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Misperception of dynamics in military planning: Exploring the counter-intuitive behaviour of the logistics chain

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ABSTRACT

Knowing from the system dynamics (SD) literature that human decision makers generally have problems when making intuitive judgements in situations involving accumulations, time lags, feedback and non-linearities, we suspect that the problems will be no less for planners of military operations. Since most conventional military operations involve the movement of forces from base or camp into an area of operations, one should expect that commanders, planning staff and analysts possess at least a basic understanding of logistics dynamics.

However (and consistent with our initial suspicion), in a simplified experimental task framed as a "Peace Support Operation (PSO)", we find that even highly educated defence analysts are consistently over-optimistic as well as demonstrate only a partial understanding of the dynamics generated by the logistics chain structure. In addition to reporting these preliminary findings, the paper makes suggestions on how to build and improve mental models of decision makers in situations of conflict, crisis and war. Further research involving actual commanding-level officers as subjects is scheduled.

INTRODUCTION

What if war was declared and nobody showed up? Until recently this could easily[1] have been the case for the Norwegian Army. For some years, a relatively constant percentage of GDP was spent on the defence sector, financing a more and more obsolete force structure. From 1980 to 1995, it is reported that the gap between (Army) structure needed and structure available was close to 40% (Diesen, 2001). In an attempt to conceal this disturbing fact, equipment was shifted around the country depending on what brigades were to be exercised next. Furthermore,

[1] Luckily, there has not been any need to mobilise and deploy large numbers of Norwegian armed forces since World War II.

capability assessments of the Mobilization Army during 1980-90 revealed that the standards in this period were so low that it could hardly represent any combat capability at all.

General Diesen (2001) calls this a strategy of "monumental folly", that is, to cling onto as much materiel for as long time as possible. This dysfunctional strategy contains two components: first, irrelevant equipment was not discarded, but rather stored and maintained at significant expense. Second, echelons were never fully equipped (50-60% coverage was common), leading to an over-proportional reduction in performance. In fact, for equipment levels below 70% of requirement, it is questionable if a brigade is operational at all.

Bakken (2000) points to the same underlying problem, but from a slightly different angle, when he observes: "[…] In spite of largely constant employee numbers, key activity indicators have been reduced by half in the same period [7-10 years]". Referring to a simple ageing chain model, he attributes this situation to two mutually supporting problematic developments: Hiring freezes lead to non-planned use of older and much more expensive officers in operative positions. And, the increasing elderly officer corps, threatened by their own extinction, find ever increasing needs for their own efforts. Thus, staff officer positions continue to rise in numbers – at the expense of operative elements. According to Bakken (2000), the solution seems to be found in reducing average retirement age, increased junior officer hiring, and reintroduction of the under-officer corps (abandoned in the sixties).

At present time, the Norwegian Defence (armed forces as well as staff and management) is undergoing a comprehensive "right-sizing" process. Still, the path taken from the late seventies and until today is a story of a public service that for some time has suffered from severe imbalance between structure, goals, and budget allocations (Holme, 1999). As such, it forms an excellent basis for a system dynamics (SD) modelling case.

Clark (1987) has identified the public budgeting process as one of the major causes of non-planned side effects in structural planning. Regarding the 1970s US Defense budget reductions, he comments: "Because unplanned budget changes are absorbed by the acquisition portion of the budget […] the result was a significant unplanned annual reduction in the funding of system acquisitions […]".

Given that long-term planning appears to be problematic in real world situations, such as for the defence sector, it is pertinent to ask: Are these problems apparent to planners or analysts themselves? And, if the answer is in the direction of "no" (which we suspect), how large is the gap between intuition (first guess or estimate) and analytical solution, not to mention actual outcome?

THE DYNAMIC NATURE OF HIGH-LEVEL MILITARY DECISION PROBLEMS

Numerous causes for these inter-temporal structural imbalances may exist. From an SD viewpoint, it is pertinent to seek explanations in the "systemic" nature of the defence sector, and look for the accumulations, time lags, feedback and non-linearities. Underlying all approaches to structural planning, and this task being dynamic in nature, should be a general understanding of the forces governing the system's behaviour. The key to successful problem solving is to recognise that an organisation or system such as the defence force is seldom shaped or commanded by direct control. Instead, the decision maker is forced to control this kind of system in an indirect manner, that is, rely on the will and ability of subordinate as well as equal-ranking officers to accomplish its tasks and reach its goals.

Even if the individual behaviour pattern of all involved elements in a systemic, indirect control task was known with certainty, the pattern(s) resulting from *interactions* (even in relatively simple systems) could be perceived as incomprehensible, and intuitive decision making would fail to a great extent. To military decision makers this fact could be particularly disturbing, since defence organisations, in their own view, should excel in making intuitive (rapid, "gut-feeling") decisions in the face of uncertainty.

The problem is essentially the same whether one looks at the long-term structuring of a defence force, or the planning and running of a military campaign. The main difference is in fact the time scale. A military operation or campaign presents the commander with a dynamic decision problem. During the campaign, the commander continuously receives status information, and on the basis of this information he will manage his resources (by issuing directives to his staff and subordinate commanders). As the directives are acted upon, subordinates will report back on outcome and new status (updated situation assessment). This cyclic procedure will repeat for the duration of the campaign.

As a practical example to illustrate, consider this general description of crisis management, taken from the NATO/PfP "Generic Crisis Management Handbook" (1997 interim version): *"Procedures and activities in crisis management range across; information acquisition and assessment; the analysis of the situation; the establishment of goals to be achieved; the development of options for actions and their comparison; the implementation of chosen options, to (finally, as feedback to close the loop) the analysis of the reaction of the parties involved."*

According to Brehmer and Allard (1991), a dynamic decision problem has the following characteristics:

- It requires a series of decisions
- The decisions are interdependent.
- The state of the problem changes, both autonomously, and as a consequence of the decision maker's actions
- Decisions must be made in real time

Following Brehmer (2000, 2002), this kind of task can be seen as a problem of finding a way to use one process to control another process, and it is the relation between the processes that determines what strategies are possible. It also means that the time scales of the task are important. The decision maker thus has two essential tasks:

- To control the system
- To control his workload and avoid being overwhelmed by the task

That a series of *interdependent* decisions is required means that the decision maker must learn to allocate (in time and space) his resources in a way that provides for the best possible overall outcome. That the task changes *both* autonomously and as a consequence of the decision maker's action means that he must be able to distinguish between the effects of his own actions from autonomous effects.

That the decisions must be made in *real time* means that the decision maker must be able to find a strategy that protects him from being overwhelmed (according to Brehmer (2002) expert decision makers are recognized by their capability to adapt their work strategies to control their work load); he must learn not only about the task, but also about his own *abilities*. He must understand how to use a process for controlling another process, find ways to handle the delays, and possess an understanding of the time scales.

SOURCES OF HUMAN MISPERCEPTION IN DYNAMIC SITUATIONS

Sterman (2000) expresses the problems with operating in, and learning from real-life experience in the following way (p 26): "Faced with the overwhelming complexity of the real world, time pressure, and limited cognitive capabilities, we are forced to fall back on rote procedures, habits, rules of thumb, and simple mental models to make decisions. Though we sometimes strive to make the best decisions we can, *bounded rationality* means we often systematically fall short, limiting our ability to learn from experience". Observing that people perform quite poorly in systems with even modest levels of complexity, Sterman (1989) labels this kind of cognitive dysfunction "misperceptions of feedback". The solution would be to develop "systems thinking" abilities.

