching the mission objectives.
- An analysis of COAs in terms of required capacity in time and space, the positive effect on reaching the objectives, the foreseen response of the environment and strong and weak points.

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.

2.2. Possibilities for M&S

During a brainstorm session with military stakeholders the possibilities for M&S support within the three processes was discussed. The conclusion was 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 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.

An often heard phrase is *'all models are wrong, but some are useful'* (Box, 1979) and the output of any (simulation) model saying something about the (future) behaviour of systems involving humans should be carefully looked at. It is important that stakeholders do not view model outcomes as predictions but as investigations of plausible futures. 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.

2.5 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 (**M**ilitary **E**nvironment **M**odelling with **P**hysical and **H**uman terrain **I**nformation **S**ervices). See Figure 3.

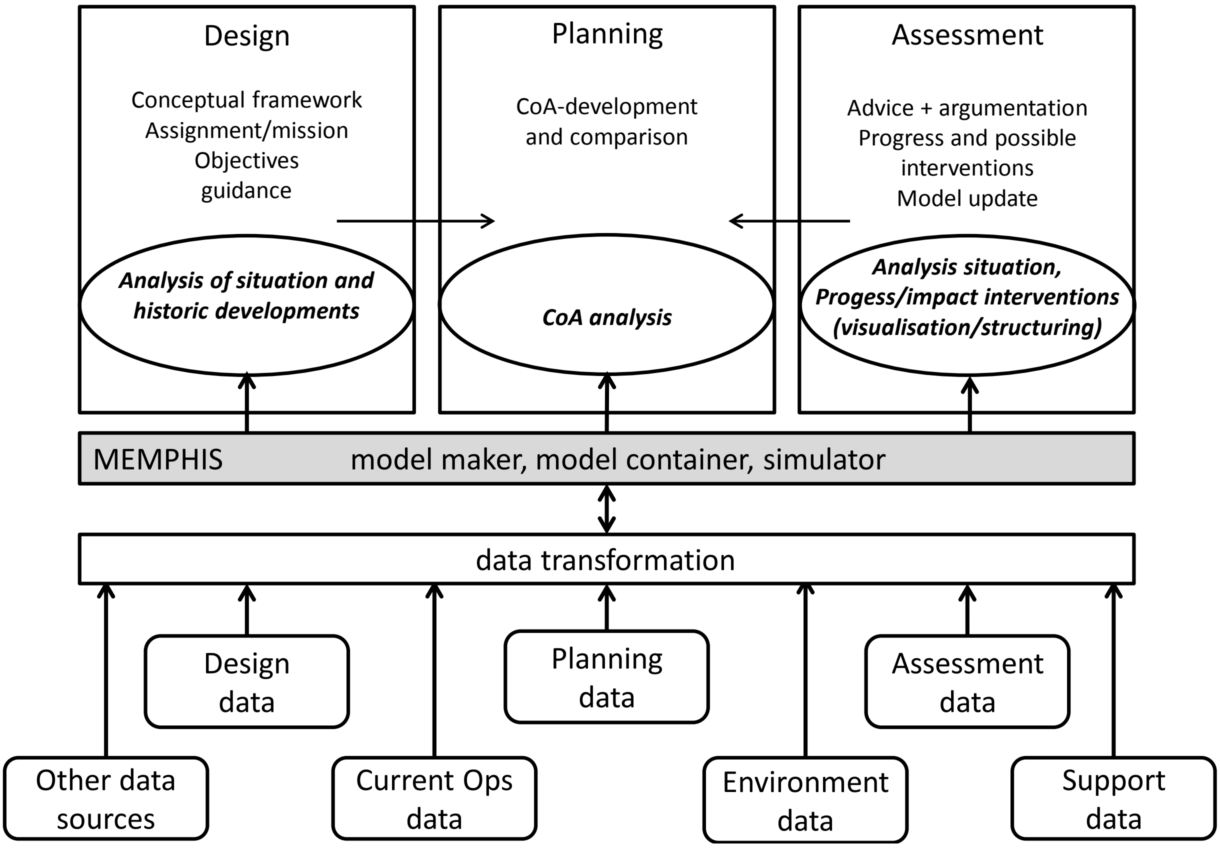

Figure 3 the MEMPHIS concept visualized

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. An example is a former DARPA program on Conflict Modelling, Planning, and Outcomes Exploration (COMPOEX) (Kott et al., 2010). However, such environments are not freely accessible. For this reason a demonstrator is being developed at TNO. To this end System Dynamics, Exploratory Modelling and Analysis and Group model building are combined.

An approach as MEMPHIS is depended on various prerequisites. For example, it assumes that data about the environment and about a units own actions is stored and is accessible. 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.

