Modeling Software Sustainment

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Abstract. Software sustainment is critical to DoD capability, but it is difficult to determine where and when to invest limited funds to produce the most significant impact for the least amount of effort and expense. An SEI research initiative is developing a model that shows the results of various investment decisions, allowing decision makers to see the effects and make adjustments before problems occur. Determining what data are needed to make the model work and how to collect it is also a significant challenge addressed by this research.

Introduction

Over the years, the percentage of functionality that depends on software has increased rapidly, making the cost of sustaining that software grow exponentially. For example, in the armed services the number of weapon system platforms is diminishing, but their projected service lifetimes are expanding. The B-52 now has a planned 90-year lifetime, and it includes functionality that could never have been imagined by its designers in the late 1940s. While hardware sustainment typically focuses on maintaining structural integrity, software sustainment is what continues to grow the capability of the B-52 and many other platforms like it. Even in the face of technological uncertainty, sustainment organizations across the DoD must plan for—and sustain—their capability to continuously improve critical software-intensive systems, update after update.

The SEI has worked with software sustainment groups in each of the services to determine how to make the best use of their dedicated software resources. In response, we are developing an economic model that can be used by decision makers to determine where and when to invest to have the greatest impact on long-term costs and fleet readiness.

Background

CrossTalk has been documenting the issues surrounding sustainment for several years. In the December 2007 issue, Capers Jones pointed out 24 major reasons that software in aging systems must be "improved" [1]. (Whether this would be called "maintenance" or "sustainment engineering" was a sidebar addressed by the editor of CrossTalk at that time, Beth Starrett.) In the same issue, the future challenges of sustaining F-35 software were described by Lloyd Huff and George Novak [2].

These future challenges led to two related studies by the Air Force in 2011. An Air Force Science Advisory Board report, "Sustaining Air Force Aging Aircraft into the 21st Century" [3] noted that sustainment was an inherently expensive process that would eventually involve the remanufacture of the entire aircraft, component-by-component, as wear-out occurred. Significant technical challenges to this type of sustainment effort were recorded as failure modes became age-driven rather than usage-driven. Significant concern was expressed in the report: "The Air Force is concerned that the resources needed to sustain its legacy aircraft may increase to the point where they could consume the resources needed to modernize the Air Force." The report sought to identify key technologies that could reduce the time and expense for the Air Force sustainment enterprise in its quest to maintain and field these aircraft through the 21st century.

The second report is the Air Force Studies Board's "Examination of the U.S. Air Force's Aircraft Sustainment Needs in the Future and Its Strategy to Meet Those Needs" [4] which addresses the broad issues of sustainment, with a specific chapter on software challenges.

The sustainment problem is made more complex because the funding decisions involve an understanding of the tensions among three different perspectives with differing definitions of value: operational need (warfighter view), the management of the portfolio (materiel view), and the capability and capacity of the sustaining organization (process, skills, tools, and people). DoD leaders must make decisions about allocating resources between the efforts that support the warfighter and the efforts that improve the performance of the sustainment organization consistently, with the goal of optimizing long-term value to the services.

The economic model that our research initiative is developing to support decisions about these investment questions will analyze factors such as demand for sustainment, the capacity of an organic workforce to do the sustainment, and the timing of funding, in terms of its impact on long term costs and the readiness of aircraft fleets. As part of this work, we developed an initial model that shows the interaction of the stakeholder values and the allocation of investment as a systems dynamics (or time-based) model. This type of model uses stocks and flows to represent sustainment performance over time [5].

