A system dynamics approach for aiding effects-based operations planning

José Carlos de Melo Júnior, Mischel Carmen Neyra Belderrain e Ana Lucia Pegetti
Instituto Tecnológico de Aeronáutica - Pça Mal. Eduardo Gomes, 50 - Vila das Acácias - São José dos Campos - SP

***Abstract*— The environment in which military operations occur have changed significantly. Asymmetric conflicts have become the prevalent form of warfare, replacing the traditional symmetric warfare in terms of geopolitical importance. This new operation environment has given rise to effects-based operations approach. This new concept requires decision makers to adopt a systemic perspective rather than an event-oriented worldview. However, warfare is complex and dynamic. Cause and effect are often distant in space and time and dysfunctional behaviour can arise from systems – some seemingly obvious solutions to problems fail or even worsen the initial situation. To address this issue, the system dynamics methodology is presented as a method which allows decision makers to overcome human cognitive limitations and to design more effective policies. To this end, a basic model of guerrilla warfare is developed and explored for the purpose of demonstrating how the methodology can explain much of the behaviour of warfare.**

***Keywords*— Effects-based operations (EBO), system dynamics, asymmetric warfare.**

I. INTRODUCTION

Planning and conducting military operations currently take place in a world of unprecedented uncertainty and complexity. Operations are no longer limited to classic cross-border invasions and campaigns of attrition. Indeed, they occur in an environment of densely interrelated networks, where effects cannot be isolated [1]. Furthermore, asymmetric conflicts have become the predominant form of warfare over the entire globe, replacing traditional symmetric warfare in terms of geopolitical importance [2].

The 'traditional American approach to war', which had worked well in the past, was found to collapse when applied to the new environment in which we operate. This failure in tackling fast changing problems and asymmetric conflicts has given rise to a more comprehensive concept: effects-based operations (EBO) [3], [1].

The effects-based concept emerged following the Gulf War in 1991 and became the *de facto* basis for the the military doctrine of the United States of America [3], [4]. Recently, there has been increasing attention paid to the EBO approach in planning and conducting operations in the Brazilian Air Force (*Força Aérea Brasileira* - FAB) (see [5], [6], [7]). Nevertheless, it remains an underdeveloped area of research.

According to Smith [1], the EBO consists of 'coordinate sets of actions directed at shaping the behaviour of friends, foes and neutrals in peace, crisis and war.' By focusing on the human dimension of war as well as considering outcomes rather than on targets and annihilation, the success of an operation is measured in terms of the behaviour produced. While destruction still forms a vital part of strategy, the ultimate aim of EBO is to shorten the length of combat by breaking the enemy's will to resist [3].

In order to change or influence system behaviour, EBO requires a deep understanding of the relationship between the various components of a system and how they interact. Decision makers must consider not only physical and immediate effects, but also their outcomes in the cognitive domain over an extended period of time [1]. However, warfare is a clash of complex and dynamic systems [3]. Systems are adaptive, nonlinear and governed by feedback. Cause and effect are often distant in space and time, and dysfunctional behaviour can arise in the interaction between agents in all but the simplest of systems [8].

As extraordinary as the human cognitive capabilities are, they are still too limited to cope with the dynamic complexity that arises from systems in the real world. As Simon stated [8], 'the capacity of the human mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behaviour in the real world or even for a reasonable approximation to such objective rationality'.

Experimental studies have shown that the performance of decision makers in systems with even low levels of complexity is poor when compared to normative standards [9]. Quite often, systems operate according to the actions of decision makers in both anticipated and unanticipated ways. In most cases the problem we perceive is a symptom of a deeper problem – not to mention that reactive short-term actions may trigger side effects that result in undesired, and sometimes long-term irreversible consequences [8]. As a result, most asymmetric conflict strategies fail: the system is not understood as a whole and the outcomes of physical actions in the cognitive domain are not considered. Moreover, some seemingly obvious and quick solutions may even worsen the initial problem.