Intuition and analysis represent the end points of the "cognitive continuum" (Dunwoody et al 2000), but the cognitive mode is rarely purely intuitive or analytical. More often, it is a mixture of both. This is referred to as "quasi-rationality" (Brunswik 1956, Hammond 1981). This "middle course" is characterized by a robust and adaptive decision making/problem solving process, and is closely associated with "common sense". Tasks that contain uncertainty, dynamics and many (redundant) perceptual cues (thereby making the task hard to analyse) will benefit from a largely intuitive approach (Dunwoody et al 2000). Intuitive decision making is quick (almost instantaneous), and happens with low cognitive control and low conscious awareness. Perhaps paradoxically, good intuition is not commonplace, and in constant need of improvement!

According to Brewster (2002), many studies within military and scientific communities conclude that [military] commanders actually rely more heavily on an intuitive versus an analytical approach when in a field environment. The intuitive approach to decision making appears to be chosen when facing: ill-structured problems; uncertain or dynamic environments; time stress; and/or high stakes. The intuitive approach is based on pattern recognition and experience, and goes within the military pr ofession under terms such as "fingerspitzengefuhl" and "coup d'oeil". The research field of "Naturalistic Decision Making (NDM)" is largely concerned with intuitive decision making, and define it as "the way people use their experience to make decisions in field settings" (see e.g. Klein, 1998).

That people have problems when applying common sense (or intuition) to static situations involving simple probability judgment is well known (see Kagel and Roth 1995, for a comprehensive review). Several authors now point to decision makers' failure to consider feedback in complex, dynamic systems. Let two recent studies illustrate the magnitude of this problem: In his studies of management of renewable resources, Moxnes (1998) observes that experienced decision makers over-invest and over-utilize their resources. He attributes this behavior to systematic misperceptions of stocks and flows, and of non-linearities. Sweeny and Sterman (2000) took a different approach when they gave system dynamics case problems to students at an elite business school. The students, who were highly educated in mathematics and science (but had received no prior schooling in system dynamics concepts), were found to have a poor level of understanding of the basic system dynamics concepts: stock and flow relationships, and time delays.

Inspired by the Sweeny and Sterman (2000) study, Ossimitz (2002) has conducted an investigation where 154 subjects were given different tasks in dynamic thinking in general, and in the interpretation of stock-flow related graphs in particular. The results were alarming, in that the mean performance of the subjects was approximately at the level of tossing a coin for each answer. He suspects that the lacking ability is to grasp that a positive net-flow results in an increase in the corresponding stock. In a related study, Kainz and Ossimitz (2002) finds that a 90-minute crash course introducing basic stock-flow concepts between pre- and posttest was suitable to bring about an improvement in performance.

Tversky & Kahneman (1987) recognized early the shortcomings of a static, one-shot approach to learning. They describe the prospects for learning in dynamic environments like this: "Effective learning takes place only under certain conditions: it requires accurate and immediate feedback about the relation between the situational conditions and the appropriate response. The necessary feedback is often lacking for the decisions faced by managers, entrepreneurs, and politicians because:

- Outcomes are commonly delayed and not attributable to a particular action
- Variability in the environment degrades the reliability of the feedback, especially where outcomes of low probability are involved
- There is often no information about what the outcome would have been if another decision had been taken
- Most important decisions are unique and therefore provide little opportunity for learning (see Einhorn & Hogarth 1978)"

Though decision-making errors may disappear with guided experience and reflection, little research has focused on the improvement in decision strategies – in particular, changes in decision making with experience have not been revealed to any extent. Notable exceptions exist, however. Bakken (1989) finds that in a simulated economy, subject's performance improves over trials. Paich & Sterman (1993), in their investigation of human performance in a product lifecycle task, finds that performance suffers as dynamic complexity increases. Brehmer (1988) finds that action lags decrease performance in a simulated forest fire, and at the same time conditions for learning get worse.

A REAL-WORLD DECISION PROBLEM

A very general structure fundamental to most (if not all) structural planning problems is the *logistics chain*[2]. In exist at all levels and magnitudes, and can be found "almost anywhere[3]", as long as there are resources (fixed or movable; personnel or machinery; financial or informational) involved in an organisation. Any unit of resource that is purchased or acquired at

[2] At the superior level, the logistics chain in military operations commonly comprises the phases: force generation – deployment – employment – sustenance – redeployment.

[3] The logistics chain perspective may be applied to central decision or planning problems in the fields of (e.g.) life cycle costing (LCC), value chain analysis, operational logistics, financial leasing, net present value (NPV) of investments, human resource (HR) management, real estate development, shipping, public infrastructure planning, procurement and re-purchase, product life cycle (PLC) management.

a cost; then put into productive work; then deteriorating with age; and subsequently discarded and replaced when its residual value falls below the cost of further maintenance, may constitute such a chain. Even when implemented in its simplest form, this structure may exhibit accumulations, time lags, feedback and non-linearities, and as such be the originator of counter-intuitive behaviour and "responsible" for a great deal of human misperception.

The forthcoming experimental task, which is built "around" an extremely simplified model of the logistics chain, focuses on the dynamic interrelations between budget allocations and cost of operations (initial purchases and running sustenance), and the short- and long-term consequences of a limited time budget expansion. The paradox encountered is that a one-time budget increase may lead not only to a performance boost in the short term (primary effect), but also to a significant penalty in the longer term (unintended side-effect). The primary cause of this behaviour is the "chaining" and thus preservation of discrete age classes (cohorts) in the model, which through time lag and negative feedback[4] conserves an imbalance of structure from the one-time increased purchases and throughout the lifetime of the resources. In fact, the one-time perturbation sets off a pattern of oscillations in performance, which, though dampened, could continue for the whole duration of the operation.

THE EXPERIMENTAL MODEL "STRATEGOS" [5]

The following compact but universal SD-model contains an "age-class" or "cohort" resource chain, with a controlling feedback loop to a purchasing function. The purchases are fed into the chain at the start, and at the end obsolete equipment is discarded. The operational effectiveness (a measure of goal achievement, performance or yield) of the equipment depends on its age – typically the unit effect drops with age. In this version of the model, only payable[6] costs are covered from periodic budget allocations, as is common in the public sector. They constitute operating expenses (fixed for the lifetime of the unit) and investment outlays (payment for new equipment). The purchasing function operates in either of three modes (more examples can be thought of):

- Budget control: New equipment is automatically purchased for the remaining funds, after covering operating expenses. No transfer of funds from one period to the next, in line with the "use'em or lose'em" principle for funding.

- Structural target: New equipment is automatically purchased when installed equipment or effectiveness level falls below a given target. There may be a time lag between ordering and installing the new equipment. In that case, the decision rule may take into account equipment "on order" when deciding new order quantity.

- Operator intervention (interactive game): The task is to attain and maintain a (moving target) level of equipment or effectiveness, by allocating funds in a "budget control" regime. Lower spending for the given performance level gives a higher degree of success.

The model described is adapted to two problems, similar in structure and behaviour, but slightly different in context: structural and operational planning, respectively. The degree of control is

[4] Negative feedback and time lag are features also found in the "Manufacturing task" by Sweeny and Sterman (2000)

[5] The word "strategos" is Greek for "general".

[6] Non-payable costs, such as depreciation, are not accounted for.

fairly limited, in that only the inflow of equipment is controlled with a purchasing function, while the outflow is merely a result of the equipment becoming outdated at the end of the chain[7].

