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A System Dynamics Model of Government Engineering Support During the Development Phase of a Military Acquisition Program

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Due to the increase of system complexity and the existing draw down of manpower allocations, today's acquisitions environment desperately needs a systems approach to decision making. Many studies have been performed to model the entire government acquisition environment. Due to the high degree of aggregation, front line decision makers have had no use for the information these models provide.

This research focuses on the Air Force's largest functional support element in aircraft systems development, engineering. I will only consider one phase of the government acquisition cycle the Engineering, Manufacturing, and Development (EMD). This is the development cycle, which begins with initial contract award (Milestone II), through the production approval (Milestone III). This model is a building block to ultimately help leaders determine the required skill-set and manpower to perform activities which can meet short term requirements while minimizing the intrinsic cost, schedule, and performance risks associated system development. The simulation presented will be used by the as an alternative decision making tool for manpower allocations for government organic engineering workforce during an eight year development effort.

Key Words: military, acquisition, simulation, manpower, engineering, system dynamics, Functional Analysis System Technique (F.A.S.T), Management Causal Matrix (MCM)

Introduction

Since end of the Cold War, the U.S. Government has made concerted efforts to reduce the costs of its acquisition processes. One strategy has been the elimination of activities that are not necessary or cost effective. This has been a difficult transition, as the entire Defense industry wrestles with conducting business within a reformed acquisition environment. No government institution has felt the ramification of the new business practices as much as the System Program Offices (SPOs). In the USAF, the SPO is responsible for managing the entire lifecycle of a designated system. This includes the initial concept exploration and requirements generation through the development, production, and retirement of the system.

For years, SPOs participated in many activities that overlapped contractor efforts. The generation of a Government Statement of Work, Government specifications, and other standard practices made government acquisitions very costly and inefficient. SPOs were filled with military and government service engineers, financial managers, program managers, and contract specialists. All were assigned to duplicate contractor effort in managing the cost, schedule, and performance of the system.

In 1991, the Government Acquisition community began to rethink the manning and skills mix for weapon system development efforts. AFSC (Air Force Systems Command) Commander General Yates and the Acquisition leadership were faced with a problem. General Yates stated, "AFSC does not have a credible, quantitative process to determine the right numbers and skills of people to properly match acquisition workload, nor can it effectively defend the acquisition workforce" (Yates:1991).

A team embarked on a three-year project to determine a process for managing the existing acquisition force. The strategy to attack the problem was first to utilize other government manpower models in combination with "top-level intellectual involvement" to develop USAF-specific manpower models. The commander believed that it was necessary to determine, quantify, and defend the value of an organic acquisition workforce; otherwise, the acquisition community would continue to dissolve. Although the effort received great visibility and attention, the team was unable to determine manning models that could defend the value of maintaining an organic workforce.

In 1995, the Secretary of Defense (SECDEF) mandated several changes to the government acquisition process. The Air Force translated these mandates into several "Lightning Bolt Initiatives" released by the Office of the Assistant Secretary of the Air Force for Acquisitions (SAF/AQ) to facilitate a reform process due to the dismantling of the Defense budgets. Lightning bolt number 3 was entitled, "System Program Office 'Slim-Fast' Plan." The goal of the Lightning bolt was to "eliminate all unnecessary SPO activities thereby reducing program costs" (Druyun:1995).

The methodology for attacking the problem was to investigate programs that had demonstrated success in a reform-like environment. One arena was classified acquisitions, or

Special Access Required (SAR) programs. Historically, SAR programs had successfully performed their mission with a substantially smaller workforce than unclassified SPOs (Druyun:1995). A tiger team assembled to develop tenets applicable to unclassified programs which could help SPO Directors (SPD) to achieve efficiencies in SPO operations and ultimate reductions in manpower.