Thus, the challenge of EBO is to determine how to move from concepts and theories to processes and tools that overcome human cognitive limitations and which help decision makers design more effective and successful policies in a highly complex environment. This includes avoiding unintended consequences derived from choices made when implementing policies.

In this paper, system dynamics (SD) modelling is introduced as a tool to handle complexity and enhance learning from complex systems. SD is a conceptual framework supported by

José Carlos de Melo Júnior, melo@ita.br; Mischel Carmen Neyra Belderrain, carmen@ita.br; Ana Lucia Pegetti, anapegetti@usp.br

a mature methodology and has gained wide acceptance for the design of more effective policies and strategies through computer simulation models [10]. Grounded in the theory of feedback control and nonlinear dynamics, it has been applied to problems ranging from business strategy to public policy and war [8].

The aim of this paper is to present the potential of SD methodology for the planning and implementation of EBO, and to demonstrate the use of the methodology in conflicts. The remainder of this paper is organised as follows. Firstly, we provide an explanation of EBO and asymmetric conflicts. Secondly, an overview of the concepts associated with SD is presented. This is followed by an outline of a proof-of-concept SD model that replicates most of guerrilla conflict dynamics. The results of the simulation are presented and, finally, the potential of the methodology to gain useful insights into complex systems is discussed.

SD cannot be expected to be a panacea, but a way to provide clarity and understanding of phenomena that arise in the interaction of elements of complex systems. Overall, this paper intends to establish the case for the applicability of the SD as a decision making tool for planning and conducting EBO.

II. Literature Review

A. *Effects-based operations and asymmetric conflicts*

The environment in which operations occur have changed significantly over the past decades. Asymmetric conflicts have become the prevalent form of warfare all over the globe, replacing the traditional symmetric warfare in terms of geopolitical importance [2]. Accordingly, nation-states are more likely to fight, not other nation-states, but ethnic liberation movements, guerrillas, or even terrorists in their homeland [1].

Specifically in Brazil, most security threats are narcotraffic and guerrilla activity in the frontier region of the Amazon. In spite of the Colombian efforts against the Colombian Armed Revolutionary Forces (*Fuerzas Armadas Revolucionárias de Colombia* - FARC), the insurgency still represents a threat to the country's sovereignty – indeed several incidents between the Brazilian Army (*Exército Brasileiro*) and the insurgents reinforce this hypothesis [11]. Furthermore, there is still the possibility of the emergence of guerrilla movements inside the country.

Anderson [12] defines insurgencies as asymmetric wars or guerrilla groups that form for some revolutionary objective. Due to the similarity of concepts, guerrilla and insurgency are used with the same meaning in this paper.

Normally, the methods used by the insurgents to achieve the desired political power involve the use of irregular forces and tactics, such as sabotage, bombings, raids, religious extremism, political ideology and ambushes. There were almost 50 insurgencies around the world in 2011, and a great number of nations massively involved in such conflict [12]. Certainly, insurgencies challenge stability and security of established governments.

However, past conflicts demonstrated that most counter-guerrilla strategies fail more often than not [12]. The main reason for this failure lies in part in the differences between symmetric and asymmetric conflicts. While in conventional warfare both actors have great means and will, in asymmetric conflicts, there are differences of means and will between the opponents. The relationship between means and will and their impact on outcomes is summarised by Smith [1] in the following equation:

$$Probability\ of\ Success = Means\ x\ Will^2 \qquad (1)$$

As can be noted from the previous equation, an enemy does not have to be both determined and powerful to win, but only determined enough to overcome the disparity of means between themselves and the opponent. Given that, it can understood why the threats of retaliation and physical attacks, which work well in symmetric conflicts, are either difficult or ineffective to defeat: they are largely focused in producing quantifiable results and do not considered an enemy's behaviour [1]. However, the most critical element in asymmetric conflict is not the physical destruction, but the enemy's will to resist [12].