In the modelling environment ithink Analyst, the aging chain of equipment is represented as a discrete "Conveyor" object, with a number of "slots" equal to the maximum age of equipment. The function QELEM is used to address each "slot" individually, and requires dt (timestep) set to 1.

The environment Vensim DSS offers a somewhat different approach, where each age class is represented by an element in an array (number of array elements is equal to the maximum age). The function SHIFT IF TRUE is used to move equipment between time steps, thus making the equipment "older" as time passes.

"Strategos" in a structural planning context

Description: "Assume, for simplicity, that one nation's Armed Forces consist of a number of unified combat units, each with an operational lifetime of 30 years (that is, after 30 years the units will no longer yield any effect when used in operations). At present, the total Force consists of exactly 120 such units. Since older units are less effective than newer ones, these 120 units in sum yield a combat effectiveness equivalent to 100 fully effective units. To maintain this level of effectiveness, 4 new units are acquired yearly, and the same amount of 30-year old units is discarded. This stable investment pattern has been followed for the past 40 years, and is depicted below."

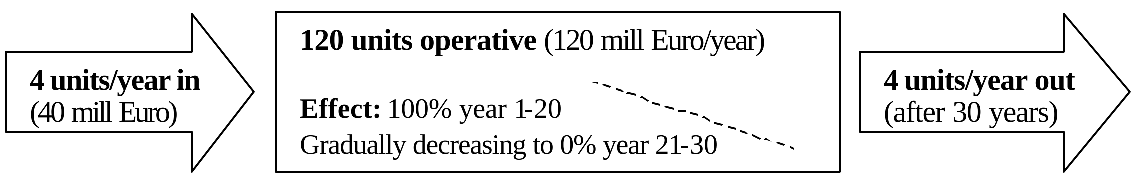

Diagram 1. "Strategos" logistics chain

This decision rule for budget[8] allocation is followed: *Of the allocated funds, the periodic sustenance should first be covered. The remaining funds (if any) should be used to equip new units for deployment (consequently, funds not used within the period, cannot be transferred to subsequent periods).*

Total budget allocated = Operational costs (fixed) + Procurement outlays (remainder)

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[7] While being in balance (steady state) from time zero, the structure is not optimal in the sense that resources could not have been allocated differently to yield higher effectiveness at the same or lover cost for the planning period as a whole. In particular, it is an analytic fact that discarding equipment before its operational effect approaches zero (due to aging), would yield a more economical materiel structure. The optimal asset lifetime can be found by relatively straightforward Net Present Value calculations of cost-effect of the operational life cycle. See also Appendix D for a discussion of optimal strategies.

[8] This being a fictitious context description, currency denomination may be chosen freely. In the experiment Norwegian kroner (NOK) is used.

"Strategos" in an operational planning context

Description: "Assume, for simplicity, that one nation's Armed Forces consist of a number of unified combat units, each with an operational lifetime of 30 days (that is, after 30 days of operating the units will no longer yield any effect when used in operations). At present, the nation contributes a total of 120 such units to a "Peace Support Operation" led by the Alliance. Since older units are less effective than newer ones, these 120 units in sum yield a combat effectiveness equivalent to 100 fully effective units. To maintain this level of effectiveness, 4 new units are acquired daily, and the same amount of 30-day old units is discarded. This stable operating pattern has been followed for the past 2 months." *Logistics flow and decision rule are the same as above, except for the denomination of time that is changed from years to days.*

"Strategos" in ithink Analyst

The model and context described above has been implemented in both ithink Analyst and Vensim DSS. Below is the model structure in ithink shown. The model listing is provided as Appendix. Note that the variables "Invest amount" and "Investing" are computed as follows:

Invest amount = MAX(0, Budget – Operating Cost)
Investing = IF Price per unit > 0 THEN Invest amount / Price per unit ELSE 0

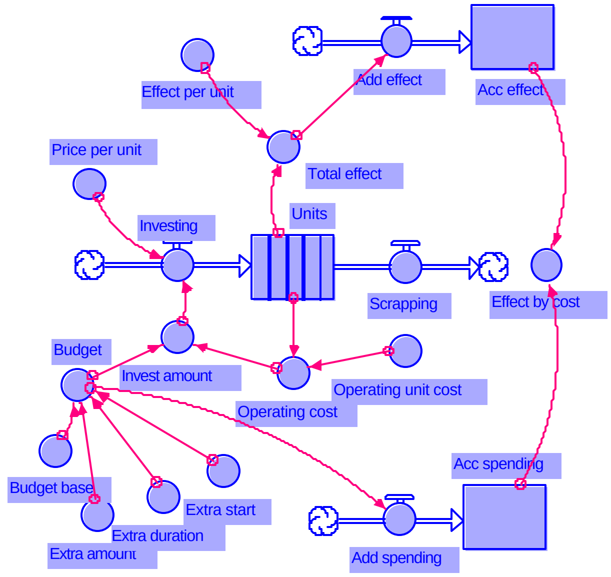

Diagram 2. "Strategos" in ithink Analyst version 7.0.3

To take into account the decreasing slope of effect as a function of age (the aging effect), the variable "Total effect" is computed, rather tediously, as follows:

*Total effect = Units * Effect per unit - QELEM(Units,10)*0.05-QELEM(Units,9)*0.15-QELEM(Units,8)*0.25-QELEM(Units,7)*0.35-QELEM(Units,6)*0.45-QELEM(Units,5)*0.55-QELEM(Units,4)*0.65-QELEM(Units,3)*0.75-QELEM(Units,2)*0.85-QELEM(Units,1)*0.95*

For the experimental task "Strategos challenge", the system is temporarily brought out of steady state. This is accomplished by increasing the budget allocation with a fixed amount of money for a limited time. Below is shown graphs of 1) Total effect (units), 2) Budget (money), 3) Investing (units) and 4) Operating costs (money) for the following values:

Budget base:	*160 (mill NOK)*
Extra amount:	*80 (mill NOK)*
Extra start:	*0 (years/days)*
Extra duration:	*5 (years/days)*

Budget = Budget base + STEP(Extra amount, Extra start) - STEP(Extra amount, Extra start + Extra duration)

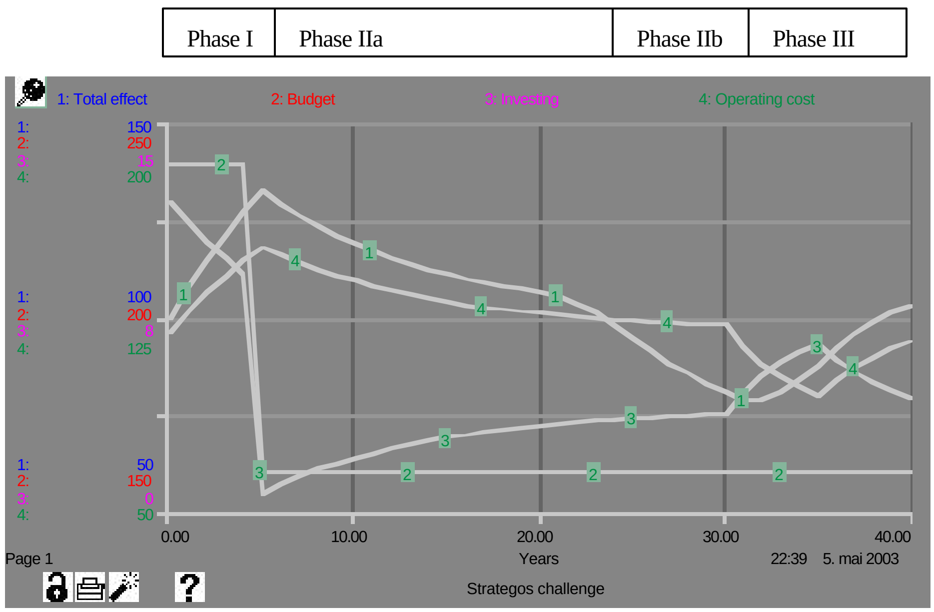

Diagram 3. "Strategos" experimental run – time 0-40, dt=1

Immediately after start of extra budget allocation, the Total effect curve climbs steadily, and in a concave fashion. The climb reaches its maximum on the last day/year of extra funding (*phase I*).