2.6 Using models in 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 and two GMB sessions 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:

- Evaluate developing a model using group model building based on knowledge available within an operational unit;
- Use the model as a testbed to develop and evaluate EMA techniques;
- Demonstrate the added value of the approach to project stakeholders and receive feedback in an early stage of development.

3.1.Introduction to modelling counter-insurgency

Previous SD representations of COIN operations are plentiful. Arguably the first system dynamics study on counter-insurgencies was provided by Coyle (1985). Coyle (1985) used a qualitative approach to create a Causal Loop Diagram (CLD) of the dynamics of COIN. He operationalized an insurgency as a division in the population between those supporting the insurgency and those who are not (and thus are neutral or supportive of the government). Coyle demonstrated how System Dynamics could be used to describe some aspects of COIN and how it could assist in policy evaluation. Baker (2006) offered a description of key feedback archetypes relevant for COIN using simple CLD models instead of one big model. His work highlights the importance of perception of security and feelings of resentment. The first simulations of COIN operations using System Dynamics did not appear until the start of this century when the war on terror renewed interested in the topic. Richardson et al. (2004) developed a generic model focused at the post-conflict phase. Both combat, infrastructure, reconstruction effort and economic and law enforcement aspects are included in the model. In his comprehensive thesis Maldonado (2009), compared several theories on different COIN strategies and developed separate stock and flow models and a fused ‘hybrid strategy’ model. His models include both information operations (ie. Psychological warfare) and combat operations. This model includes the so-called winning the “hearts and minds” aspects of COIN, but devoted less attention to economic and civic aspects. The current standing US doctrine on COIN is described in the U.S. Army and Marine Counterinsurgency Field Manual (FM 3-24) (Department of the Army, 2014). The dynamic theory of COIN described in this manual was modelled and evaluated using system dynamics simulation by both Pierson (2008) and Anderson (2011). The former is sometimes referred to as the precursor of the infamous Afghanistan ‘spaghetti diagram’, an elaborate qualitative diagram of the conflict in Afghanistan (PA consulting, 2009). The model by Pierson (2008) provides an integrated view on the ‘logical lines of operations’ as identified by FM 3-24 (Department of the Army, 2014): Combat, Host nation security forces, Governance, Essential services, Economic development, Information operations and Intelligence. The model by Anderson (2011) focusses on the importance of intelligence for effectively conducting COIN operations. With this, the paper provides a more in-depth look at the effectiveness of forces than found in other models. All models to some extent address the motivation of people becoming an active member (combatant) in an insurgency, often this motivation can be classified as economic motives (‘greed’) and the influence of negative prior events (‘grievances’). Other SD literature of relevant topics, include studies on conflict and state-stability (see for example: Wils et al. 1998; Saeed et al. 2013). Although not specifically related to COIN operations, these papers describe dynamic theories of the forces that can destabilize a country and result in violence. Together the literature discussed above provides several interlocking ideas on underlying reasons for insurgency and the dynamics of intervening in such a situation. All models discussed so far have one thing in common: An insurgency is operationalized as a polarization conflict. This is a ‘you are either with us or against us’ view on conflict. As we would find out during model building sessions with military analysts, this is a very coarse aggregation of the operational reality[1]: *‘Differentiating between insurgents, insurgent supporters, neutrals, and the host-nation government supporters is difficult.’* (Department of the Army, 2014 p. 4-19). The same observation was also made by Anderson (2011, p. 138): *‘… most insurgencies are actually a collection of smaller insurgencies, each of which battles each other as well as the government.’* The importance of group identity is stressed in FM 3-24 (Department of the Army, 2014) and other analyst sources. We will refer to a group with a shared identity as a faction, this identity can be formed on the lines of: ethnicity, tribal affiliation, religion, regionalism, political affiliation, or class (US Government, 2011).

3.2.Participatory Process and insights

Interviews were conducted prior to the workshops and were used to develop a concept model. The Subject matter experts (SME’s) assisted in defining the scope of the model to be appropriate for operational level decisions. They stressed the importance of integrating PMESII-PT factors to describe the situation. They also helped to define an operation as means to influence ‘factors to mitigate’ (such as violence), ‘factors to exploit’ (such as available security forces) and ‘factors to influence’ (such as economy), focused on reaching a desired end-state.

The previously discussed work on COIN was evaluated and served as the starting point for a concept model. The model included the ‘with or against us’ view on COIN described above and a high level view on ‘quality of life’. For the workshops we invited (former) personnel of the Netherlands armed forces. All SME’s possess extensive operational experience and have been deployed to countries such as Iraq and Afghanistan.