The misperception of this concept is what lead decision makers to respond to a symptom of a much deeper and less visible problem. People have a tendency to adopt an event-oriented worldview, interpreting experience as a series of events where each event has a cause closely linked in space and time [8]. However, cause and effect are rarely proportional or close. Moreover, people are unable to understand the full range of feedback and delay operating in the system due to their limited cognitive capabilities. As a consequence, some seemingly obvious solutions to guerrilla conflicts may fail or even worsen the initial problem. This is when the concept of EBO provides an answer [1].

EBO are about shaping behaviour, and encompass the full range of actions that may be necessary to induce a given response from an enemy, ally or neutral party. Its focus is on the creation of psychological or cognitive effects; physical destruction is just a factor to achieve them. Shifting the perspective to a systemic worldview, the approach allows decision makers to understand how operations can be better orchestrated in order to achieve the desired result. This means considering the system as a whole [1].

As warfare is a clash of complex adaptive systems that produces nonlinear behaviour, high leverage strategies are not often obvious [1]. The only practical way to learn and make better inferences about behaviour in complex systems is through simulation [8]. Under those circumstances, SD methodology has great potential in offering useful insights about the behaviour of systems while providing decision makers a tool to understand the complexity of conflicts [13].

B. *System dynamics*

1) Concept: According to Meadows [14], 'the system dynamics paradigm assumes that things are interconnected in complex patterns, that the world is made up of rates, levels, and feedback loops, that information flows are intrinsically different from physical flows, that nonlinearities and delays are important elements in systems that behaviour arises out of system structure'.

Broadly speaking, SD models are behavioural representations of systems. The behaviour of a system arises due to interactions of the elements that compound its structure (i.e., feedback loops, stocks and flows, and nonlinearities) [13].

SD is also a set of conceptual tools that allows a dynamic complex system to be represented as a feedback system, and a computer simulation approach that can enhance the understanding of system behaviour with the purpose of generating useful insights into situations of dynamic complexity [10]. Overall, it supports the decision making process and improves learning in complex systems and should be used in order to explore the nature of problems. In this way it a useful tool for the modeller to investigate what drives systems behaviour [15].

The methodology has been used in military and defence modelling in order to address many of the increasingly dynamic complex problems of military planning. Due to its effectiveness, the approach has proven successful in a wide range of operations, from political instability and conflict management to natural disaster management and counterterrorism simulations [10].

2) System structures: Mathematically, a SD model generally consists of a set of differential equations that describes their numerical solution through time [16]. The equations represents system structures through several diagramming tools, such as causal loop diagrams and stock and flow maps [8], shown schematically in Fig. 1.

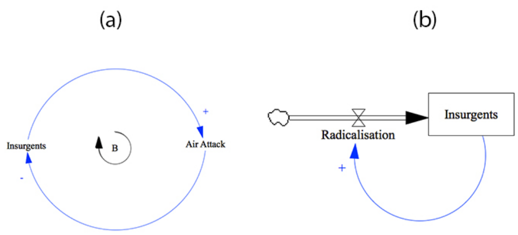
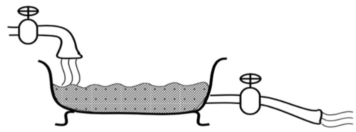


Fig. 1 - System structures represented by (a) causal loop diagrams and (b) a stock and flow diagram.

The relationships between the elements of a complex system are represented by arrows and can help to identify the feedback loops. A polarity (negative or positive) can be assigned to each relationship depending of the direction of the causal influences. Positive polarity means that increasing (or decreasing) the independent variable causes the dependent variable 'to rise above what it would have been (and a decrease causes a drop)'. Negative polarity means that increasing (or decreasing) the independent variable causes the dependent variable 'to decrease (or increase) beyond what it would have been' [8]. As causal loop diagrams are limited in many ways, they usually serve as a blueprint for the subsequent implementation of the stock and flow model [17].