In *phase II*, the Total effect is gradually reduced from maximum (convex trajectory), albeit in a slower pace than in phase I. The reduction accelerates slightly for the last third of operational lifetime, where effect per unit is lower due to ageing. Investing is at an all-time low at the start of phase II, because the extra purchases installed during phase I, now draw operating costs at the expense of new acquisitions.

The Total effect crosses the baseline ("100") between time 23 and 24, and continues to drop until it reaches an all-time low between time 31 and 32. At the same point in time, Investing reaches its baseline of 4 units/time, and overshoots its baseline in *phase III*. Along with the upturn in investments and operating costs declining sharply, due to the extra units acquired in phase I now being phased out, Total effect rises again and overshoots its baseline between time 38 and 39.

As is pictured in diagram 4 below, the extra allocation (flat rate of 50% above base) of funds for a given number of time steps induces a severe disturbance to the system. The imbalance between investments and operations created during the period of extra funding results in oscillations that will continue "forever", although dampened as time passes.

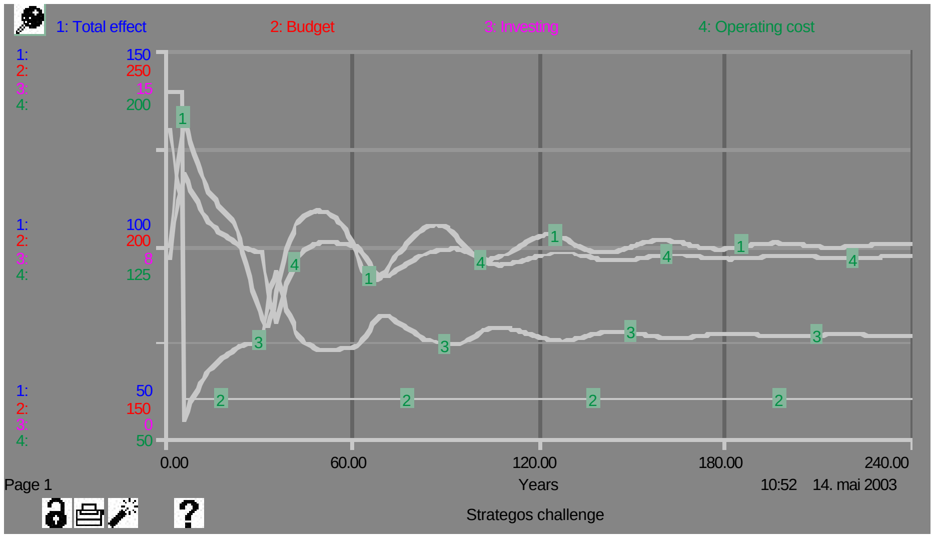

Diagram 4. "Strategos" experimental run – time 0-240, dt=1

EXPERIMENTAL TASK AND PROCEDURE

The description of the experimental task "Strategos challenge", is provided as Appendix A. Enclosed is also the original text in Norwegian as well as a sample grid for answering the task (Appendix B).

8 subjects took part in the experiment in the late winter of 2003, and assembled immediately after the lunch break, where the task description[9] and answer grid was handed out. The subjects, which all were junior and senior defence analysts with diverse academic backgrounds[10] such as mathematics, economics and social science, took 15 minutes to complete the answer grid with a hand drawn sketch of the *estimated*[11] total effect curve between the time of starting extra funding (t=0) and 40 days ahead in the simulation (t=40). 1 subject found the task too difficult and resigned shortly after receiving the documents. The tasks were all completed individually, and without any computing assistance.

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[9] In the task description, complete information to the whole problem was given, so that subjects would not have to infer any exogenous influence. Furthermore, all information was certain, so that no stochastic relationships existed.

[10] 1 subject had a background in system dynamics, which, as we will see, had a significant positive impact on the ability to solve the task correctly.

[11] It is essential to note that subjects were explicitly told "It is not important to draw an exact diagram, so long as the main features are present."

RESULTS

From the preceding discussion, we find the task to possess the following "systemic" challenges:

1. The extra funding is given as a "sharp" amount for limited time. From Clark (1987) this kind of strategy usually results in unplanned cuts in acquisitions, and penalises on renewal of the structure, which would be necessary for stable performance.
2. After the time of extra funding has elapsed, it is implicitly withdrawn without explicitly given the ability to reduce number of older units in the chain (as this could partially have solved the long-term instabilities).
3. The performance falls more than 20% below base after approx. 30 days. Oscillations continue for the duration of the operation, though dampened. This is only perceived if the model is actually run, though a person with SD-background might spot this problem initially. A real-world military unit would be close to inoperative around day 30.

Hypothesis: We propose that subjects to a great extent will tend to *ignore* the imbalance created by the sharp increase in funding (in a system with negative feedback and time lags). Unaware of the imbalance, subjects will perceive the increase in total effect as greater (in particular, longer lasting) than it really is, and without the marked "under-shoot" of baseline as the units become less effective late in their lifetime.

Below, in diagram 5, is shown sketches of Total effect as drawn by the subjects. The sketches were transferred to MS Excel for readability.