In the first GMB session the concept model was used to introduce the method and its intended use. Additionally, it served to jump start the conversation about COIN and put the next exercise, the initial policy options script, into context (Hovmand et al. 2011). The participants suggested policies across the DIME spectrum, emphasizing both combat and non-combat operations aimed to stabilize the conflict. In the next exercise participants discussed which addition had to be made to the concept model. The concept model served as a useful boundary object, generating discussion and cognitive conflict among the participants. The participants reached the conclusion that the concept model was too one-dimensional with its focus on combat operations by coalition forces in a ‘us against them’ conflict. There was strong agreement that the model should focus more on underlying causes of the (un)stability of a state, which provides the opportunity for insurgents to grow. Factors considered important in this respect were economic prosperity and existing power structures, such as tribal structures. It was concluded that the aggregation level of existing SD models was not appropriate for supporting decision at the operational level. Participants emphasized the importance of including multiple factions (tribes) in the model and simulating the dynamics between these factions, such as: grievances. jealousy and ultimately violence.

[1] For example: Wikipedia offers an overview of current parties in the Syrian conflict, the list identifies over 100 different factions, semi-organized in various coalitions (https://en.wikipedia.org/wiki/List_of_armed_groups_in_the_Syrian_Civil_War)

The expert feedback on the initial model, and a subsequent literature review of counterinsurgency literature confirmed that tribal dynamics and tribal leadership were underrepresented for a model to be used for operational level decision-making. At this level of analysis the interaction amongst and within tribes is both a source of conflict and a source of resilience (Connable & Libicki, 2010, Kitzen, 2012; Connable et al. 2014; Manyena & Gordon, 2015). At the operational level, most COIN interventions cannot be viewed outside of the context of a certain tribe or other type of faction that is affected by them. Interventions that influence a certain faction then change the dynamics between that faction and others, potentially positive and negative.

Before the second workshop a new concept model was developed that focused on the internal dynamics of one faction and its relation with other factions and coalition forces. Based on the initial policy options script from the first workshop, participants were asked to think about variables which are not yet in the model that could be relevant for the efficacy of the policy. During a facilitated discussion participants added the generated variables to the model. The structure of the model resulting from the second workshop was considered by the participants to have the potential for supporting operational level decision making once the interaction among several tribes (tribal structures) was implemented successfully and connected into one model. After the sessions the model was developed further by the model building team.

3.3. The stock and flow 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. Our motivation for building the model is described in the introduction of this chapter. 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).

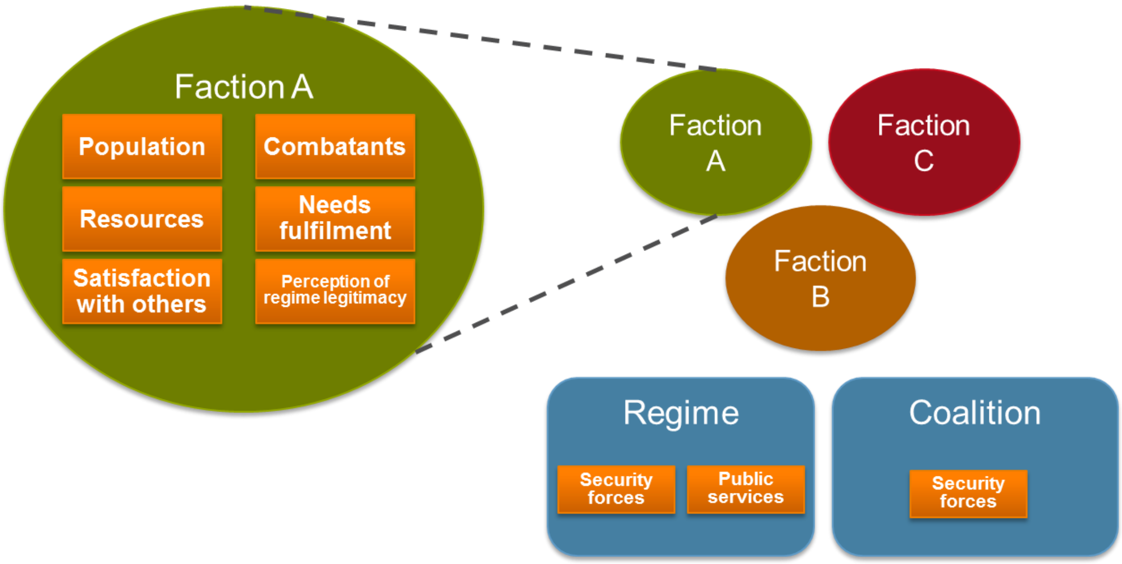

Figure 4 Overview of different actor in the model and their most important variables

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 (Figure 5).