Stocks and flows represent the core of dynamic systems theory. Stocks are accumulations that act as buffers and provide a kind of memory for the systems (mathematically represented by integrals). Flows are a set of differential equations that expresses rates of change which modify stocks. Sterman [8] uses the bathtub metaphor to explain the concept behind a simple stock-flow diagram, as seen in Fig. 2.

Hydraulic Metaphor:



Stock and Flow Diagram:

Integral Equation:

$$Stock(t) = \int_{t_0}^{t} [Inflow(s) - Outflow(s)]ds + Stock(t_0)$$

Differential Equation:

$$d(Stock)/dt = \text{Net Change in Stock} = Inflow(t){-}Outflow(t)$$

Fig. 2 - Four equivalent representations containing the same information [8].

All SD models rely on just two forms of feedback loops: positive and negative. Positive loops are self-reinforcing and describe the interactions where elements reinforce one another. Negative loops are self-correcting and counteract change. All systems consist of networks of these two kinds of loops and all nonlinear dynamic behaviour of a system arises out of the interplay of these loops [8].

Due to the limitations of human cognitive capabilities, individuals are often unable to understand the full range of feedback interactions and delays in a system. Adopting an event-oriented approach to problem solving will lead to the implementation of immediate solutions. However, taking action that is seen as obvious in the short-term may fail. The problems could worsen or even become irreversible [18]. As stated by Sterman [8]:

> '. . . people seeking to solve a problem often make it worse. Our policies may create unanticipated side effects. Our attempts to stabilise the system may destabilise it.'

As the complexity of systems overwhelms our cognitive ability, simulation is the only practical way to understand and learn effectively about the behaviour of complex system models. SD methodology was designed specifically to test hypotheses and evaluate the most likely outcomes of policies through simulation, and it is a powerful tool for planning EBO [8].

III. System Dynamics and Effects-Based Operations: A Counter-Guerrilla Example

The purpose of this section is to take a first step towards developing a model which will aid the understanding of guerrilla warfare behaviour. This is done by simply replicating most of its dynamics in an approximate sense. The model is based on the Joint Publication 3-24 (Counterinsurgency) [2] policy recommendations and supplemented with theories from other sources ([19], [12], [20]).

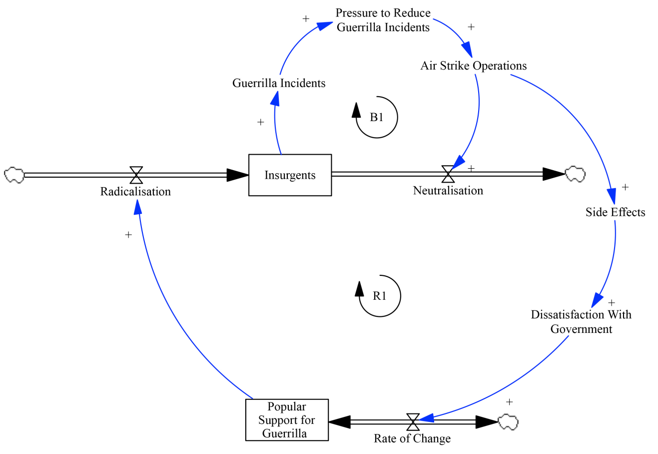


Fig. 3 - Guerrilla suppression and creation structures.

Most studies agree that a critical element of counter guerrilla strategy is decreasing popular support for the guerrilla movement. The conflict between the insurgents and the government for the support and loyalty of the people is the main characteristic of this kind of conflict, and is proven to be key in successfully suppressing guerrilla activities. Insurgents attempt to increase their support by coercion, fear or even apathy of local population. Popular support for guerrilla movement can be understood as supporting new recruits, harbouring ammunition and supplies, or even providing intelligence to the insurgents [20], [12], [2], [19].

In asymmetric conflicts, the strategies must be different from those used in symmetric conflicts. Decision-makers must see the system as a whole and understand the impact of physical actions on the cognitive domain. For example, the use of kinetic (search-and-destroy) operations may validate the guerrilla's cause in the minds of population due to its collateral damage. With more people supporting the guerrilla's purpose, more insurgents can be recruited. Thus, instead of suppressing the movement, we would escalate it [2].