New SPO manning goals were established setting new thresholds for manning acquisition programs. Large development programs that previously employed over 300 military and civil servants were limited to 140 total personnel. Systems in the production phase that once had 150 employees were challenged to employ 50. The goals represented the total workforce manning, including government and support contractor resources. These goals were quite aggressive, up to a 90 percent reduction for some efforts. No apparent analysis was presented to verify or validate these numbers.

After two years of interviews, assessments, and analysis of streamlined acquisition practices, the Lightning Bolt team presented a list of "inherent government functions" to be retained by a SPO. These functions include the following:

I. Contracting - The processing of the contractual documentation and obligation of the government to pay for provided materiel and/or services.

II. Program Management - Evolves around understanding and managing risk through evaluation of program cost, schedule, and performance. A key component of this area is technical assessment - determining pass/fail of intermediate and final test criteria.

III. Requirements Determination - Setting the quality, quantity, and performance characteristics required from a procurement.

IV. Budgeting and Financial Management - The programming for, obligation of, and accounting for SPO funds.

It was determined that all other activities could be "source through the prime contractor, support contractors, or eliminated completely" (Lightning Bolt #3:1995). The functions were then reduced to several tenets described by the team as approaches which, if implemented intelligently, would lead to streamlining improvements. These tenets are as follows:

A. Aggressive Risk Management - A move away from risk avoidance toward risk management

B. Insight vs. Oversight - Understanding contractor processes and managing the program via process metrics

C. Clear Accountability in Design (CAID) - To the extent practical, the Air Force assumes no design responsibility below the functional baseline (system specification) level until the end of EMD

D. Integrated Weapon System Management (IWSM) - Non adversarial team membership to include the contractor and user

E. Reduce Contract Data Requirements List (CDRLs) - Use existing contractor systems for insight

F. Communication of Performance specifications - What we want the system to do, not how to build it

G. Flat SPO structure - accessibility to the Program Director

H. Maximum use of electronic media

I. Maximum use of commercial off the shelf (COTS) items—Only develop what needs to be developed.

Additional tenets were provided to the government system program director (SPD) to consider. These embrace the following key elements:

A. Maximize the teaming efforts to include other government agencies

B. Establish long-term government-contractor relationships

C. Minimize the number of contracts/line items and make them milestone based

D. Contractor develops a logistics support plan focused on 4 critical parameters

E. Minimize and refocus engineering staff

F. Borrow expertise rather than maintain within the SPO

Openly, the team admitted that the "report is not a 'cookbook' or a mathematical model for SPO sizing." They explained that their intent was to present a "tool box" for SPDs, which is to be "applied thoughtfully, based on the careful judgment of the program office personnel" (Lightning Bolt #3:1995).

The government acquisition community generally agreed that these steps could optimize certain portions of the acquisition cycle. However, many of the tenets were difficult to integrate in existing programs and some were unrealistic for some programs.

It was interesting that the tenets removed the engineering function. Government engineering support was one of the largest resources previously utilized in the system programs offices. Removing engineers would immediately reduce the manpower load by 50 percent for development activities. This may be attractive for the acquisition reform leadership, but it was unreasonable for the services and the contractors who rely on the engineering support to provide independent assessment of a program's technical performance. Many philosophical debates persisted throughout the acquisition community on the usefulness of maintaining a large engineering function within the SPOs. However, no analytical solutions could quantify the value of organic engineering support.

System Dynamics Modeling of Government Acquisition Systems

In the Air Force, I located five efforts at modeling all or part of the DoD acquisition system that were performed in the late 1970's and early 1980's. These include Elder and Nixon, Lawson and Osterhaus, Kaffenberger and Martin, Whittenberg and Woodruff, and Gonzalez and Sarama. The first 5 studies were performed during the Cold War arms race. Whispers of U.S. Government acquisition reform were evident in the text, but there were irreconcilable differences in fundamental assumptions, model boundaries, political, and environmental issues to further their research.