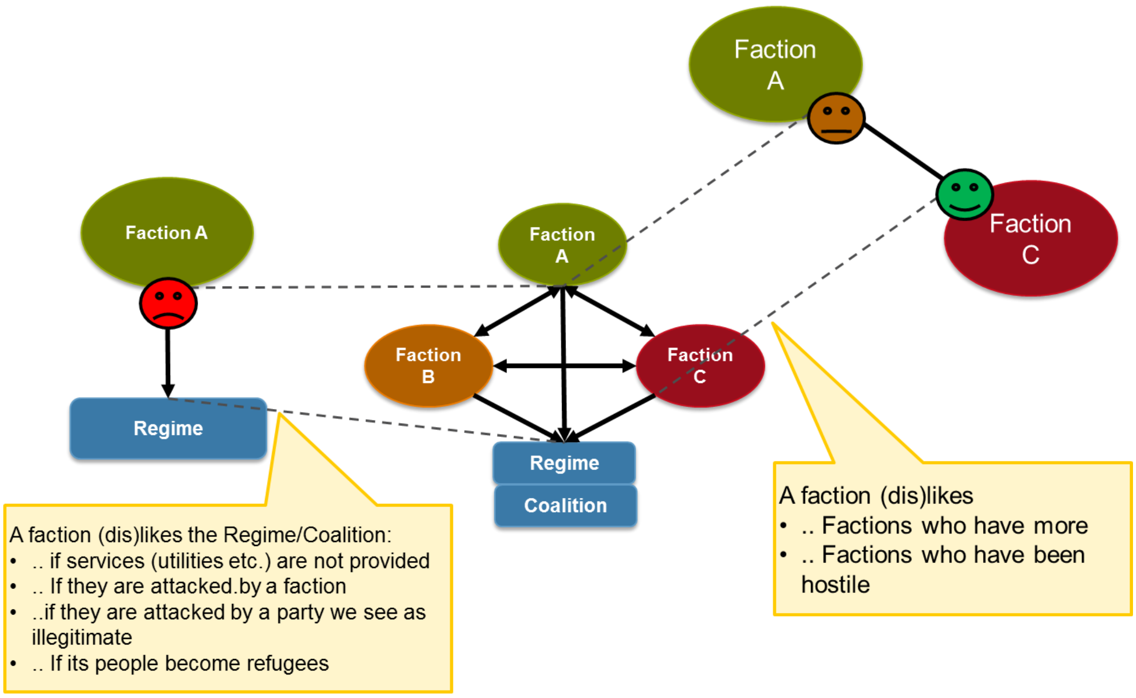

Figure 5 Satisfaction and legitimacy in the model.

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.

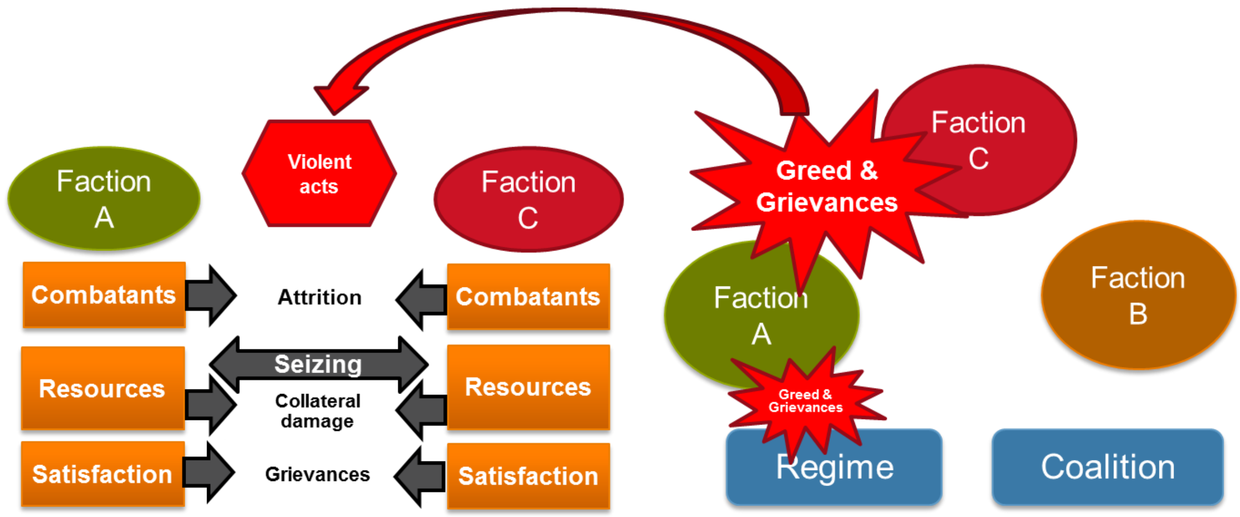

Figure 6 Violent acts between two factions

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
  - **Provincial reconstruction team** (PRT)
    - **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.