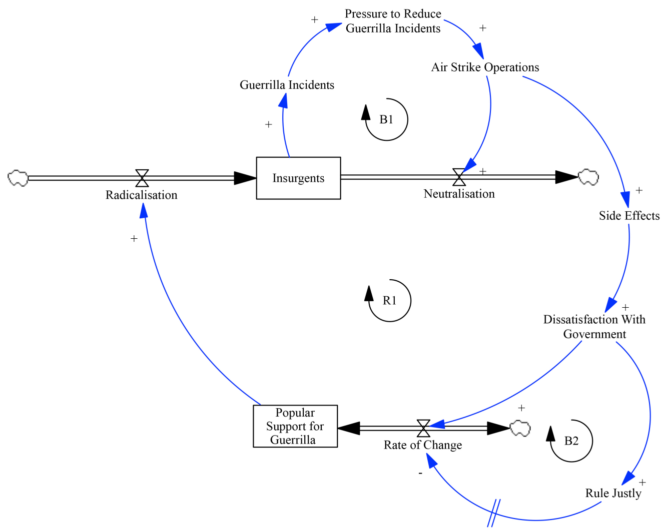


Fig. 5 - In this second model a new balancing loop *B2* is included.

The basic guerrilla suppression and insurgent recruitment loops are represented in the first model (see Fig. 3). Firstly, an increase in the number of insurgents result in an increase in the number of guerrilla incidents (e.g. bombings, raids or other activities). Over time, the number of incidents increases pressure on the Brazilian government to provide the security of population. The pressure to reduce guerrilla incidents then leads to squadrons to undertake air strike operations, which result in the neutralisation of insurgents. This sort of loop (*B1*) is termed a 'balancing loop', once an increase in the number of Insurgents will result in a pressure to reduce it.

Initially, the direct action reduces the stock of insurgents, which begins at 100, but almost any decision carries a long-term consequence – in this case, diametrically opposed to the short-term consequences. The air strike operations also produce side effects (i.e. collateral damage). The dissatisfaction with government then increases the rate of change and, consequently, increases the popular support for guerrilla move-

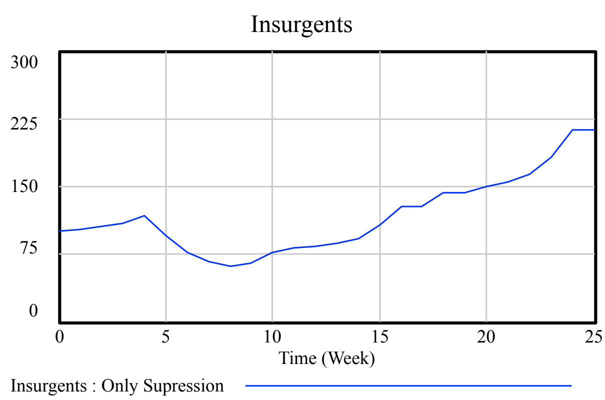


Fig. 4 - The dynamics of complex systems can result in counterintuitive behaviour. In this case, a purely attrition-based approach worsened the problem.

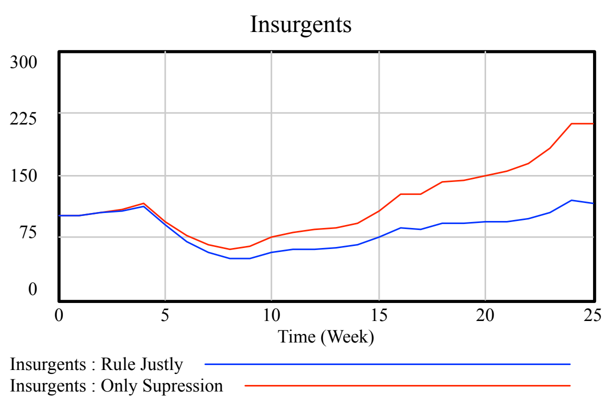


Fig. 6 - Although the measures for appeasing popular grievances had a positive impact on the model, it is still not enough to suppress the guerrilla movement.

