System Dynamics and Defence Analysis

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Introduction

Operational Research (OR) had its origins in the need to make decisions about the use of resources in support of national defence. The specific case was the invention of radar in the late 1930's and the military problem was to decide how this new technology could best be employed, in conjunction with the existing assets, such as fighter aircraft, for the air defence of the United Kingdom. It was, in short, necessary to conduct research into how military operations could be carried out, and hence the discipline was born. In fact, for the last 50 years, the military have been major users of mathematical modelling. System Dynamics is, however, a relatively new tool in military analysis. This paper surveys a few published applications and suggests reasons why SD is particularly appropriate for certain classes of military problems. The paper then goes on to discuss the potential role of SD in the analysis of strategic problems. Finally, some problems of military theory are discussed.

System Dynamics and Military Tactics

One of the difficulties in surveying work in any military related field is that much of the published work is in classified sources. This makes it difficult to assess exactly how much work has been done, but it is clear that little use has been made of SD until fairly recent times. This is especially true if one ignores applications of SD to defence logistic and manufacturing problems which, though they relate to military equipment, deal with functions and processes which are not, of themselves, directly to do with military operations. Indeed, the only papers known in the open literature which apply SD to the tactical level of military operations are Coyle (1983, 1985A) and Wolstenholme and Al-Salusi (1987). Even such a small sample as these three papers indicates some interesting aspects of the characteristics of SD which, it is believed, make the approach especially appropriate for military analysis.

There is no doubt at all that military problems are very complicated. Many factors interact in any given case and the problem for the military commander is to maintain a clear view of the interactions. The first two papers show the use of the qualitative aspects of SD (Wolstenholme and Coyle, 1983) in the portrayal of complexity. In each case, the elements of a very complex problem are represented on one piece of paper and, by applying qualitative analysis to the feedback loops, one can arrive at insights into policy options. Indeed, in the study of counter-insurgency operations, one can indicate in very broad terms the balance to be struck between different kinds of responses by the government forces. One can also relate the properties of the diagram to the four classic phases of revolutionary war. It is, incidentally, very curious that some of the mechanisms present in the counter-insurgency case also occur in the treatment of psycho-geriatric hospital patients.

The third paper is a more 'classical' SD approach using a simulation model to evaluate tactical options for the use of artillery against attacking armour. The fascination of this work is the extent to which the authors have gone beyond the simple calculation of losses, which characterises a very large part of military OR, and have allowed for such aspects as the effect of artillery in disrupting and confusing an enemy attack. This is much to be welcomed as there is a large amount of historical evidence that casualties, per se, have little to do with the outcomes of military engagements. The other noteworthy aspect of this work is the inclusion of variables such as 'momentum'. This is a classical military concept, much used in Soviet military writing and highly credible to military men, but often excluded from standard military OR. In this paper, momentum is represented by the physical analogy of mass*velocity. While that has an interesting parallel in the concept of organic mass (Simpkin, 1985) it raises a challenging research question of the best formulation to use for this important military variable. At a more technical SD level, the tank tactics study makes heavy use of optimisation of the SD model and thereby illustrates the most powerful development in SD 'technology' since the field was established. (Keloharju, 1982; Coyle 1985B).

The Military Credibility of System Dynamics

These military applications illustrate two or three aspects of the SD discipline which, the author believes, make it particularly appropriate to military use. The first is the ability to deal with, and portray, complexity. That is not at all the same thing as being able to handle detail. Many military models other than SD can do that and some, in fact, go into the most unbelievable level of detail. Models requiring the equivalent of 20000 lines of FORTRAN code are by no means uncommon. The qualitative phase of SD, on the other hand, by reducing the complexities of a problem to an influence diagram on one side of paper has the power to engage and hold the attention of military decision makers. The value of the diagrams really lies in their use as agenda for discussions. They support the kind of wide-ranging debate which is conducive to fresh thinking about difficult problems. The qualitative approach has, indeed, proved so attractive that it is now regularly taught to military students at Shrivenham, though it may be many years before it becomes standard procedure within the MoD.

The diagrams are acceptable precisely because they portray the feedbacks which the military clients intuitively know to exist in their real world. The clear identification of time delays is also important. The other attractive aspect of SD for military use is the ability to transform the diagram into a simulation model. This makes the model much less of a black box to the client because it is simply the diagram they can accept rewritten into equations. The clarity and acceptability of the influence diagrams is thereby linked, very naturally, to the clarity and simplicity of SD coding. This allows military officers to learn, very quickly, to build their own models, with, perhaps, very limited support from an analyst.