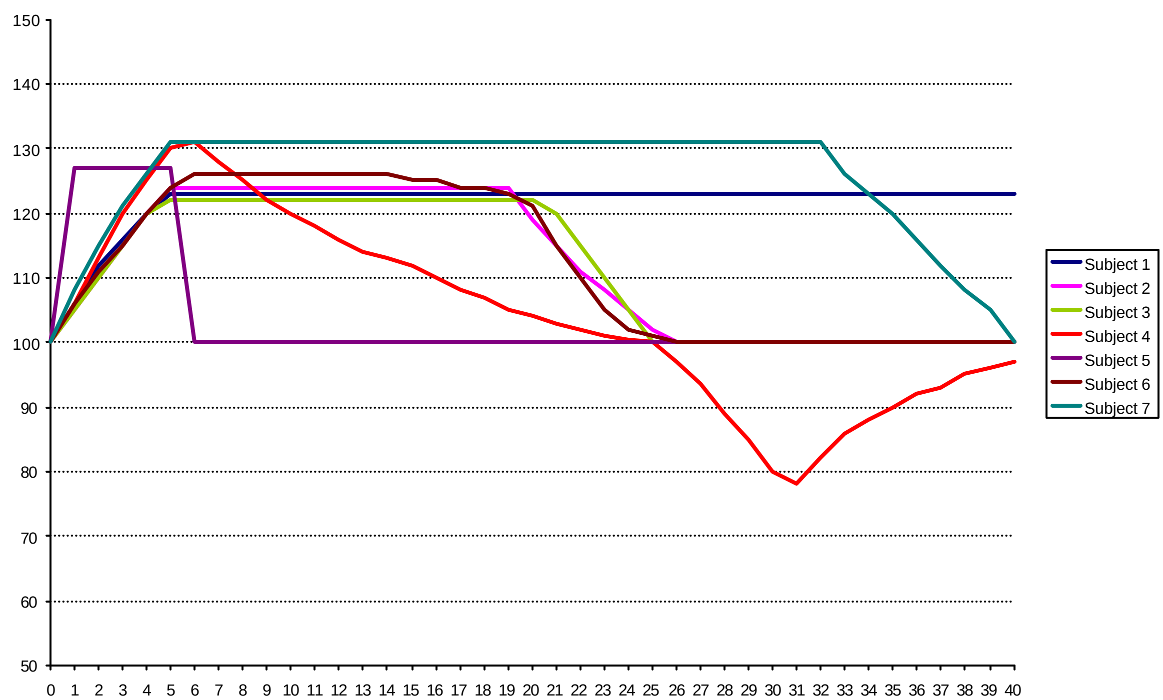


Diagram 5. Estimated Total effect sketched by subjects #1-7

Detailed observations - the 3 phases of the operation

Phase I, Total effect experiences a steep concave increase for the duration of the extra funding (5 days). Only subject nr 5 suggests that the increase is completed by day 1, which is wrong. Thus, most subjects get this phase right.

Phase IIa, Total effect undergoes a gentle downward slope after extra funding stops. 5 subjects misperceive this, and instead assume that the new, increased level of efficiency is maintained for (at least) another 15 days.

Phase IIb, Total effect trajectory approaches original baseline between days 23 and 24. There are 4 subjects who estimate that the Total effect will be back to baseline by that time, and thus get this roughly right.

Phase III, Total effect curve drops below baseline and reaches an all time low between days 31 and 32, before turning upward again. Only 1 subject perceives this pattern correctly. This is subject number 4, who happens to have an educational background in system dynamics.

Other anomalies:
Subject 5 depicts a distinct "plateau" between day 1 and 5, and drops down to baseline from day 6. Subject 1 and 7 project a way too long period of increased Total effect.

Overall, subject 4 with background in SD, has the "most correct" perception of development in Total effect. He (or she) predicts a steep concave increase in Total effect from day 0. He also matches the gentle downward slope from days 6, the slight increase in drop and crossing of baseline at approximately days 23-24, and the subsequent upturn from day 31-32.

Most common (5 subjects) misperception is the "plateau" depiction of the period with increased effectiveness, where a pointed peak would be most correct. The sketched pattern thus resembles the budget increase pattern, but is more stretched out in time, probably made to correspond with the unit lifetime.

Too optimistic estimates

The effect of increased budget spending on Total effect is (on average) perceived as being more than 3 times larger than what it really is. While subjects on average predict an accumulated increase in Total effect above baseline of 521 (found by integrating the net positive area under the sketched graphs for t=0 to t=40), the model gives the answer 172 for Total effect above baseline. This is to be interpreted as the extra 5 x 80 = 400 million buying an extra Total effect of 172, giving a price of 2.3 mill (kroner) per unit of Effect. Compared to the "regular" price (in steady state) of 1.6 million per unit of Effect, would imply that the budgeting regime results in paying almost 50% more for the extra effect, as would have been the case with a more balanced force structure[12].

[12] The difference between the price per unit of Effect in balance and out of balance would be smaller and approach zero if the units were to be discarded at the optimal point in time. This difference would also tend to diminish if the time span was extended to multiples of 40 days. See also Appendix D.

What have we found? The subjects appear to use the first order intuitive judgement as an "anchor" to which subsequent adjustments *may* be made (processing in spreadsheet or SD modelling software might reveal the analytic solution, but this approach usually takes valuable time which otherwise might be spent on environment monitoring and other management/executive activities). When the necessary SD insight is lacking, in this case the ability to recognise that a significant time lag coupled with negative feedback tends to produce oscillations around a baseline, such adjustments rarely happen. This kind of misperception results in over-optimism when it comes to estimate the performance of the system, because over-shoots are perceived as extended for a longer time than appropriate, and "under-shoots" are not detected at all. The probable roots for this will be discussed in the following. What is the nature of these problems, and how may they be remedied?

DISCUSSION

How commonplace is it to misperceive the complexity of planning tasks, and subsequently underestimate costs/overestimate effect? In a study undertaken at the University of Aalborg (Denmark) was found a consistent tendency to underestimate the costs of larger, public projects. This tendency is observed in many countries, and with undiminished magnitude between the years 1910 and 1998 (Flyvbjerg et al., 2002). The average cost overrun for 258 larger projects observed in the study was 28%. The study indicates either that one is incapable of exploiting previous experience, or that costs deliberately are underestimated in order to get a project approved for funding. In the latter case, it is the decision makers who are incapable of learning from previous experience. In any case, there might be a decision making *bias* at work, so that when costs are initially estimated, the sheer complexity of the task will render many costs undiscovered. These initially undiscovered costs, which later turn up as *unexpected* costs, might well result from an incomplete perception of feedback, time lags and non-linearities.

McKean (1965) was probably one of the first to suggest taking a "systemic" approach to public management, and promoted the use of quantitative analysis in comparison of alternative courses of action – and finds that analytic methods are wanting. But the point of this study is not the lack of mathematical methods and the knowledge or time to use them, but the faulty intuition applied by decision makers when first confronted with a non-trivial decision problem. If first-order intuitive judgements had been adjusted in light of subsequent quantitative analysis, all might have been well. But all too often major decisions are made without troubling to get more detailed data, or running the appropriate computer based planning tool. It seems like confidence in the accuracy of own judgements is superior to reason (for a review of decision making biases, see e.g. Lai, 1999).

According to Kleinmuntz (1993), it is a very real possibility that faulty mental models of the task environment cause the misperception phenomenon. First of all, it is believed that decision makers are more likely to detect feedback loops if: they perceive that there is connection between past action and future effects; the time lag is short; actions and effects are of similar kind; and exogenous variables are proved to be irrelevant. All these point to the benefits of building "dynamic intuition" in a controlled, interactive environment, such as a decision game. Oherwise, it is possible to present information in a way that emphasizes the perceived causal relevance of a feedback structure: Graphical displays may make co-variation more visible; previous actions are presented in direct relation to current effects, and in compatible presentation formats; stress that the (only) relevant information is that given in the task description (no chance events or other external events are relevant).

Brehmer (2000) points to two main principles when it comes to interpret people's problems in handling dynamic settings:

- Overemphasis on the present: Decision makers tend to attend to only the information currently at hand, and as a result experience difficulties in accommodating feedback delays. The world is perceived "here and now", and the information is not processed any further.
- Lack of systems thinking: the tendency to think linearly, that is, to believe that actions and results are directly related and ignore the side effects of actions. This tendency can also be viewed as an overreliance on information that is readily available, along with a tendency to ignore what must be inferred – such as side effects.

Dynamic Decision Theory (DDT) argues that peoples' relatively low level of understanding in dynamic environments may be explained by (from Bakken 1993):

- People seek confirmation for their theories (Einhorn & Hogarth 1978), and as a consequence they are often stuck in severely sub-optimal decision strategies (Dörner 1980, Sterman 1989). Decision makers do not seek out alternative strategies when they are satisfied with outcomes, especially when it would take a long time to test newly generated hypotheses.
- More often than not, decision makers in dynamic environments underestimate or ignore dynamic processes. As a consequence, they leave out concerns for side effects and self-reinforcing dynamics (Dörner 1980, Brehmer 1987, Sterman 1989, Fuglseth 1989).
  People fail to adjust their decision strategies to account for delays in the system (Bakken et al 1992), and expect feedback to arrive before the system can provide such information.
- Decision makers go into dynamic scenarios with inappropriate scripts based on apparent task characteristics, and they make little or no attempt to challenge the appropriateness of these scripts (Kleinmuntz & Thomas 1987).
- As a result, learning may not take place if assumptions and strategies are not challenged from inside or outside the decision environment (Schön 1983, Salomon et al 1991).

