Background Paper
On
System Dynamics as a Tool for Effects Based Operations (EBO) Analysis

Abstract.

Effects Based Operations (EBO) analysis requires simulation to capture the cause-effect relationships in logical interdependencies. This is particularly true when the problem is less linear and more dynamic, when the problem contains feedbacks and/or delays, when the question mixes dissimilar systems, when particular subsystems or technologies are of central interest, or when the problem contains human factors. Solutions to these types of problems need the support of a systemic architecture discipline and are benefited from an intuitive quick means of developing computer simulations.

Introduction: Effects Based Operations (EBO)

In Effects Based Operations analysis the first key point is to define and understand the exact desired effect. This is an iterative process of one or more people who have knowledge and understanding of the systems and processes involved. The next two steps are to develop a solution hypothesis and the associated primary parameters, which portray cause-effect relationships. This hypothesis building likely starts as a “if this, then that” discussion.

If the “effect” is defined at a very high level, e.g. “win the war in three months”, it may need to be broken into a logical set of sub-effects. For example, a series of missions can comprise a military campaign. Another difficult task in this work is to characterize the system directions related to human factors (awareness, fear, fatigue, ingenuity etc.). System Dynamics is ideal for solving complex problems of the EBO category.

Introduction: System Dynamics (SD)

System Dynamics is a discipline to develop realistic conceptual models of systems. It is coupled with simulation tools to aid in this development and the subsequent testing of the candidate solutions. First developed in the 1950s at the Massachusetts Institute of Technology (MIT) it continues to be part of the graduate curriculum at that and other universities. A System Dynamics Society has membership in over 30 countries and publishes a quarterly periodical.

The discipline also has a number of SD companies that offer tools and training. The tools provide the model developer with the usual array of math functions plus simple graphical means to build complex simulation difference equations. They often include a library of generic constructs of past system problems to support the training and to serve as start-points for new problems. Figure 1 shows a simple SD construction and the four basic geometric elements for building such simulation models. This depiction is based on a commercial PC based application called *iThink* tm by High Performance Systems, Inc.

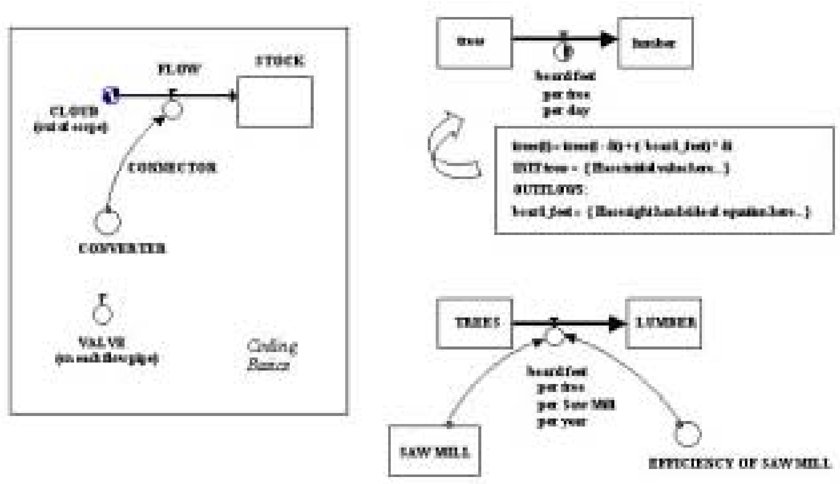


Figure 1. Systems Dynamics (SD) Building Blocks and Simple SD Construction

SD enables EBO studies due to its attributes:

- Feedback loops and time delays that can expose surprises such as dynamic behavior, indirect effects or unintended consequences
- Time-delays that simulate real world event sequences
- Vertical integration, or "drilling down", that allows digital system models (DSMs) to be realistically represented by their supporting sub-systems or technologies of interest to the customer or stakeholder
- Horizontal integration that allows symbiotic coupling of disparate systems; and enable a system-of-systems for an overall mission or campaign representation
- Methods to handle non-quantitative people-oriented variables such as perceived success/failure, word of mouth influence, etc.
- Probabilistic functions to representation random chance variation

Based on the above points and discussions it is the author's belief that SD and EBO are one in the same. Others may better accept that SD very well models EBO.