3.4.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.

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, Figure 5, Figure 6).

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.

3.4.1. 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 7 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 7 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.

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[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.

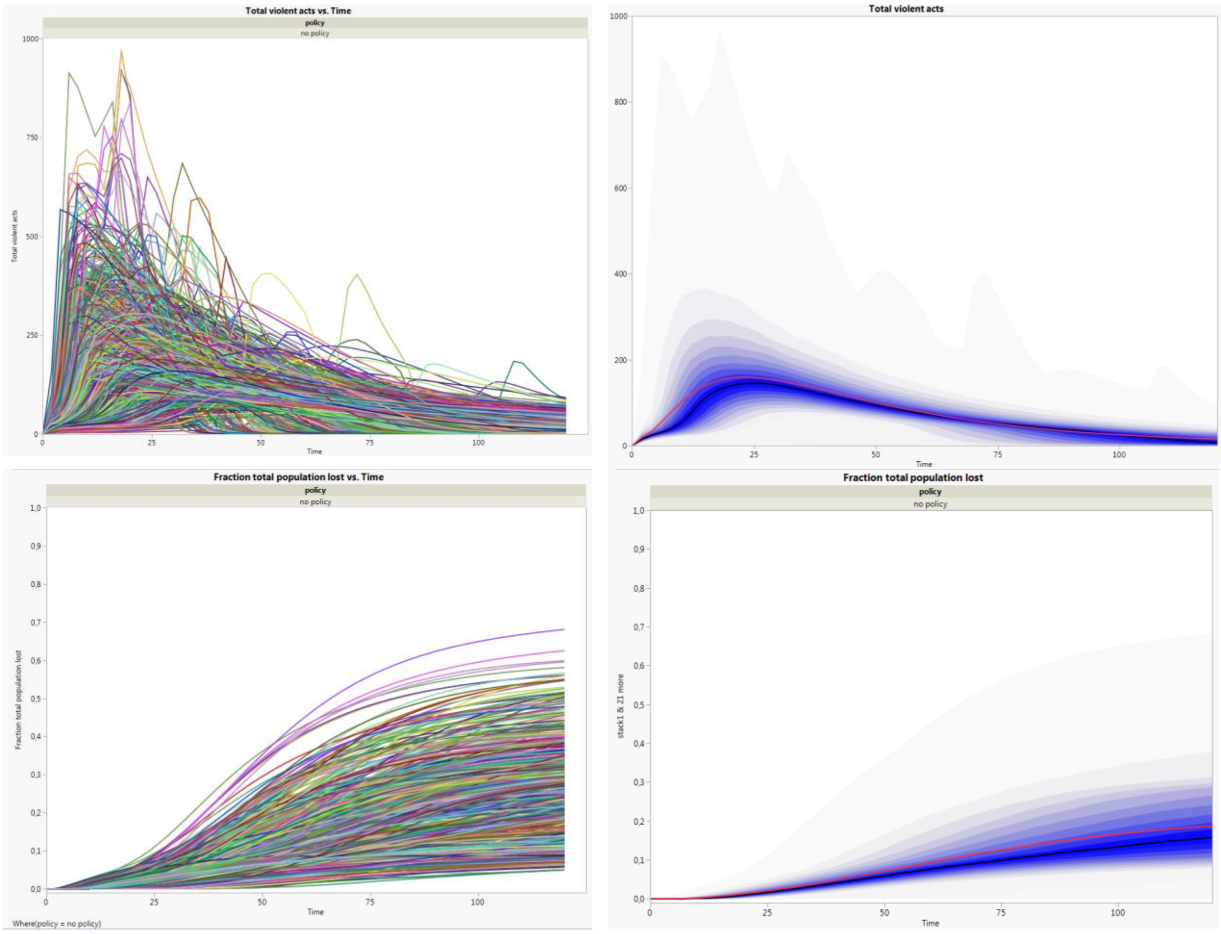


Figure 7 Simulation results for the 'no policy' situation. Top: The total violent acts in the area per month. Bottom: The total fraction of the population lost either due to people becoming a refugee or due to loss of life. The two figures on the left display the results for each individual run (as is 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 8 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 8 bottom right), while combatant losses are roughly average (Figure 8 bottom left). Cluster 9 appears very unfavourable, all replications in this cluster lead to very high population losses.