To challenge improper beliefs people have about causal relations have been a major focus in improvement research. But the same line of research shows in essence that learning from experience in complex, dynamic tasks is a troublesome and demanding undertaking. It also tells us that even though much effort may be put into training in realistic (and usually realism is positively related to complexity) settings, little or no learning outcome may be expected. One key to effective learning seems to be found in environment simplification, which will be discussed in the following.

The most salient problem with the experimental task is that grants are given for discrete periods (with no intertemporal transfer possible). Normally this would not be a problem, except for when unexpected or "fluctuating" allocations occur. It requires only a very simple model to illustrate the severe effects of e.g. an unplanned budget cut, or the bad economy of giving extra grants as lump sums rather than more evenly distributed.

Another problem is the failure to anticipate escalating costs and declining efficiency with age. In the experimental task, such information was given explicitly, but subjects apparently did not manage to integrate that information. It is probably not common knowledge that when a public grant is given for a shorter time than the lifetime of the structure it is meant to finance, then there is a risk that the rest of the organisation (eventually) will "pay" the residual?

Yet another source of problem is related to "illusion of control" – by that is meant the (wrong) belief that you have more control than what is really the case. This could be a perception that the mode of control is more direct than it really is (e.g., that fixed resources can be manipulated as if they were movable), or that time between issuing a directive and until implementation is shorter than it really is.

Finally, it is the question of controlling with the right goals in mind. For example, it could be wrong to invest heavily in new resources when getting rid of the older and less efficient ones would produce the same effect but at a lower cost. If the goal were to preserve status quo, cost what it may, the former would be a good strategy. If the goal were to create and maintain a sustainable, balanced structure, the latter could be better. To put focus on short-tem outcome rather than long-term is probably the best recipe for creating organisations that are out of balance.

In order to achieve balanced organisations, when unbalance is the current state, the following remedies could be tried:

The logistics chain could be made more flexible, through hiring, leasing and outsourcing, rather than buying. The power to make decisions could be delegated, so that budget follows responsibility. The incentives could be tailored so that profitability and balanced scorecard ratings are rewarded, rather than headcount and activity level. Last but not least, training in systemic thinking could be fostered. For example, no long-term investment plan should be approved without considering possible side effects caused by e.g. feedback and non-linearities.

LEARNING STRATEGIES TO IMPROVE SYSTEMS THINKING ABILITIES

When the task is very complex, training/practice has little effect by itself. When tasks are simpler and more transparent (that is, more information on the dynamics of the task is given) training may have a positive effect. Isaacs and Senge (1992) and Bakken et al. (1992) argue that so-called "microworlds" used in a training context will alleviate many, if not most, of the "barriers to learning" in dynamic environments. Brehmer (2002) gives the following advice to make training and practice more effective (see also Bakken and Gilljam, 2001):

- Make the dynamics of the task transparent;
- Decompose the task into smaller, manageable parts (part-task training); and
- Teach decision makers general strategies for coping with complexity, for example:
- Collect information and test hypotheses systematically; and
- Focus on long-term goals and identify trends.

It is reasonable to assume that mental strategies of this kind contribute to better performance in experienced managers, as opposed to inexperienced. From this assumption it follows that such strategies may be learned from experience.

Sterman (2000) makes the following recommendations for instructors who want to enhance participant learning in microworld-based training:

- Take time to reflect on outcomes;
- Supply preparatory training in scientific method (hypothesis testing, and so on);
- Apply a structured procedure—for example, keep laboratory notebooks, and formulate hypotheses;
- Spend time to address participants' defensive behaviour;
- Ensure participants are confident that the model is an appropriate representation of the problem under study;
- Allow for inspection, critique and change of assumptions underlying a model; and
- Allow for active participation in model development.

The various tools and techniques that have been developed for group model building should be given special consideration. These include causal loop diagrams, policy structure diagrams, interactive computer mapping, and various problem structuring and "soft systems" methods.

According to Clark et al. (1980), active participation in model development is an especially useful approach to aid in the study and understanding of a social system. First, a one-to-one correspondence between verbal descriptions of the real-world system of causes and effects and a flow diagram representing a causal chain is maintained. Second, a flow diagram provides an excellent vehicle for communication with actors in various parts of the actual system, thus soliciting their perceptions of how the system works. Therefore, the decision makers' understanding of system structure is increased during the modelling process. Third, a rapid feedback of results from the simulation provides further clues as to the aptness of the emerging model.

SUMMARY AND CONCLUSIONS

This paper has presented preliminary experimental findings from a planning task focusing on the dynamic interrelations between budget allocations and cost of operations, and the short- and long-term consequences of a limited time budget expansion. The paradox encountered is that a one-time budget increase may lead not only to a performance boost in the short term (primary effect), but also to a significant penalty in the longer term (unintended side-effect). The primary cause of this behaviour is the "chained" structure of the discretised logistics flow in the model, which conserves an imbalance of structure from the one-time increased purchases and throughout the lifetime of the units. In fact, the one-time perturbation sets off a pattern of oscillations in performance, which, though dampened, could continue for the whole duration of the operation.

When prompted, the experimental subjects did not manage to reproduce the cyclic performance resulting from the one-time budget increase. Instead, graphs sketched (by hand) resembled more the "plain" budget profile, but stretched out in time. Only one subject correctly perceived and rendered the "unintended" performance penalty, but he had also a background in system dynamics (SD). Despite the low number of experimental subjects (N=7 completed the task), the conclusion is that intuition is a poor judge of dynamic processes. It is left for further research to investigate whether some kind of SD training may contribute to more robust dynamic mental models in the minds of military commanders and analysts.

APPENDIX A: Task description in English

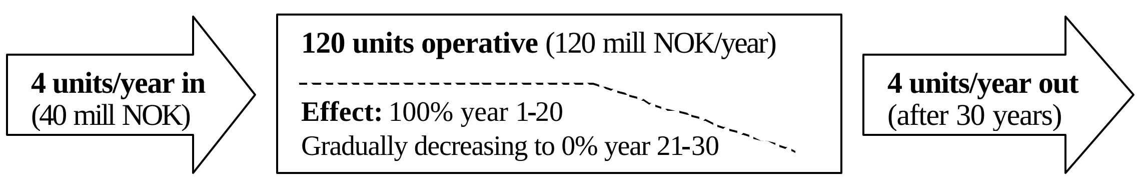
Below is presented a very simplified problem of relevance to military operations. The task is to be completed within 15 minutes, and without the aid of calculator or computer.

The state Utopia has on request from the Alliance agreed to contribute a number of military units to an international peace support operation. The contribution constitutes a minor fraction of Utopia's standing forces, for which there is no alternative domestic usage for the duration of the operation.

To equip one military unit with fuel, spare parts, provisions and ammunition for deployment costs 10 million NOK[13]. Consecutive sustenance (salaries, supplies etc.) costs 1 mill NOK per unit per day, as long as the unit resides within the area of operations. Each unit yields full effect during the first 20 days of operation, thereafter the effect gradually declines to zero during the subsequent 10 days (the daily sustenance costs remain the same, however). Every unit can therefore remain in the area of operations a maximum of 30 days, before it returns to home to Utopia. The duration and costs of transportation between Utopia and the area of operations can be disregarded.