Examples of SD Use in Military EBO Model Development

Four categories of EBO studies shall be examined by example:

- Direct effects
- Indirect effects
- Undesired effects
- Unexpected effects

The approach to SD (or EBO) modeling is to build the simulation to answer the specific question or hypothesis. This means avoiding (the quagmire of) building a general model to answer all situations. It bounds the problem to primary cause-effect parameters, and hopefully avoids an incorrect or marginal EBO mental model development.

<u>Direct Effects</u>. A simple attrition combat between two antagonists is shown in Figure 2. The model is highly aggregated, which might suit the Air Force analyst characterizing a combined weapons land battle, or likewise the Army analyst representing an air-to-air battle. Note, it could be defined to represent specific weapons: infantry, or tanks, or submarines, or artillery, etc. The lethality factors (shown by the circled converters) could be deterministic, e.g. “kills-per-soldier”, or could include a probabilistic modifier such as “soldier-combat-experience”, or “weapon lethality”, etc.

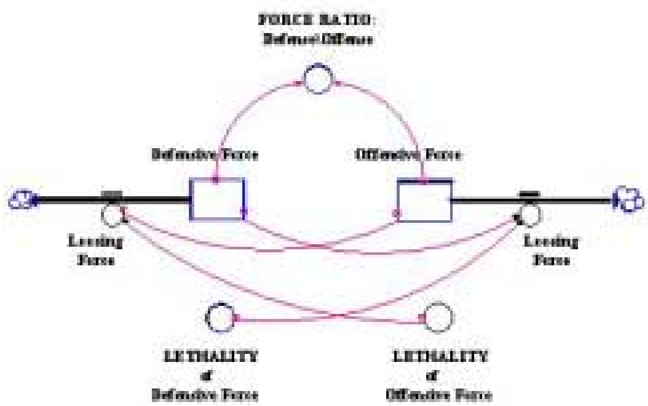


Figure 2A. Simple Attrition Combat

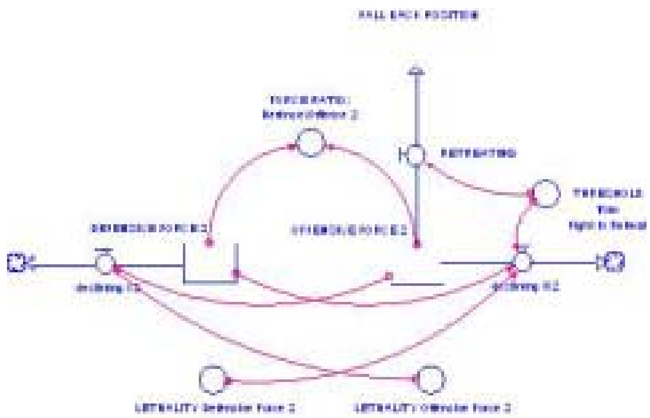


Figure 2B: Retreat Additive To Simple Attrition Model

The simulation output is force size as a function of the initial size and combat time. In this case it was also represented as a force ratio; attackers divided by defenders. If a ratio of 6-to-1 were defined as a “win”, the defending force would win in 25 days. This may be based on a scenario where the terrain allows the defender to have a much lower attrition than the attacker. Figure 2B adds some realism by allowing the force being crushed to retreat when a attrition threshold is reached. Figure 3 shows the output of the 2A example; it also shows the model is essentially linear.

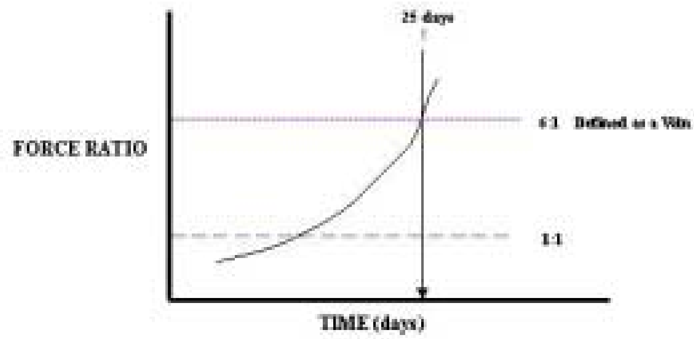


Figure 3. Output of Figure 2A Example

An attacker's goal may be to flatten his attrition curve. The following construction would be such an attempt.