Foundations of Our Approach

Systems dynamics work traces its roots to Jay Forrester at MIT in the 1950s and has been used as a modeling approach in the study of economics and organizations. Systems dynamics models allow people to study systems with many interrelated factors. When many factors are changing at once, their interaction can cause emergent effects that can result in a sudden and dramatic change in outcome. For these situations, traditional, simpler economic models such as return-on-investment and net present value are insufficient to understand what is happening. Through the modeling and analysis research, we are looking for the minimum amount of data, a signal, that can forecast a sudden and dramatic change (a "tipping point"). Forecasting the tipping point gives decision makers time to take action before a problem becomes intractable. Our research asks the following questions:
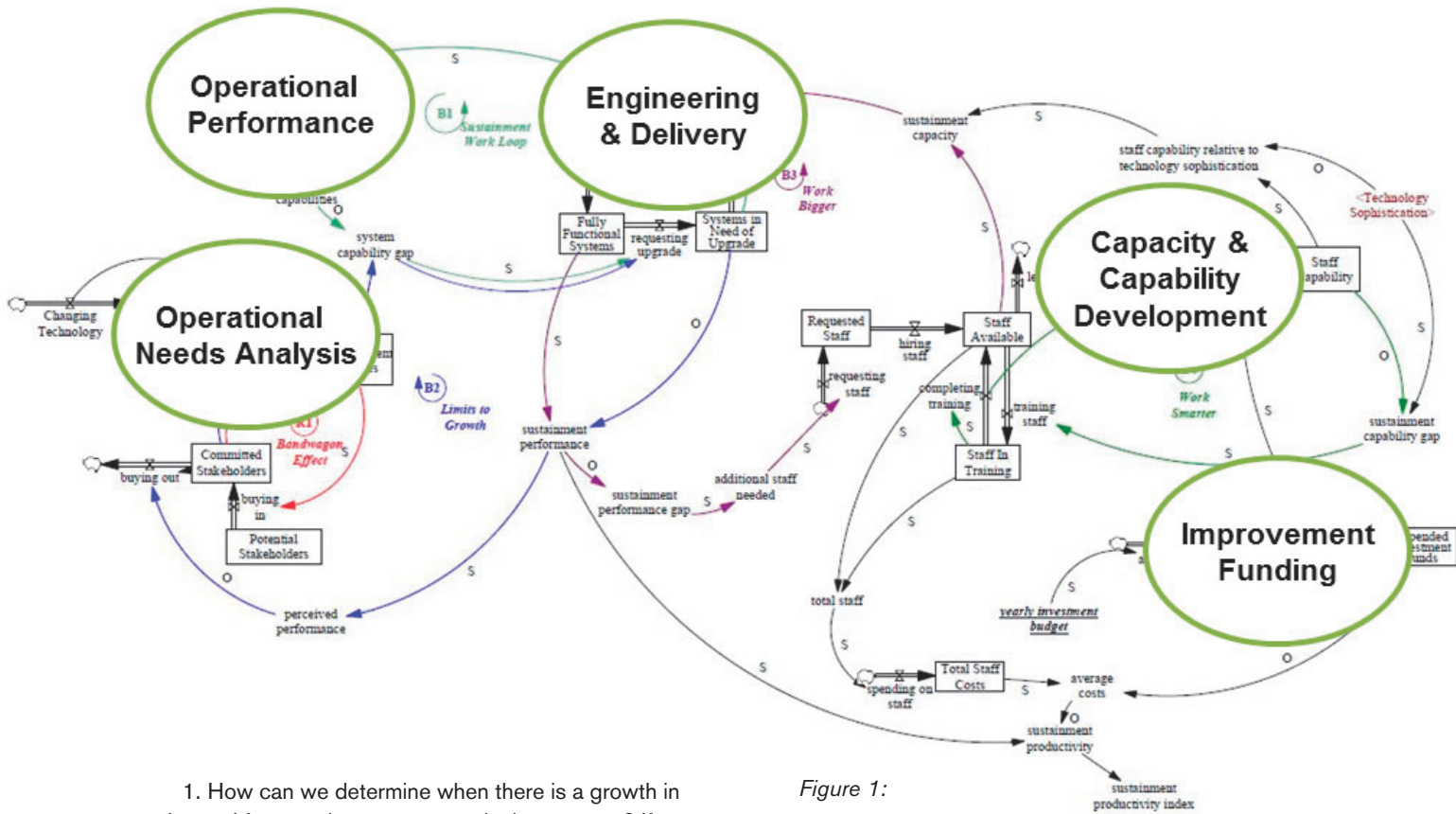
Figure 1:

1. How can we determine when there is a growth in demand for sustainment on a particular program? If we can identify the needed data, will it be possible to collect it and do the necessary analysis?

2. Do the models we are developing provide actionable information to decision makers in a timely manner? For example, does reallocating some resources from the sustainment work to the development of the workforce (tools, etc.) help reduce the cost of sustainment?