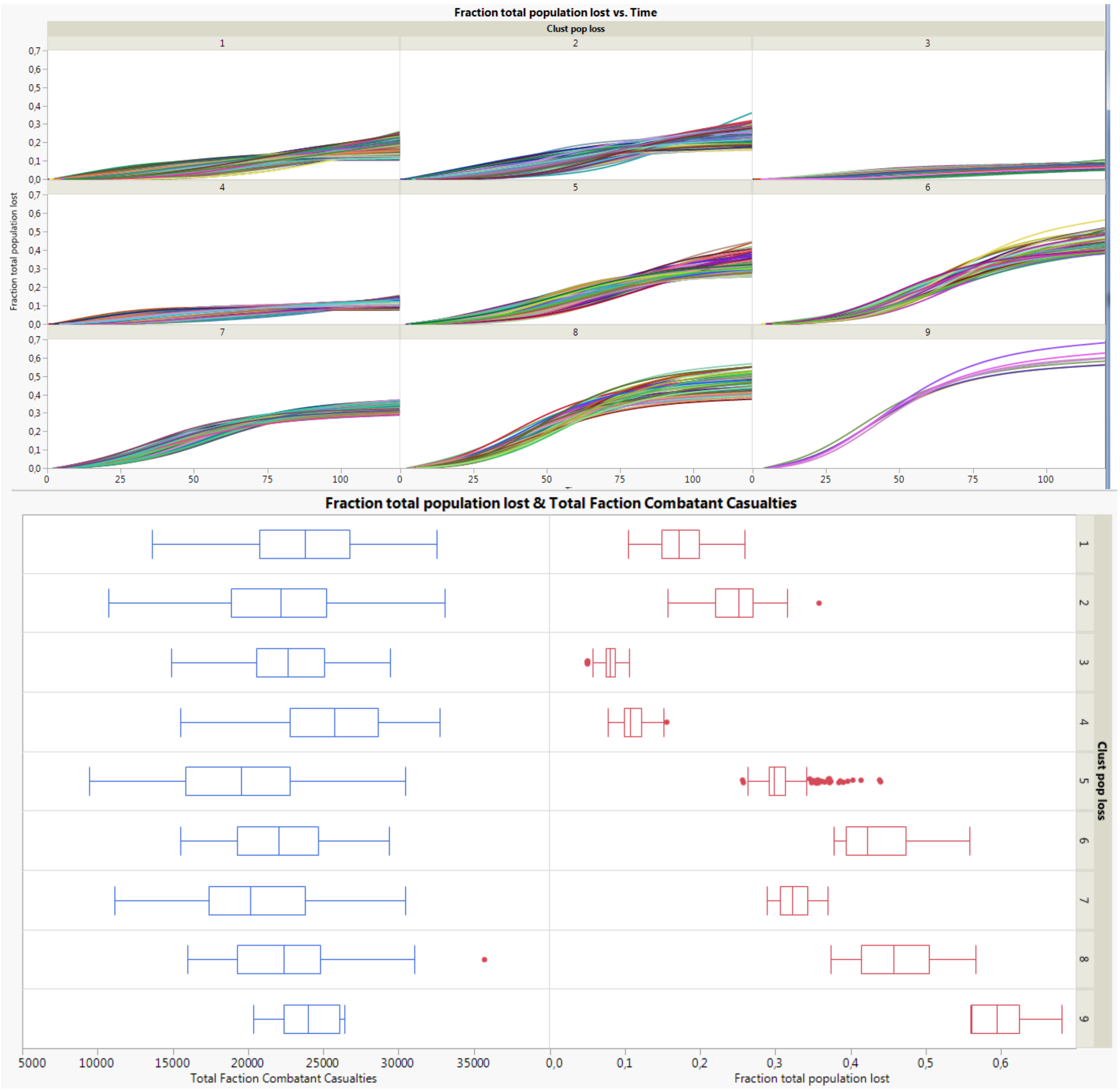


Figure 8 A different set of clusters based on the fraction of the total population lost (Civilian casualties and refugess). Cluster 3 appears most favorable, civilian losses are minimized (bottom right) while Combatant losses are average (bottom left)

Based on the clusters we can determine which uncertainties in the model drive the favourable (cluster 3) and unfavourable (cluster 9) behaviour. Figure 9 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 provincial reconstruction teams (PRT).