Elder and Nixon developed a conceptual model of the USAF program management activities being performed at Aeronautical Systems Division. They did not produce a completed model (Elder and Nixon:1976).

Lawson and Osterhaus developed a six-sector model depicting the entire DoD acquisition process, circa 1980. The causal relationships described in the text were not well understood or parameterized to be useful. The process was completed by a series of interviews with Senior Defense acquisition leaders and executives (Lawson and Osterhaus:1978).

Kaffenberger and Martin added four more sectors to Lawson and Osterhaus' model. Their model captured and described several causal relationships and systemic behaviors of the US- USSR arms race. Their contribution rested primary on the structure of the system and provided no validation or analysis (Kaffenberger and Martin:1979).

Whittenberg and Woodruff provided a capstone thesis, which completed the work of the previous studies as well as the work of Bechtel and Sweeney. Their comprehensive model of the acquisitions was quite an undertaking. Like the others, the model was designed for, and aggregated at, the highest level. Though the model was run and the provided some useful information to acquisition policies for the cold war environment, little was applicable to today's current world environment (Whittenberg and Woodruff:1982).

Gonzalez and Sarama developed a causal model that looked at the acquisition process from a Washington DC policy perspective. They modeled sectors including the political, economic, contractor, and multiple government agencies at a very high level of aggregation. They were unable to develop a computerized model of the system, but the well-defined causal structure provided insight to the complexity of the system (Gonzalez and Sarama:1999).

The very high level of aggregation and the enormous scope of these projects provided little detail or information for frontline managers to make decisions.

Model Objectives

The general objective of this research was to develop a conceptual understanding of the complex, dynamic nature of a government development program, and subsequently develop a computerized model that reflects the structure of the engineering function within a system program office (SPO). In the USAF, the SPO is responsible for the managing the lifecycle for a designated system. The lifecycle includes the initial concept exploration and requirements generation through the retirement of the system. The SPO consists of US government employed program managers, engineers, financial managers, and contract specialists.

The specific objectives were as follows:

1. Identify the structure of the system using traditional systems engineering tools such as Functional Analysis Systems Technique and Design Structure Matrix in concert with a system dynamics approach.
2. Isolate the interactions and influence of the components and variables within the system.
3. Describe the decision structure that determines the allocation of engineers to the SPOs.
4. Construct a mathematical model that represents the components, relationships, information flows, and decision policies of the system.
5. Develop a computerized model that can be used as a learning laboratory for policy analysis and development to optimize engineering support of a high-risk USAF development activity.
6. Identify areas of sensitivity or critical issues in engineering manpower allocation.

Methodology:

Information Gathering: A military development program is a complex and poorly understood system of multiple interrelationships and interdependencies. The role of the engineering function within this structure was extremely difficult to define initially. To gather information about the system, I employed group and individual knowledge elicitation techniques. These methods and tools are described in the following sections.

F.A.S.T.: Defining the model boundary and determining an adequate degree of aggregation was the first task. The Functional Analysis System Technique (F.A.S.T.) was used as a group knowledge elicitation method. (Bartolomei et al:2001) Several F-22 systems experts developed to describe the existing organizational structure by function. Over 150 functions performed by the program office were defined using the F.A.S.T. methodology. (Fowler:1990) Of the 150 functions, the team determined that engineering support was only required for certain functions.

Based on the F.A.S.T. exercise it was determined that the value of engineers to a program was to identify risk, mitigate risk, and broker information. The goal of the model was to determine the proper number of engineers required to achieve the government's cost, schedule, and performance goals and ability to adequately inform the customers.

Once the functions were identified, the team identified all of the daily activities that are performed to support the functions, the customers of the functions, and the required manpower to support the functions. Measures of performance for the activities within the system were also identified. As a result of this activity, all of the variables existing with in the system had been defined. The next step was to determine the interrelationships, which existed within the system and the predicted behaviors of the system.