To give a few examples, officer students at Shrivenham have built simulation models of, for example, the preparation of a parachute regiment for an airborne assault. This is a complicated problem, involving the preparation of up to 1000 men and a large number of vehicles. Each vehicle has to be inspected, and rigged with parachutes after which the riggers themselves have to dress in parachute equipment. The whole set of tasks has to be completed at the correct times for aircraft departure in order for the right numbers of men and equipments to arrive over the target in the successive assault waves called for by the tactical plan. The preparation has to be done in limited space and through several potential bottlenecks. The value to the planner is to be able to work out who has to move at what time, and in what order various tasks have to be accomplished, so the problem is of considerable military practicality. A team of three students built a model of several hundred lines of COSMIC code, and validated it against their own practical experience and data from exercises in a period of three weeks. In a similar study, another group of officers built, validated and used a model for the movement of reinforcements. A third team developed an influence diagram of air defence; the result being a useful framework for the management of other studies of this complex and costly area.

The problems of introducing SD usually lie with military analysts who, quite reasonably, sometimes tend to be unenthusiastic about new approaches until they can be convinced by real results. There can, in addition, sometimes be real problems with obtaining acceptable data and it is usually necessary to be rather cautious about going beyond the influence diagram into model construction. However, a balance must be struck between excluding a known factor because no data are available and including it with rough estimates of parameter values. To exclude a known factor is equivalent to including it with a parameter value of zero, which is the one value which is known to be incorrect. In practice, the analyst must use his judgement and, usually, qualify his results to reflect parameter uncertainties. He is, however, much assisted by the use of the simplifier variant of the SD optimisation approach. That can often give good indications of how 'important' a model segment is to overall behaviour and thereby casts light on the data problem.

Strategic Modelling Problems

The work described above relates mainly to tactical problems where the issue is how an operation might be carried out or how existing equipment might best be used. There is, however, a 'higher' or strategic level of military analysis which deals with the study of overall defence capabilities in relation to strategic goals, political objectives and geographical realities. This was, indeed, the subject of an early SD model of defence problems (Coyle, 1981).

The nature of the decisions involved is well illustrated by documents such as national defence reviews, of which Canada (1987), Dibb (1986) and West Germany (1987) are good examples. Clearly, at this level, one is dealing with some very fundamental issues, involving colossal levels of expenditure and grave risks if the 'wrong' answer is put forward. What then, is the role of SD at the strategic level of analysis ?

There is no doubt, as far as the author is concerned, that the role of any analyst at this level should be characterised by modesty. To pretend, or even to believe, that one can provide definitive answers to such broad questions as the relative sizes and operational roles of the army, navy and air force would be the utmost folly. Such problems are far too difficult and far-reaching for solutions to emerge from any one approach, no matter how powerful one knows it to be. The best that can be hoped for is to support other thinking and to try to add clarity to what is, at best, a very cloudy area. This carries with it the obligation to be aware of other approaches and methodologies, especially those which make systematic use of expert opinion. With that caveat, one can imagine two type of problem in which SD can have a valuable role. They two types will be illustrated here by imaginary and hypothetical examples.

The first illustrative problem is that of handling the geographical facts of military life. Faringdon (1986) gives a fascinating tour d'horizon of the geographical aspects of the military confrontation between the nations of NATO and the Warsaw Pact. He describes in some detail the well-known fact that NATO nations contribute in different ways to the common defence and that these contributions are heavily influenced by geography.

At a hypothetical level the problem can be shown in a simple influence diagram, Fig 1. This suggests that an area, A, supports air bases which are protected by land forces. The air bases generate sorties of aircraft which can be used to defend A itself or to support naval operations in an adjacent sea. For simplicity, we will assume that the aircraft are capable of either operation, though that is not generally true. The problem for the commander is whether to use his air forces to defend the land or to ensure that sea borne reinforcements can reach him. He requires a broad idea of what to do in different circumstances, and such broad ideas are called concepts of operations. The peace-time defence planner has to decide whether to spend available money on land, sea or air forces, or on more air bases, stocks of ammunition, fixed defences such as coastal forts or on command and control facilities. In fact, there are a host of other possibilities.