<u>Direct Effect; including Horizontal Integration</u>. Shown in Figure 4 is the previous model of Figure 2A expanded to include four other systems contributing to the same mission. It may also have been constructed to answer the relative impacts of Close-Air-Support (CAS) and/or Interdiction on the land battle. For example, how many combat days could be eliminated while striving for a Force Ratio of 6:1?

Ultimately a best joint force is likely desired. It may be based on minimum costs (operational or life cycle), or minimum losses, or minimum time, etc.

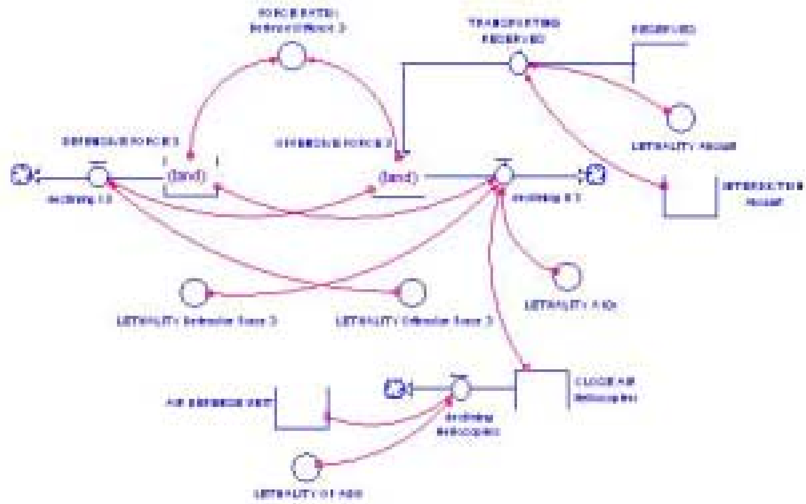


Figure 4. Figure 2B Example Expanded

Direct Effect: the Flanking Movement. A different attempt to flatten the attacker's attrition curve may be a change in tactics from a frontal assault to a flanking movement shown in Figure 5. This construction includes a modification to the simulation stock (reference Figure 2). It is called a "conveyor", and like an ordinary conveyor, represents force movement (explanation in Figure 6).

The rationale would include a time delay to represent vehicle speed over a specific terrain. The lethality of the attacker vs. defender would also be adjusted to represent a benefit to the attacker for preparation and surprise, and a penalty to the defender for the need to prepare a hasty defense with rear area support forces.