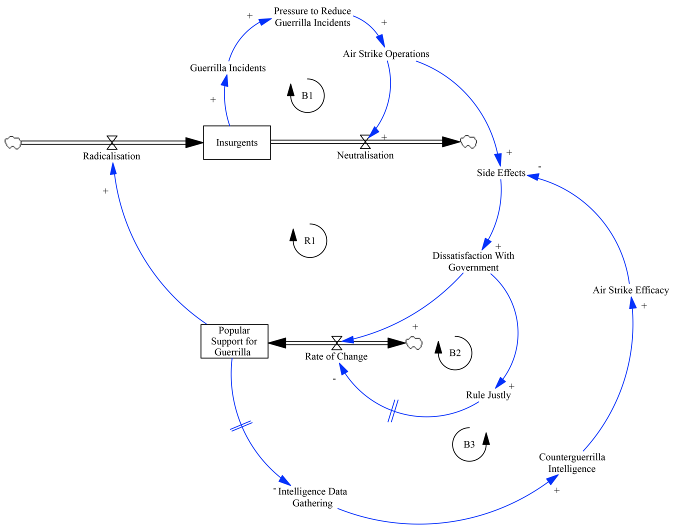


Fig. 7 - In this complete model an intelligence loop is added. It has a nonlinear impact in popular support for a guerrilla movement once it allows for the reduction of collateral damage.

ment. This leads to the radicalisation of a certain percentage of the local population, who in turn become insurgents (Fig. 4). This sort of loop (*R1*) is termed a 'reinforcing loop', as the dissatisfaction with government increases the popular support for guerrillas and hence increases the number of insurgents.

Feelings of resentment have a tendency to develop faster than feeling a sense of security [20]. As a result, the reinforcing loop *R1* will have a shorter time duration than the balancing loop *B1*. Consequently, the simultaneous interaction between the variables decreases the number of insurgents initially, but then the numbers begin to grow. This results in an upswing in the number of insurgents.

Although direct air strike operations create side effects, they are still necessary to provide security to the population. However, the government's efforts should simultaneously seek to reduce the popular support for the guerrilla movement through measures that resolve popular grievances (i.e. medical clinics, food, shelter, power and security). Moreover, the combination

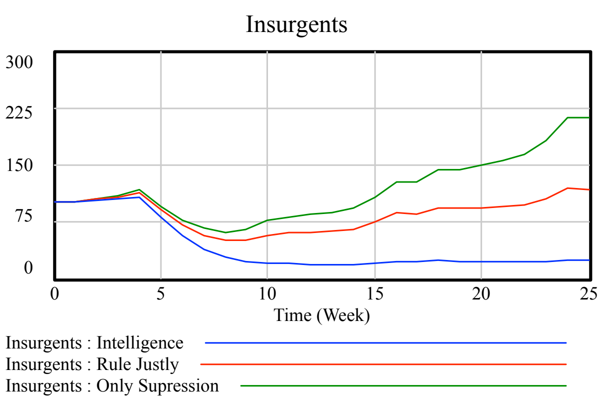


Fig. 8 - The last scenario supports modern counter-guerrilla theory that the most critical factor to successfully suppress guerrillas is to reduce popular support for their cause.

of these measures with policies, such as economic stimulus to reduce unemployment can have a great impact in increasing the legitimacy of the government [2], [12].

The balancing loop *B2* in the second model (see Fig. 5) includes the *Rule Justly* variable, which involves many measures that address some of the most severe popular grievances. As there is a delay between the actions of *Rule Justly* and the perception of population, its effects are not immediate.

The simulated results of the updated model compared with the first case are presented in Fig. 6. The effects of this new balancing loop resulted in a more effective policy when compared with the first case. However, the number of insurgents remains higher than the beginning of the simulation, which means that the measures to appease popular grievances are not enough to suppress the guerrilla movement.