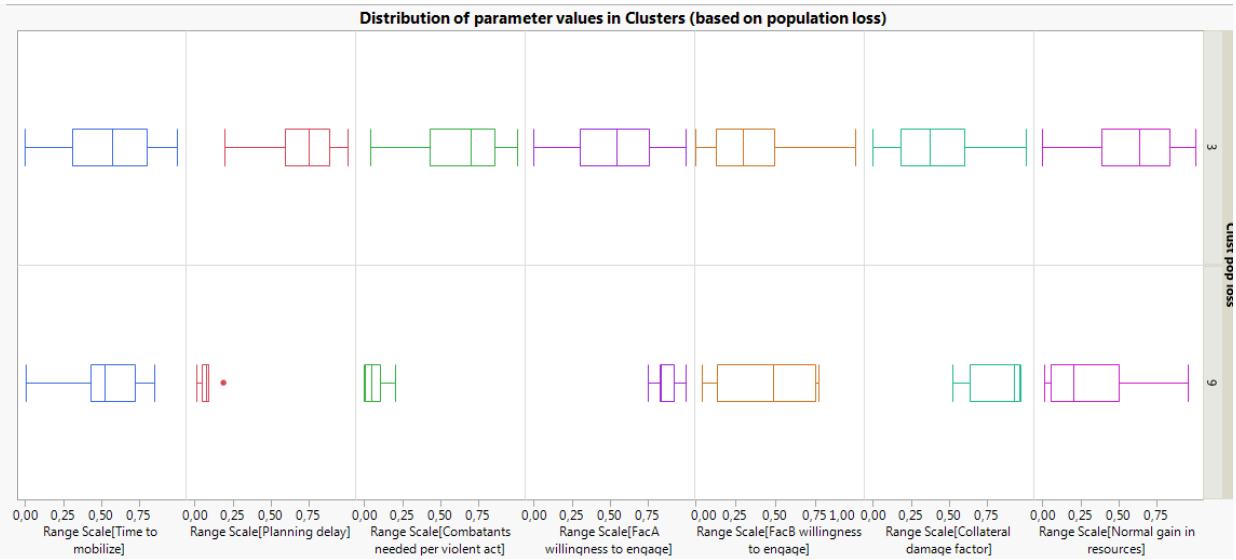


Figure 9 Analysis of the influence of parameters on clusters of population loss behaviour (see Figure 9). Only cluster 3 (favourable outcome) and 9 (unfavourable) are displayed. The distribution of the input parameters is displayed as a subset according to the cluster. Input parameters have been normalized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

3.4.2. 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 10 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.