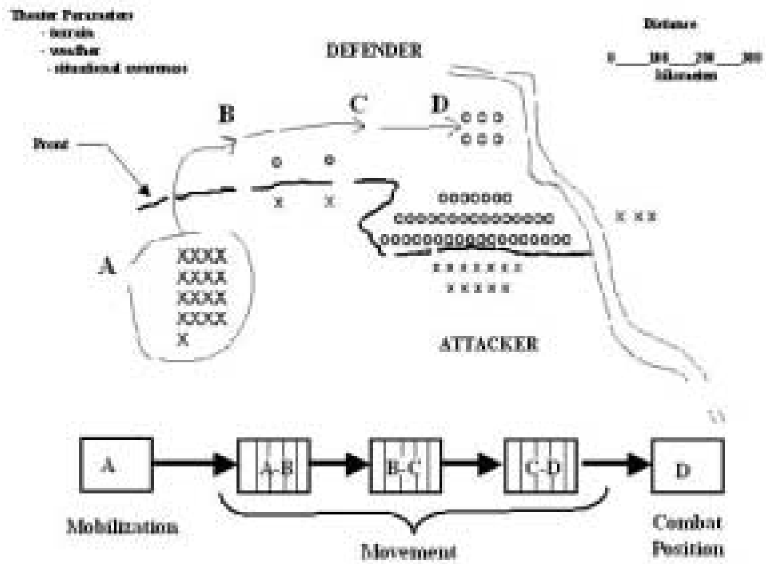


Figure 5. Example Flanking Movement

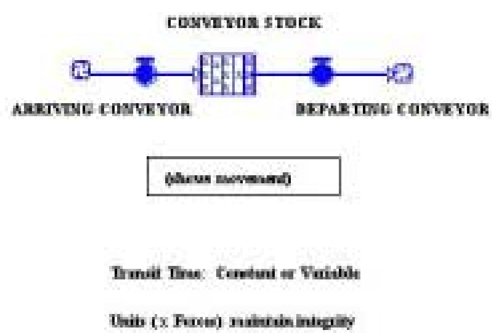
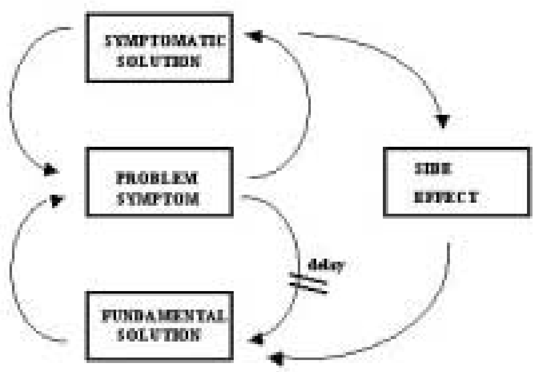


Figure 6. Conveyor as a Force Movement Representation

<u>Indirect Effects</u>. In the plan of an actual flanking operation, the Battle Staff would add and vary parameters to assess best/worst case scenarios (weather vs. speed, defender's intelligence vs. surprise, etc.). If these are evaluated to be significant to success and are of high risk, they become <u>Direct Effects</u>. The "Weather in Flanking" is an example of a vertical scope expansion. The more difficult is the horizontal scope expansion, e.g. if the "Flanking" is successful, what are the enemy's (good) options? This is the case of thinking 3 or 4 moves ahead in chess. Thus, the original scope of the envisioned solution (the Direct Effects architecture) must be expanded/tested until the analyst is certain that the indirect effects do not negate the intended purpose, or provide Undesired Effects.

<u>Undesired Effects</u>. Figure 7 shows a cause-effect diagram, which includes an undesired effect. The omission of the fundamental solution may be an oversight or due to its difficulty or time to effect.



reference: "The Fifth Discipline"; Peter Senge

Figure 7. Cause and Effect Diagram (includes undesired effect)

A number of military situations come to mind:

- Inadequate battlefield preparation (deploying into a strong anti-access force)
- Battlefield fragmentation (USN & USAF in an uncoordinated air campaign)
- Inadequate combat support (lack of electronic warfare (EW) assets)
- "A Bridge Too Far" (a single narrow vulnerable attack route)

Figure 8 and 9 show an example of an Undesired Effect, due to a weapon utilization mistake. A marginally sized attacking force may be tempted to a 100% use of a limited supply of smart weapons (showing short term results), whereas a judicial use may definitely win the war albeit taking a longer time, but with less logistics risk.