Management Causal Matrix: A Management Causal Matrix was used to organize the variables and to visually represent the interrelationships that exist in the system. The purpose of the Management Causal Matrix was to provide a visual structure of the system. The matrix form is very conducive for identifying interrelationships within the system. Once this was accomplished, the boundary of the system was defined. The next task was to explored the dynamic relationships and information feedback found with in the system. Attached is a diagram of the management casual matrix of the engineering in a SPO. (Bartolomei:2001)

Individual Interviews: Several interviews were performed with experts in the government engineering community. Interviewees included the following individuals: the USAF Aeronautical Systems Engineering Director and former F-22 Program Chief Engineer, the USAF

Aeronautical Systems Chief System Engineer, the former F-22 SPO Chief Engineer, the Director of Engineering of the USAF Aging Aircraft Program, and the current F-22 SPO Deputy Director.

Prior to the interview process, several key dynamic relationships were isolated to present to the interviewees. Each interviewee was permitted to describe the behavior of the presented interrelationship and provide further comments in other areas that they felt needed to be addressed. The interviewing process was iterative, and each interviewee was allowed to see the comments of the other individuals. As a result, the individuals reached a consensus on the critical behaviors to be modeled. The method was similar to Ford and Sterman's expert knowledge elicitation method (Ford et al:1998).

Define System Behaviors: Behaviors identified during the interview sessions are identified in the following sections.

User Requirements Over Time:

This variable looked at the change in user requirements over time. Many weapon system development activities begin with a fuzzy set of user requirements proposed for the development. For aircraft development, many requirements include technologies that are unproven and extremely high risk. As a result, program managers and governmental agencies often manipulate the requirements during the development phase.

Figure 1 is a graphical representation of varying user requirements. Above 0 indicates a net gain of requirements or a requirement increase. Below 0 indicates a decrease.

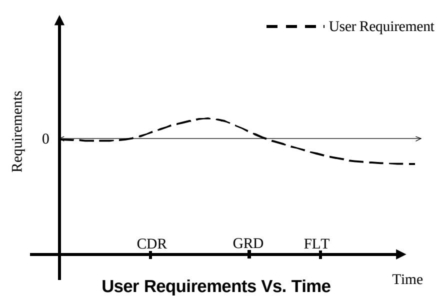

Figure 1. User Requirements Behavior

CDR represents the critical design review. GRD, represents ground testing, and FLT represents the beginning of flight test. The graphic shows that user requirements are generally stable until CDR. CDR is the first time that the program clearly communicates to the user the design proposed to meet the user requirements. Many times, there are discrepancies in requirement definition, and requirements are often increased. The CDR timeframe is also one of the last times in the process that the user can add work to the contract before it is too costly. This is why a slight increase in requirements is illustrated.

Ground testing, GRD, is a significant milestone for many programs in that it signifies that the first articles have been produced. Immature technologies and gold plating requirements are addressed. The users often relieve requirements to an acceptable level of risk, due to cost and schedule constraints. This is illustrated by the slight decrease of the overall system requirements during the last half of the development program.

<u>Technical Maturity vs. Time:</u>

Technical maturity, for most programs, has a goal-seeking behavior as seen in Graph 2.

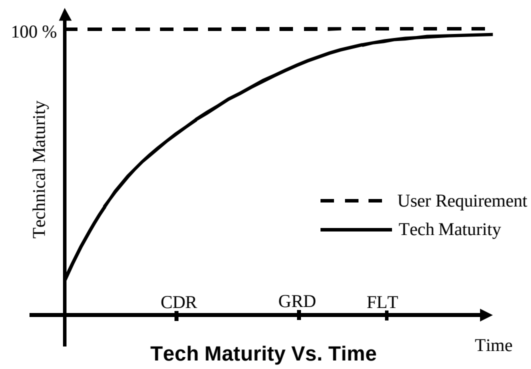

Figure 2. Tech Maturity Behavior over Time

This graph describes the percent of the system meeting the user requirement. This is a highly aggregate representation of the system. The inherent risks of multiple subsystems interacting makes this metric almost impossible to quantify since many portions of the system exceed user requirements and others will never approach the desired capability. As a whole, the interviewees accepted this to be an accurate representation of technical maturity over time.