Finally, intelligence contributes to a more reliable and holistic understanding of the conflict environment. Moreover, it is essential to more effectively target and neutralise insurgents per attack, coupled with the reduction of collateral damage. This means more surgical air strikes. However, the intelligence gathering effectiveness is related to popular support. As popular support for guerrilla movement increase, less people are likely to contribute information. On the contrary, if people feel secure and recognise the government legitimacy, the military will more likely acquire more intelligence [2], [12].

In Fig. 7, another loop is added, reflecting the use of intelligence. While the popular support for the guerrilla movement decreases, the intelligence data gathering increases. When people feel secure, they tend to retribute by providing intelligence data such as information about guerrilla activities and cadre members [20], [2].

There is a delay between perceived security or legitimacy and the use of collected data to counter-guerrilla intelligence. Better information will provide more specific targets. Better air strike efficacy will also decrease side effects.

Fig. 8 shows that under this simulated scenario, the number of insurgents remains almost the same in the short-term due to delays in the system. However, when the measures to appease popular grievances (*Rule Justly*) and the increase use of intelligence begins to dominate the model, the number of insurgents falls into a downward trend.

The results of the model support the policy recommendations of Joint Publication 3-24 (Counterinsurgency) [2]. In the final analysis, the first simulation showed that a purely attrition-based approach against insurgents increased the rate of radicalisation, which escalated guerrilla activities rather than suppressing them. The second simulation demonstrated that the combination of kinetic operations with measures to resolve popular grievances slowed the rate of radicalisation, but did not stop the number of insurgents. In the last simulation, more effective air strikes attacks helped to decrease side effects and, consequently, the popular support for guerrillas. In the final analysis, guerrillas cannot exist without popular support. The government must focus its efforts in reducing the support for insurgent while increasing its own legitimacy. This will prevent the insurgent's cause to be validated in people's minds, and motivate them to contribute information. More intelligence gathering means more reliable and holistic

ISSN:1983 7402

understanding about the conflict. Consequently, more surgical attacks are carried out with less side effects, which suppresses the guerrilla movement in the long-term.

IV. Conclusions

To succeed in a modern operating environment, it is necessary to shift the focus from a contest of means to a contest of will. Operations are no longer purely or even predominantly military in nature. Instead, they require a balance between military and non-military means to create effects in the cognitive domain. EBO has caused a paradigm shift in the way we plan and conduct military operations by changing our focus from damage and targets to behaviour and stimuli that influence behaviour. Specifically, it has provided a new way of fighting asymmetric conflicts against non-state actors such as terrorism organisations and guerrilla movements.

However, the power and promise of EBO lies in how we move from concepts and theories to tools and processes that help us design better strategies. As demonstrated in this paper, the capacity of the human mind to understand complex system behaviour is very small. Strategies fail because people are often unable to see the long-term consequences of their short-term actions. With this in mind, we introduced SD methodology as a way to handle the inherent complexity of conflicts.

SD has been demonstrated to be useful in the planning and implementation of EBO. In particular, a proof-of-concept model was used to illustrate how dysfunctional behaviour can arise from systems and how seemingly obvious short-term solutions to problems can fail and even worsen the initial problem. By understanding certain system characteristics and the long-term consequences of physical and immediate actions, we were able to change the focus for producing effects in the cognitive domain. The results offer an incentive for further application of SD to EBO. Despite certain limitations in the model, this work has provided evidence of the value of SD methodology.

SD is fully consistent with the main assumptions underpinning EBO and represents a useful tool for strengthening and complementing decision makers' analyses. In particular, the methodology provides insights into the structure and dynamics that arise from the simultaneous interactions of elements. The ideas described in this study have the potential to contribute to an improved understanding of the use of SD for planning and conducting EBO in FAB.