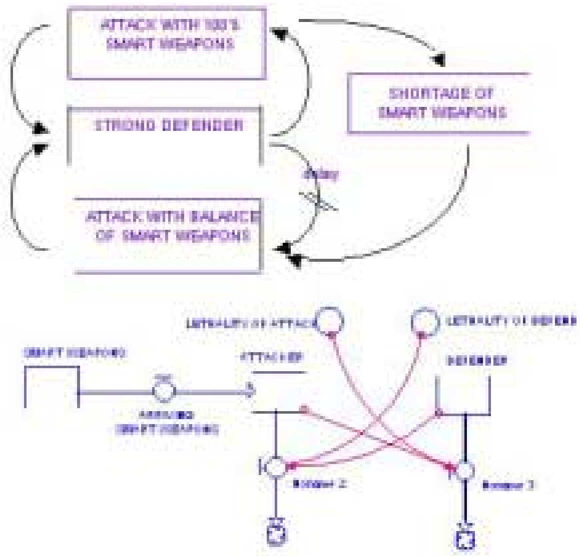


Figure 8. Example Undesired Effect - Weapon Utilization

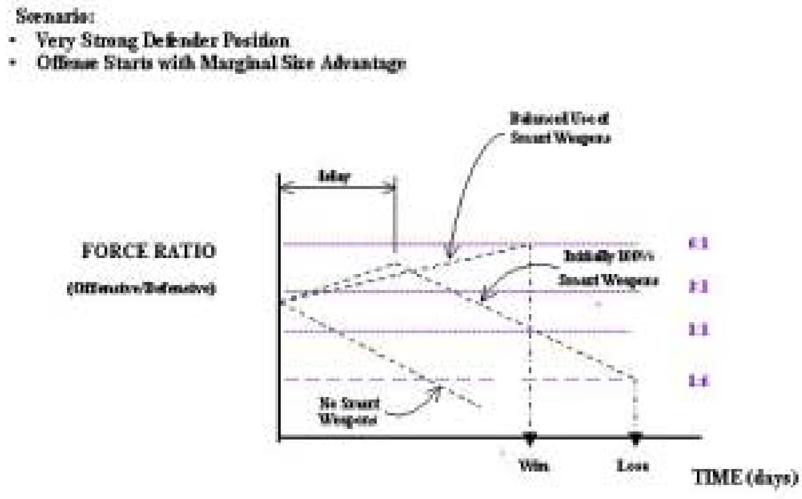
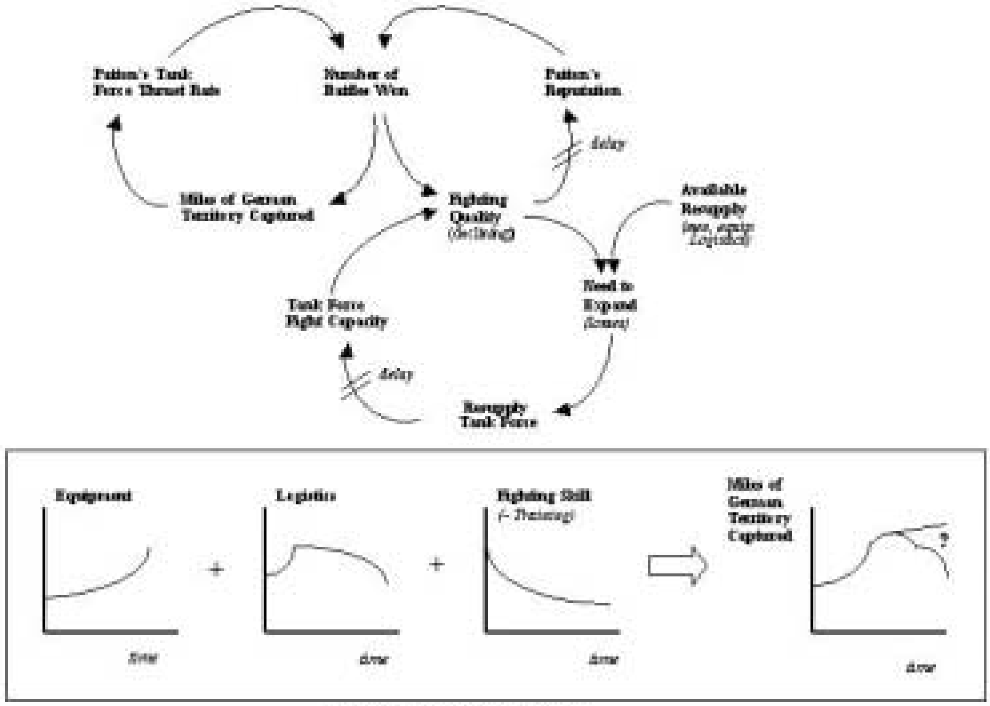


Figure 9. Undesired Effect of Weapon Utilization

Unexpected Effects. A system model may have feedbacks of small changes, which can grow into large consequences – good or bad. Often this can start with a success that grows quickly, but realistic limits can slow, stop or suddenly reverse. Figure 10 is a causal-loop diagram that tries to capture a notional "Patton-run-Amuck" dynamic. This suggests that in the face of constant intense combat, and even with enough logistics (fuel & ammo), the lack of training/experience of the replacement tank teams could reverse Patton's successes.



Assumption: *Constant Fighting*

Figure 10. Patton-Run-Amuck Dynamic

Summary and Projections

- Effects Based Operations (EBO) planning & assessment requires simulation; particularly if the problem is non-linear
- When using System Dynamics (SD) to model EBO, the logic should be limited to answering a specific question (the hypothetical solution)
- Graphical construction of SD code makes it easy to drill down from the mission, to the system and to the underlying technologies
- SD modeling also facilitates horizontal integration – it allows the linking of an end-to-end campaign: mobilization, deployment, bed-down and combat missions
- For dynamically complex issues, SD can be used to find long term patterns and high leverage decision points
- Although the coding of SD models is quite easy, the understanding of cause-effect in particular systems needs expertise and is aided by experience. A library of generic military structures would be a great aid to the military analyst and decision maker