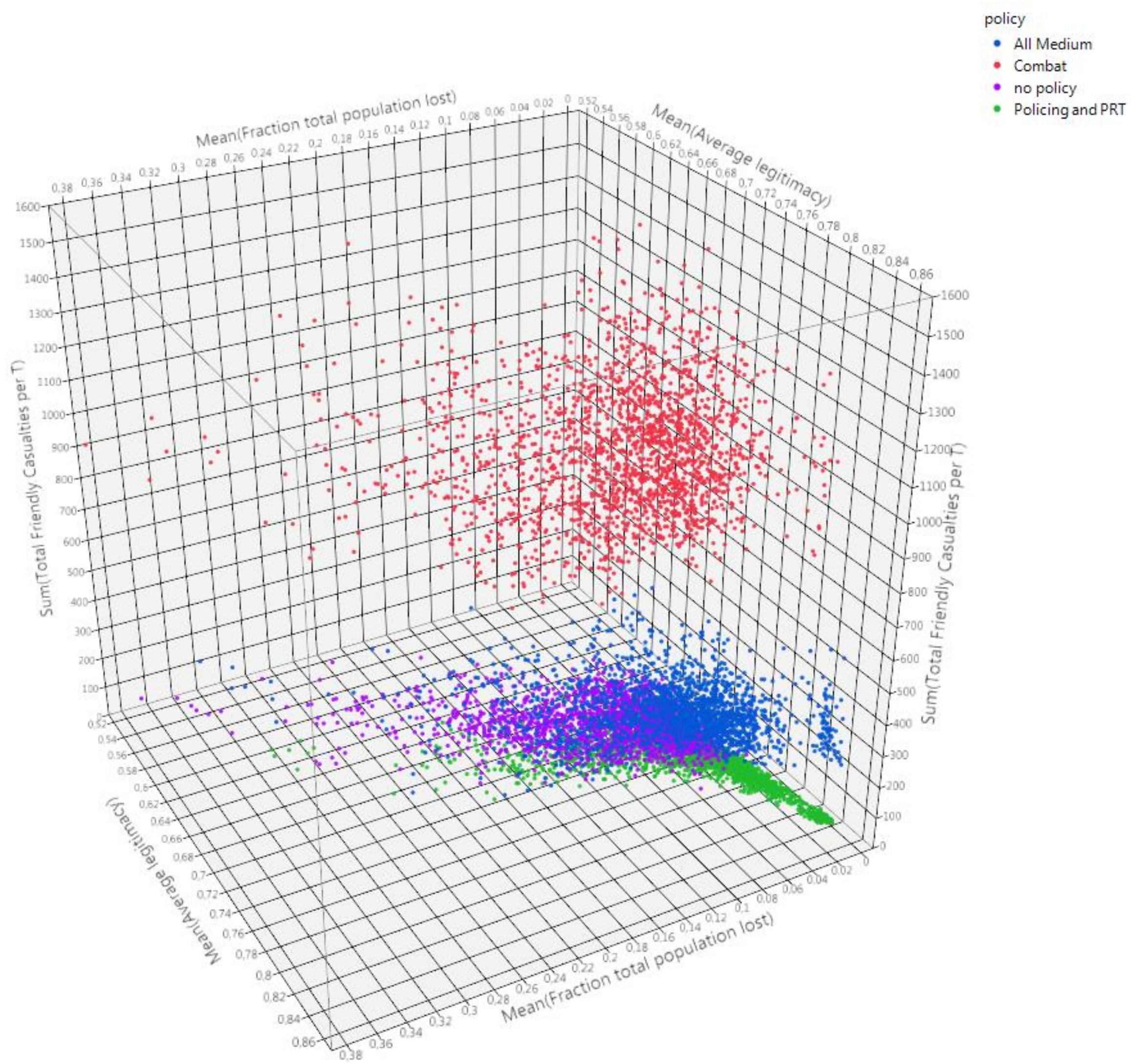


Figure 10 Comparison between policy outcomes based on three MOE: The fraction of civilian population lost, the average legitimacy of the government as perceived by all three factions and the total casualties suffered by friendly forces (regime and coalition)

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.

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 published SD models, especially with regards to modelling different actors in the conflict. 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 multi-method models.

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

Furthermore, 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. 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 during previous missions. However, learning takes places 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.

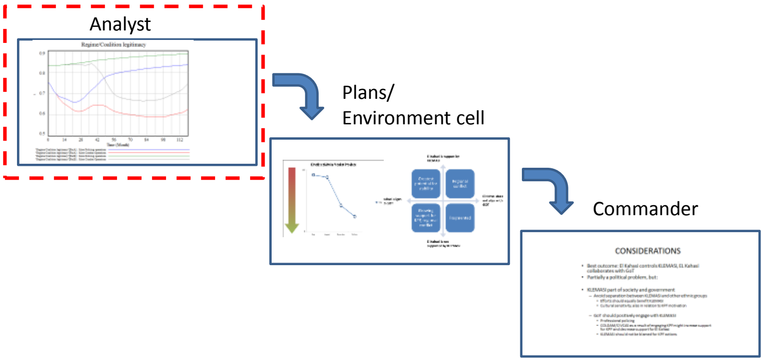
We found that the use of EMA facilitated the use of simulation within a deeply uncertain environment. Furthermore, we found that EMA could provide benefits beyond the commonly referenced benefit of identifying robust policy options. For example:

- Which capability (specific units/equipment etc.) will never/always be useful?
- Which threat will the proposed policy options never/always mitigate?
- Which input uncertainties should be reduced (by for example tasking intelligence units) for a maximum decrease in outcome uncertainty?

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.

We proceed our project by focussing on the following subjects:

1. <u>Introduce MEMPHIS to stakeholders and refine its integration in the operational process</u>
   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 analyst who has 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 demonstrated and tested during an operational exercise.



2. <u>Explore visualisation possibilities</u>
Analysing and presenting results is a critical step in working with complex models in an operational context. In this regards both flexibility and transparency are essential. We will look into different visualisation possibilities for the three levels identified in the previous bullet point. We will use some ideas from different NATO projects on "Developing Actionable Data Farming Decision Support for NATO" where a tool with different visualization capabilities is being developed (NATO MSG-124, 2016).
3. <u>Further experimentation and development of EMA techniques</u>
Analysis via data visualisation techniques offers a powerful means to create insight while being accessible to a large audience. However, the amount and complexity of data created by EMA analysis can make analysis by visual means alone problematic. The use of advanced data analytics techniques together with SD is largely unexplored (Pruyt and Islam, 2016; Yücel and Barlas, 2011; Barlas and Kanar, 2000). Therefore we will explore the use of analytics techniques for a number of purposes, such as: Time series clustering, the influence of parameters on uncertainty and outcomes and root cause analysis of time series outliers and tipping points.

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