The Alliance will cover all costs to equip and sustain Utopia's military units, for the whole duration of the operation. At present time a daily sum of 160 million NOK is allocated. This amount covers consecutive sustenance of 120 operating units, as well as the initial equipment of 4 units daily. At the same time, 4 units return daily to Utopia (after 30 days of operating). This pattern of operation, which has been stable for more than two months, yields a total effect corresponding to 100 fully effective units.

The diagram below shows the situational picture:



Task[14]:
The following directions for spending the daily allowances from the Alliance are given: *Of the allocated funds, the daily sustenance should first be covered. The remaining funds (if any) should be used to equip new units for deployment.* Until today the daily allowance has been 160 million NOK. Now the Alliance wants to increase the effectiveness in the area of operations for some time, and allocates 80 million NOK extra per day for 5 days (note: after 5 days the daily allowance is down to 160 million NOK again).

Assume that the above directions are followed; that there are available units for deployment; and that less than a single unit (e.g., ½ unit) may be quipped. Use the supplied grid, and sketch the development in total effect from the time the extra allowance starts (day 1), and 40 days ahead in time. It is not important to draw an exact diagram, so long as the main features are present.

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[13] 1 USD = approx. 7 NOK. 1 Euro = approx. 8 NOK.
[14] A second task was the question: "Is there a way to increase the total effect, without allocating extra funds? If that is the case, how?". Only the subject with SD background answered this question correctly; that is, to cut back on the number of days each unit is in operation.

APPENDIX B: Original task description in Norwegian

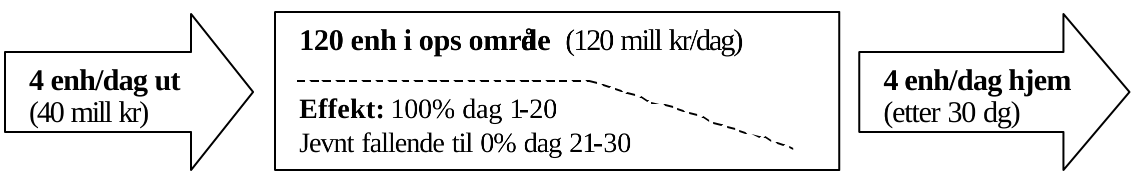
Under presenteres en svært forenklet problemstilling av relevans for operativ virksomhet. Oppgaven skal besvares på max 15 minutter, og uten hjelp av kalkulator/datamaskin.

Staten Utopia har på forespørsel fra Alliansen sagt seg villig til å bidra med et antall militære enheter til en internasjonal fredsstøtteoperasjon. Støtten vil utgjøre en mindre del av Utopias stående styrker, som det under operasjonens varighet ikke er noen annen bruk for i hjemlandet.

Å utruste én militær enhet med drivstoff, reservedeler, proviant og ammunisjon for utsending koster 10 mill kr. Løpende understøttelse (lønn, etterforsyning mv) koster 1 mill kr pr enhet pr dag, så lenge enheten er i operasjonsområdet. Enheten yter full effekt de 20 første dagene i operasjonsområdet, deretter faller effekten gradvis til null i løpet av de 10 påfølgende dagene (daglig kostnad for understøttelse er imidlertid den samme). Hver enhet kan derfor være i operasjonsområdet i maksimalt 30 dager, før den sendes hjem. Se bort fra transporttid og -kostnader mellom Utopia og operasjonsområdet.

Alliansen vil dekke alle kostnader forbundet med utrustning og understøttelse av Utopias militære enheter, så lenge operasjonen pågår. For tiden bevilges 160 mill kr daglig. Dette beløpet dekker løpende understøttelse av 120 operative enheter, samt utrustning av 4 nye enheter daglig. Det returnerer også 4 enheter daglig til Utopia (etter 30 dagers tjeneste). Dette operasjons-mønsteret, som har vært stabilt i mer enn to måneder, gir en total effekt tilsvarende 100 fullt effektive enheter.

Figuren under viser situasjonsbildet:



Oppgave 1:

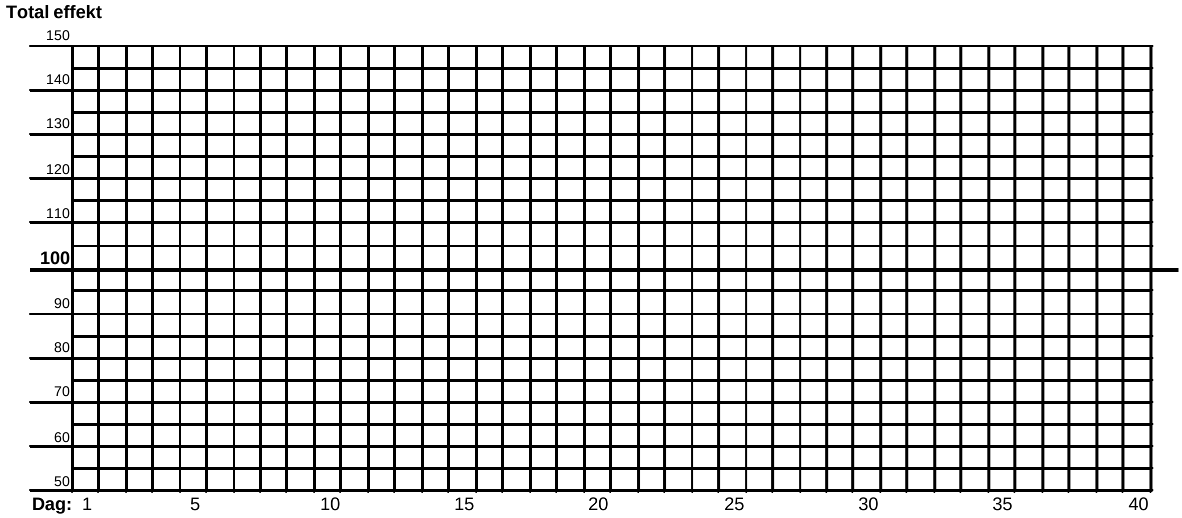
Følgende instruks er gitt for anvendelse av de daglige tildelingene fra Alliansen: *Av tildelte midler dekkes først daglig understøttelse. Når understøttelse er dekket fullt ut, anvendes eventuelle overskytende midler til å utruste nye enheter for utsendelse.* Frem til i dag har det som nevnt vært bevilget 160 mill kr daglig. Nå ønsker Alliansen å øke effekten i operasjonsområdet for en tid, og bevilger 80 mill kr *ekstra* hver dag i 5 dager (merk: etter 5 dager er de daglige bevilgningene igjen tilbake til 160 mill kr).

Forutsett at instruksen over følges, at det finnes tilgjengelige enheter for utsendelse, og at det eventuelt kan utrustes mindre enn én enhet (f eks ½ enhet). Bruk vedlagte rutenett, og skisser effektutviklingen fra det tidspunkt ekstrabevilgningen starter (kall dette dag 1), og 40 dager frem i tid. Det er ikke viktig å lage en nøyaktig skisse, det viktigste er at hovedtrekkene fremkommer.

Oppgave 2:

Finnes det noen måte å øke den totale effekten på, uten å tildele ekstra midler? I så fall hvordan?