Clearly, the concept of operations is influenced by the forces and other assets available. On the other hand, providing a different balance of assets might make another operational concept feasible. In practice, the concept should make the best use of available forces but the forces underpin the concept and make it feasible. This, in very brief form, is the essence of military planning and the author knows of no modelling methodology other than SD which even comes close to being able to analyse such matters. Certainly, building a very large simulation model, involving tens of thousands of lines of FORTRAN, is about the worst possible approach. What is required is a depiction of the complexity and interactions so that the problem can be thoroughly understood and so that new ideas can emerge. That is of cardinal importance, as planning is about imagination. The qualitative thinking, while of fundamental importance, only takes one so far as decisions have to be made about whether to buy (or cut) 10 fighters, one frigate or two battalions. To do that requires a quantitative model, though one should not pretend that such a model can predict the outcome of anything as complex and chaotic as a war. SD models for this type of problem have been developed; an example is given in Coyle (1984).

Problems in which one is concerned with the interaction between concepts of operations and force capabilities in a given geographical context address essentially static issues. The military planner has to deal with the evolution of capabilities as time passes and equipment programmes take effect. A planning period of 10 years is quite typical. It is impossible to know what new technological developments will take place over that time span, and the extent to which promising technologies will prove to be unsatisfactory over that period is similarly opaque. The planner therefore really requires to have broad indications of priorities for defence improvements. However, the priorities have to be related to war fighting capability in specified geographical contexts. There is, therefore, a clear link with the kind of study referred to above.

One possible approach to the time-dependent prioritisation problem is to use the COSMOS optimisation software to represent the effects of increments of expenditure. Each tranche of money might represent the next 5 years of defence expenditure so that three tranches would correspond to the long-term financial plan for the next 15 years. A performance index might be defined to reward the ability to maintain control of a given geographical area, but to penalise overspending of the budget. The parameter values are suitable descriptors of force composition, such as numbers of air defence aircraft, and the parameter ranges correspond to excursions on either side of existing force levels. Optimising the model three times, once for each of the 5-year planning periods, might allow one, after careful study of the optimisation results, to deduce that the first priority is, say, to increase airfield defences to a certain point. Once that has been achieved, one can build up the air force, and finally, the navy's patrol boat capabilities should be expanded. (It should be stressed that these are purely imaginary and illustrative examples of the **type** of results which could be derived from such an approach)

Military Theory

One of the standard sources of information for any modeller is the theory of the problem being addressed. System Dynamics modellers have, in the past, proved remarkably adept at extracting theory from other disciplines and using it as the basis for their models. A particular example is the modelling of biological processes, though there are many other cases. Indeed, one suspects that some of the criticism of SD in the past has not been for misusing theory from other disciplines but for making more of it than the originating discipline had been able to do. In applying SD to military problems, and not only at the strategic level, there is the opposite problem that military theory is very scanty and unsatisfactory. There are, to be sure, the 'principles of war', but these are usually expressed at such a broad level of generality that they seem like little more than vague precepts. For example, the importance of seizing the initiative is usually stressed but what the initiative is, how one knows when it has been seized, and how much it matters if one does gain it are left to the individual aided, perhaps, by some historical examples. The trouble is that for every example, there is at least one counterexample.

This leads one to wonder whether the problem could not be turned round and SD be used to develop military theory. Fig 1, even in its simple form, clearly shows the presence of negative and positive feedback. The former represents command and control, and the constraints of military resources and logistics. The latter seems to relate to the idea of the accelerating collapse of a defeated force. It might, therefore, be possible to relate the relative power (represented, perhaps, by gain and delay) of different loops to the underlying causes of military outcomes. From that, it might be possible to make intellectually coherent connections between concepts such as seizing the initiative, concentration of force, selection and maintenance of the aim, and the other principles of war. That would be fascinating study and one hopes to report on progress in due course.

Summary

This survey of the role of SD in military analysis has touched on a number of issues. The signs are encouraging that SD has a useful role to play in this complex and important area. The clarity of the influence diagram seems to carry great conviction with military clients. The scope of the software allows one to model practically any problem, no matter how complex. The underlying point of view of SD, namely that dynamic behaviour is important to the health of a system and that such behaviour is produced by the interaction of management, or command, decisions, the inherent physics of the situation, corresponding got force composition, and the effects of exogenous shocks, reflecting the actions of the enemy seems to match very well with the nature of military operations, both as they are and as they are believed to be by the clients for the work.

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