3. What measure of warfighter readiness correlates to the predictive factors in the model?

Using this approach, we aim to help DoD programs better plan their financial investment in software sustainment to ensure that the products are sustainable for as long as possible and deliver the best value for the taxpayer dollar. A working model will help senior managers test alternative strategies for investment. Satisfying the senior managers that the model correctly anticipates the behavior of the systems requires us to focus our research on discovering what sources of data can be used to calibrate the model for real application. Accomplishing this requires us to:
- identify data collection points within the sustainment processes
- identify opportunities to measure warfighter readiness or system use
- develop standards for applying data collection across different sustaining organizations

The Systems Dynamics Model

The basic goal of a simulation model is first to represent the normal behavior of a system and then to introduce a new input to see how the responses change. The model that we have developed

represents the behavior of the different aspects of the sustainment process, including the warfighter, the technical capability of the sustainment organization, and the capacity of the sustainment organization to deliver the work. We are testing the system response to various change scenarios, including the following:

Threat. An external change (such as a new threat to the warfighter) results in a request to update the system capability. This request means the sustaining organization will have to perform both product and process changes; the development process and testing may need to change as well. The changes often require funding to re-equip the facility and re-train the workforce. Our systems dynamics model helps decision makers analyze the effect if funding for this improvement is delayed.

Support Technology. The sustainment organization decides to improve its own throughput and adopts new processes to "do more with less." Typically the change is also in response to new quality goals. In this case our model helps codify the effect on sustainment capability, and capacity and therefore on operational performance.

Workforce. Sequestration effectively decreases the staff available to sustainment organizations by 10% to 20 %. How does this decrease affect a sustaining organization's ability to meet its sustainment demand? Does it affect aspects of the warfighter mission as well?

Our current model of sustainment consists of five basic processes and five dynamic feedback loops, shown in Figure 1. (Model details are blurred to emphasize the loops rather than exact feedback forms.) Process definitions provide suggestions for measures of inputs and outputs. Those inputs and outputs can then be calibrated for the forces and feedback functions.

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The processes in the model are listed below with input and output suggestions:

1. **Operational Performance**
   Input: Missions measured by capabilities used and mission-capable availability
   Output: Action reports measured by %success, and availability gap

2. **Operational Needs Analysis**
   Input: Mission performance measures and new potential threats, technologies, uses, and mission-capabilities
   Output: New capability definition

3. **Engineering & Delivery**
   Input: Sustainment demand (accepted and not-accepted requests)
   Sustainment capability required (skills, tools, facilities)
   Sustainment capacity required (throughput)
   Output: Delivered products by count of deployments and costs
   Sustainment gap (requests not accepted)

4. **Capacity & Capability Development**
   Input: Changes to training, tooling, facility, processes
   Hiring, furloughs, and attrition
   Output: Capacity available (%of request)
   Capability available date or delay

5. **Improvement Funding**
   Input: Funding requested for capability and capacity development
   Output: Time required to fund, amount funded

The following dynamic loops have been identified:

1. Bandwagon Effect. Successful missions and high mission performance lead to additional demands for capacity and capability.

2. Sustainment Work. Product use and environmental effects increase demand for sustainment work.

3. Limits to Growth. Capacity and capability of a sustainment organization limit the rate of completion of sustainment work. As these limits begin to extend the time required to redeploy, the long-term effect may be a reduction in demand or a switch to an alternate platform.

4. Work Bigger. A sustainment organization may attempt to meet sustainment demand by requiring overtime work or employing extra contract employees. Either of these approaches may work for a short time or a small additional cost, but they stress the organization and quickly reach the limits of their effectiveness. The organization can hire staff, but it must also allow time for training and acculturation of new hires to meet performance objectives.

5. Work Smarter. A sustainment organization invests in new capabilities (skills, tools, and processes) and possibly additional resources (people and facilities) to improve capacity for sustaining work.

Each of these scenarios entails several decisions in the process loops and stimulates response curves from the model. The response curves help decision makers forecast how deferring decisions or reallocating resources affects both warfighters and sustainment organizations. Our systems dynamics model will be helpful to decision makers if they are able to make faster decisions and if the data from the model makes it

easier to get sponsor support for the decisions. Our systems dynamics model will be helpful to researchers because the inputs/outputs of the model process suggest how to validate the model with sustainment data.

Initial Results and Future Work

Our research thus far has shown that the system dynamics model exhibits the expected and observed behavior of product sustainment. Of particular interest has been the impact of work-force changes on the sustainment cycle—positive effects like training and new software tool sets, and negative ones like the recent furloughs. As the system responds to change, the model helps us see that the effects have distinct cycles. A furlough has immediate impact, but a decision to fund new engineering environments can take years.

Model calibration is needed to capture specific, real world situations. Calibration will require significant work with programs and sustainment organizations. We are initiating a collaboration with a sustainment organization that could potentially provide the needed data for this research, and we are soliciting broader participation across the services and agencies.

Additional Reading:
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