Oppgave 1: Skisser effektutviklingen dag 1-40



Oppgave 2: Hvordan øke den totale effekten uten åtildele ekstra midler?

APPENDIX C: Model listing – "Strategos" in ithink Analyst 7.0.3

Acc_effect(t) = Acc_effect(t - dt) + (Add_effect) * dt
INIT Acc_effect = 0
INFLOWS:
Add_effect = Total_effect

Acc_spending(t) = Acc_spending(t - dt) + (Add_spending) * dt
INIT Acc_spending = 0
INFLOWS:
Add_spending = Budget

Units(t) = Units(t - dt) + (Investing - Scrapping) * dt
INIT Units = 120
    TRANSIT TIME = 30
    INFLOW LIMIT = INF
    CAPACITY = INF
INFLOWS:
Investing = IF Price_per_unit > 0 THEN Invest_amount/Price_per_unit ELSE 0
OUTFLOWS:
Scrapping = CONVEYOR OUTFLOW

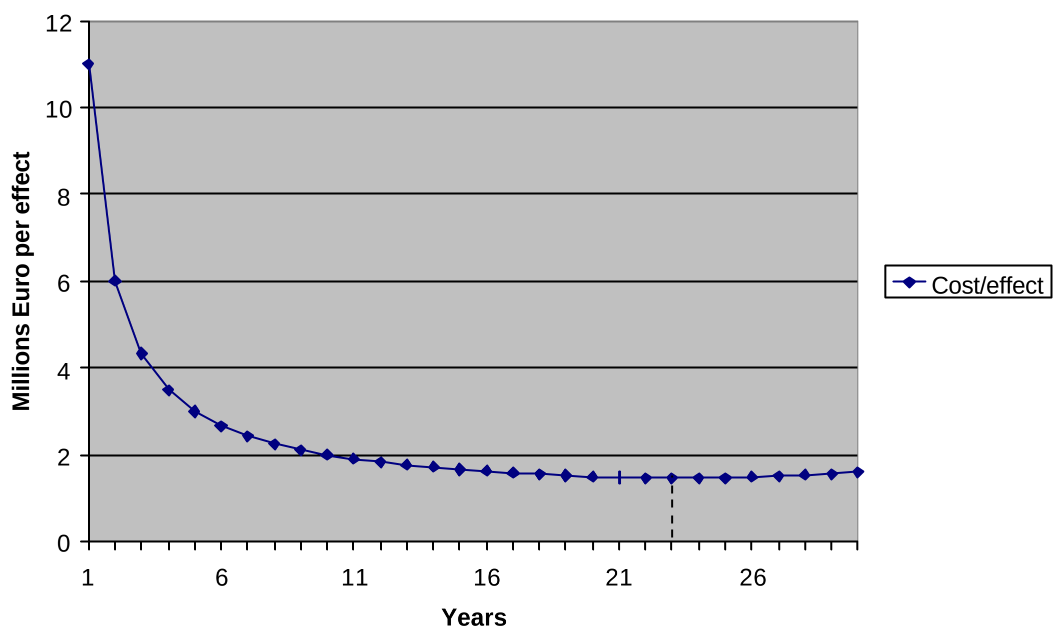
Budget = Budget_base + STEP(Extra_amount,Extra_start) - STEP(Extra_amount,Extra_start+Extra_duration)
Budget_base = 160
Effect_by_cost = IF Acc_spending > 0 THEN Acc_effect/Acc_spending ELSE 0
Effect_per_unit = 1
Extra_amount = 80
Extra_duration = 5
Extra_start = 0
Invest_amount = max(0,Budget-Operating_cost)
Operating_cost = Units*Operating_unit_cost
Operating_unit_cost = 1
Price_per_unit = 10
Total_effect = Units*Effect_per_unit-QELEM(Units,10)*0.05-QELEM(Units,9)*0.15-QELEM(Units,8)*0.25-QELEM(Units,7)*0.35-QELEM(Units,6)*0.45-QELEM(Units,5)*0.55-QELEM(Units,4)*0.65-QELEM(Units,3)*0.75-QELEM(Units,2)*0.85-QELEM(Units,1)*0.95

APPENDIX D: Increasing the effect without increasing the funding

One of the aims of defence planners is to achieve the greatest defence capability for a given budget (Coyle, 1992). There are two ways to increase the total effect of the force, without increasing the total amount of funds:

- Discarding the units before their effects have reached zero
- Spread the funding through the focused period, in order to reach a more constant effect

The optimal time to discard the units is when the accumulated cost per effective unit is least. This happens when the units are discarded after 23 years, when total cost of investing and operating one effective unit averagely costs € 1,46 mill. Keeping the units beyond year 23 reduces the cumulative effect/cost of the units.

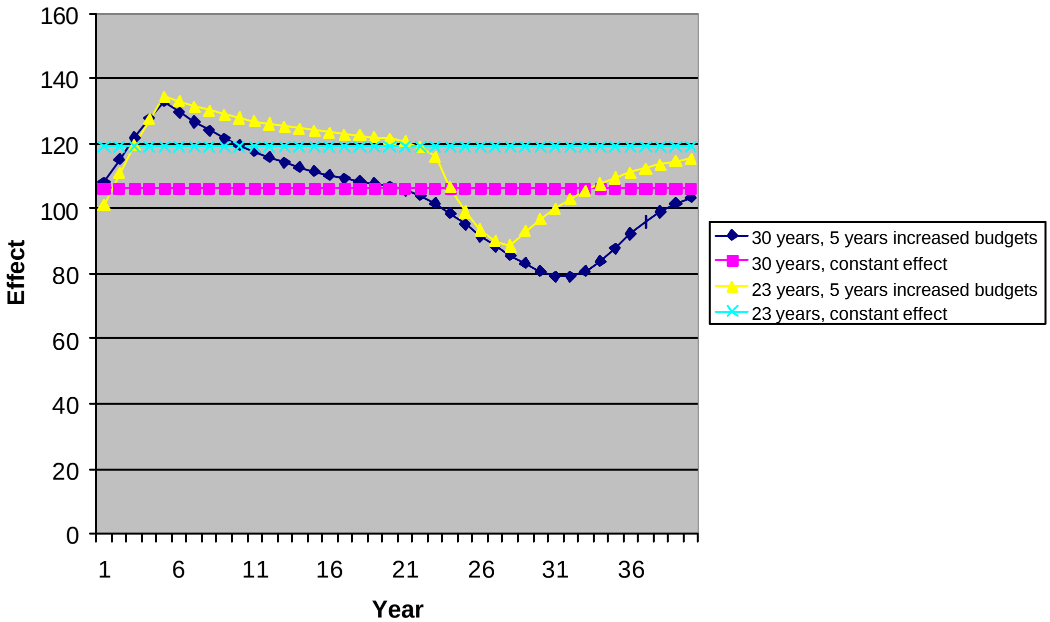


Spreading the funds so that the effect is constant during the period, isolated will increase the effect of the extra funding (above € 160 mill per year) by more than 40 percent. Additionally, it is often preferred to have an approximately constant ability to carry out an operation, at least when this model is set into the long-term defence planning perspective.

The cumulative effect from the base case was 4000 through 40 years. When increasing budgets by€ 8 0 mill for 5 years, the effect increased to 4172. The table below shows how these € 400 would give much higher effect, up to 4728, by taking two simple actions:

- Reduce operational life-time to 23 years
- Spread budget allocations to achieve stable effect during the operation

	30 years	23 years
5 years increase	4172	4570
Constant effect	4243	4728



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