<u>Program Risk vs. Time:</u>

Risk performance versus time is another dynamic relationship that is difficult for which to gather data and quantify. Program risk is defined as the unidentified, “unknown, unknown” factors inherent to the system, which affect cost, schedule, and performance. The behavior of this variable is entirely system dependent. The role of government engineers is to provide expertise to identify these risks and to help the contractor mitigate them.

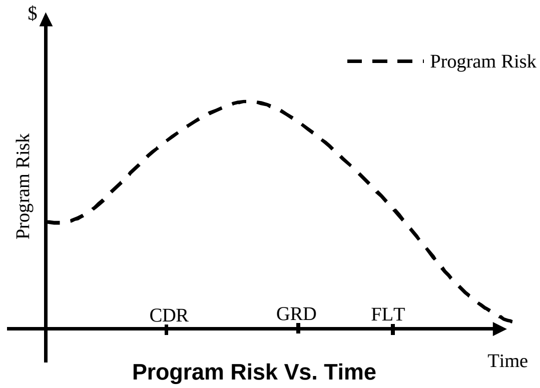

Figure 3. Program Risk Behavior over Time

Figure 3 illustrates the behavior over time. Initially, a development effort has identified a certain amount of programmatic and technical issues that are labeled as risk. Depending on the maturity of the technologies associated within the system, risk is identified through CDR until GRD. Once the initial development articles are produced, fewer risks are identified. The development team, in concert with the users, will look at requirement relief and the application of management reserve to mitigate the risk. The result is marginal risk as the development program begins to transition into production.

Number of Program Inquiries vs. Time:

For highly visible and politically charged military programs, information brokerage is one of the most important services a SPO provides. Engineers who understand the critical details of system performance and technical risks are called upon to answer other government agencies and Congress. The interviews reveal that answering inquires produces an S-curve behavior. In the beginning of a program, there is little external interference due to the immaturity of the weapon system. CDR is when programs generally start seeing inquiries. These inquiries come from various groups and generally deal with design critiques, new requirements, and new cost, schedule, and performance estimates. Programs offices see an exponential growth and then a tapering of inquiries as the program approaches Milestone III and the production contract decision, the biggest decision for any acquisition effort.

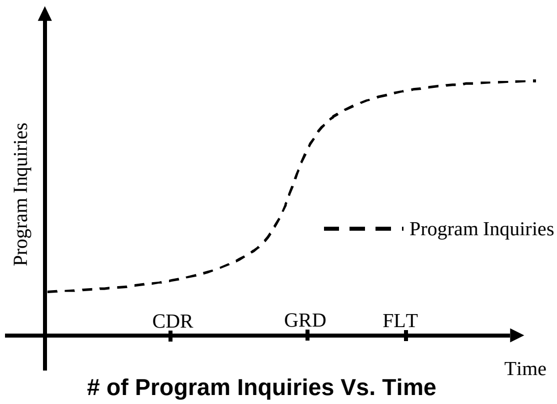

Figure 4. Program Inquiry Behavior over Time

Engineering Manpower vs. Time:

The next relationship presented in the initial interview was the allocation of engineering manpower over time.

Figure 5 illustrates the common approach to engineering manpower that reflects the contractor's manpower. Initially, manpower is added to the program at the beginning of the program and reaches a peak near the CDR. Once the design is set both the government and contractors dissolve the engineering workforce by two/thirds at completion.