References

[1] E. A. SMITH, "Effects Based Operations: Applying Network Centric Warfare in Peace, Crisis, and War". DOD Command and Control Research Program, CCRP Publication Series, 2003.
[2] UNITED STATES OF AMERICA. "Counterinsurgency: Joint Publication 3-24". Joint Publication, Washington DC: US Government, 2013.
[3] J. P. HUNERWADEL, "The Effects-Based Approach to Operations". Air & Space Power Journal, v. 20, n. 1, p. 53–62, 2006.
[4] UNITED STATES OF AMERICA. United States Air Force. "Air Force Doctrine Document 2. Operations and Organization", 2007.
[5] M. ZAWADZKI, "Metodologia para Avaliação de Operações Planejadas com Foco na Geração de Efeitos". 2009. 142f. Tese de mestrado, área de Produção - Instituto Tecnológico de Aeronáutica, São José dos Campos.
[6] H. COSTA MARQUES, "An Inference Model with Probabilistic Ontologies to Support Automation in Effects-Based Operations Planning". 2012. 161f. Thesis of Doctor of Sciences in Computer Science - Instituto Tecnológico de Aeronáutica, São José dos Campos.
[7] E. BARRIOS, "Diagramas de Influência para Comando e Controle no Processo de Seleção de Alvos sob o enfoque de Operações Baseadas em Efeitos". 2008. 148f. Tese de mestrado, área de Produção - Instituto Tecnológico de Aeronáutica, São José dos Campos.
[8] J. D. STERMAN, "Business Dynamics: Systems Thinking and Modeling for a Complex World". New York: McGraw-Hill, 2000.
[9] M. A. CRONIN, C. GONZALEZ, J. D. STERMAN, "Why don't well-educated adults understand accumulation? A challenge to researchers, educators, and citizens". Organizational Behavior and Human Decision Processes, v. 108, n. 1, p. 116–130, 2009.
[10] J. P. THOMPSON, S. HOWICK, V. BELTON, "Critical Learning Incidents in system dynamics modelling engagements". European Journal of Operational Research, v. 249, n. 3, p. 945–958, 2014.
[11] G. R. Da Silva, "FARC's Influence in Brazil". Kansas: School of Advanced Military Studies, 2013
[12] E. G. ANDERSON, "A dynamic model of counterinsurgency policy including the effects of intelligence, public security, popular support, and insurgent experience". System Dynamics Review, v. 27, n. 2, p. 111–141, 2011.
[13] J. STERMAN, R. OLIVA, K. LINDERMAN, E. BENDOLY, "System dynamics perspectives and modeling opportunities for research in operations management". Journal of Operations Management, v. 39-40, p. 1–5, 2015.
[14] D. H. MEADOWS, "System dynamics meets the press". System Dynamics Review, v. 5, n. 1, p. 69–80, 1989.
[15] W. RASHWAN, W. ABO-HAMAD, A. ARISHA, "A system dynamics view of the acute bed blockage problem in the Irish healthcare system". European Journal of Operational Research, n. 1, p. 276–293, 2015.
[16] N. HOWARD, E. CAMBRIA, "Development of a Diplomatic, Information, Military, Health, and Economic Effects Modeling System". International Journal of Privacy and Health Information Management, v. 1, n. 1, p. 1–11, 2013.
[17] C. NEUWIRTH, A. PECK, S. P. SIMONOVIĆ, "Modeling structural change in spatial system dynamics: A Daisyworld example". Environmental Modelling & Software, v. 65, p. 30–40, 2015.
[18] P. M. SENGE, "The Fifth Discipline: The Art & Practice of the Learning Organization". New York: Currency Doubleday, 1997.
[19] E. G. ANDERSON, "An initial simulation model for aiding policy analysis in urban insurgencies". IEEE PRESS. Proceedings of the 39th conference on Winter simulation. 2007. p. 1168–1176.
[20] J. BAKER, "Systems thinking and counterinsurgencies". Parameters, US Army War College, v. 36, n. 4, p. 26, 2006.