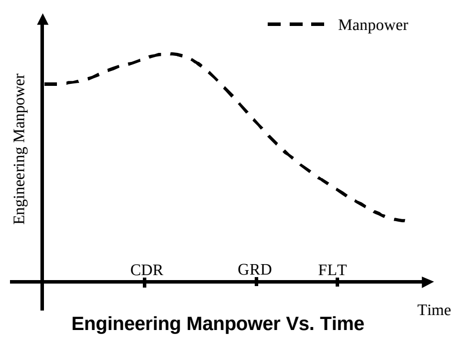

Figure 5. Engineering Manpower Burndown vs. Time

Cost to Mitigate Risk vs. Time:

This relationship illustrates the cost associated with making changes and the mitigation of risks during the development phase. Until CDR, the cost of mitigating risks is relatively low. After CDR, the same risks become increasingly more expensive. Early identification and mitigation of risk is essential in minimizing program costs.

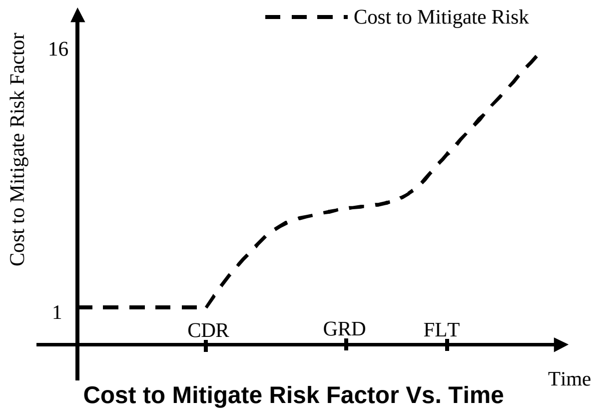

Figure 6. Cost to Mitigate Program Risk over Time

Risk Impact to Schedule vs. Time:

Similar to the cost factor previously mentioned, there is a varying impact of risk to a program's schedule. The earlier risk is identified, the less the impact. Figure 7 was generated by the interviews. The curve is identical to the Cost to Mitigate Risk Factor mentioned above.

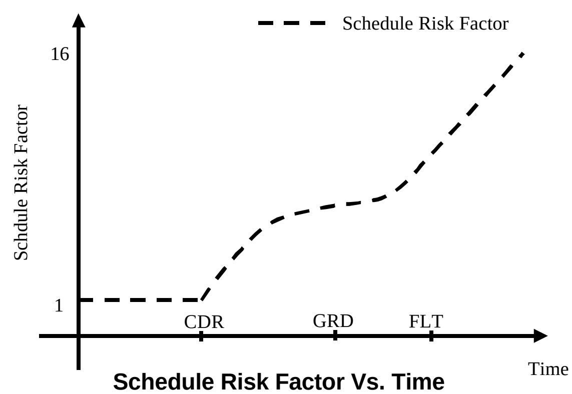

Figure 7. Schedule Risk Factor over Time

Model Description

Once the information-gathering phase was completed, the I-think® computerized system dynamic modeling tool was used to develop a stock and flow structure. The development of the simulation model was an iterative process. An object-oriented approach was used in which individual sectors were developed and validated and then incrementally integrated with other sectors. There were nearly 30 iterations and several expert interviews performed during the I-think development process. The following sections describe the system dynamics sectors that were modeled.

Requirements Sector:

This sector addresses the user requirements over the life of the development program. The **New Requirements** variable is an input to the system and is an independent factor. Requirements are reduced when the **User Willingness to Relieve Requirements** threshold is exceeded. The **Business Performance** input (earned value) is the variable that affects the users willingness to relieve the requirements. If the Earned Value performance is bad, then the **User Willingness to Reduce Requirements** increases. The **Performance Requirement Gap** represents the difference between **Tech Maturity** and the user **Requirements** goal.

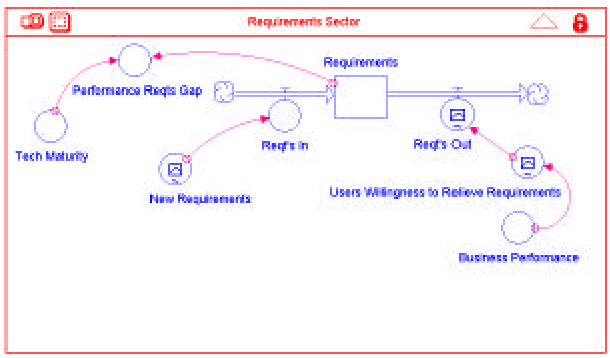

Figure 8: Requirements Sector

Identify Risk Sector:

This sector models the identification of risk within a government program. The premise is this: If the engineering support is manned with the appropriate number of individuals, the SPO will identify risk at an acceptable rate. If there are too few individuals, then risk identification is slow. Based on the behaviors presented earlier, the earlier risk is identified, the smaller the impact to program cost. The longer it takes to identify a risk, the more expensive it is, by a factor of ten, to mitigate.

Discovery Profile is an input variable, which is a time-phased input to **Units of Risk to be Identified**. The **Performance Reqts Gap** input drives manpower planning. Most SPOs determine the number of individuals required on a program by the maturity of the system. For a more mature system, fewer engineers are required to identify risks. **Available Manpower to**

Identify Risk is the actual engineering manpower allocated by the SPO. The delta between actual and required yields the **Confidence in Risk Assessment** variable. This factor determines the **Rate of Risk Identification** variable that is the output factor for the **Units of Risk to be Identified.**

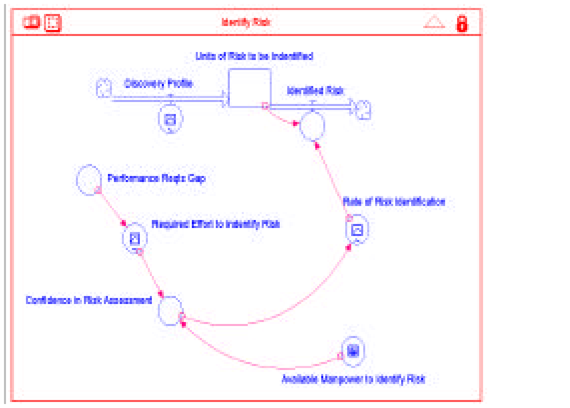

Figure 9. Identify Risk Sector

Mitigate Risk Sector:

This is the most complex sector in the program. The sector describes the flow of risk in a program. There are two ways for programs to address risk. First, management reserve can be applied to risk, thereby eliminating cost increase. Second, the SPO and contractor can work to mitigate risk or cost growth potential through “other means,” including technical problem solving, business practices, etc.

There are two major stocks in this sector, **Reported Program Risk** and **Management Challenge**. **Reported Program Risk** is the amount of risk that is reported external to the program. **Management Challenge** represents risks that currently exist yet are under mitigation.

The inputs to the **Reported Program Risk** stock come from the different inputs of risk into the system. These inputs of risk include the **Identified Risk v**ariable from the Identify Risk sector; **Risk Increase Due to New Requirements,** which represents additional costs due to the user increasing the weapons system requirements; **Unmitigated Risk,** which represents the risk that was unable to be mitigated; and **Mitigated Risk Out,** which represents one-third of the mitigated risk that reenters the system. The outflow is the **Management Reserve** that is applied to the risks. Another pathway for **Program Risk Out** is the **Requirements Relief Risk Out**. If the user relieves requirements, then risk is reduced from the program at a rate defined as **Risk Relief Due to Reduced Requirements**.

The **Management Challenge** input is dependent on the **Selected Management Challenge** factor. This is a time-phased factor in which, early in a program, the SPO accepts a larger percentage of risk as management challenge. This is because there is time to mitigate the risks. As the program matures and the design is well established, less management challenge is applied due to the decreased likelihood to reduce the program costs. There are two outputs to the **Management Challenge** stock: the **Unmitigatable Risk** and **Mitigate Risk Out**. The **Unmitigatable Risk Factor** is a time-phased variable that controls risk mitigation. Early in the program, there is a much higher probability to mitigate risk than later in the program. The **Mitigate Risk Out** variable is governed by manpower allocation.

The **Management Challenge** figure dictates the number of engineers required to mitigate risk, defined as **Manpower Required**. The **Available Manpower to Mitigate Risk** dictates the number of engineers allocated to mitigate risk. These two variables are computed to determine the value of **Confidence in Risk Mitigation**. This variable governs the **Mitigate Risk Factor**, which determines the **Mitigate Risk Out**.

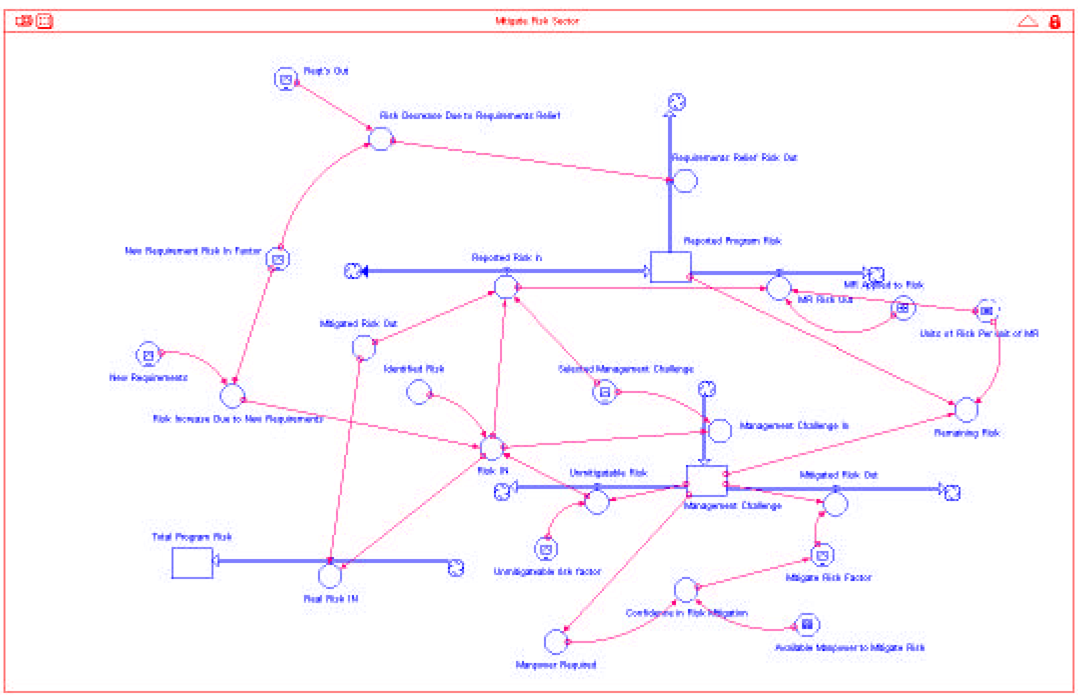

Figure 10. Mitigate Risk Sector

Other factors in the sector include **Remaining Risk**, which represents the sum of **Management Challenge** and **Program Risk**. **MR Applied to Risk** represents the number of units of management reserve to be applied to risk. **Units of Risk Per Units of MR** is a conversion factor between risk and management reserve. In reality, both risk and management are measured in dollars. This simulation represents the value of one unit of risk to be substantially less than a unit of management reserve by a factor of six. **Total Program Risk** is a measure of the total risk associated with the program.

Technical Maturity Sector:

Tech Maturity is a goal-chasing curve and is an input into the system. **Initial Maturity** is the maturity already achieved prior to the beginning of the development program. The **Requirements** stock comes from the requirements sector, and is the variable that changes when new requirements are added and subtracted. **Program Schedule** represents the number of quarters the program office is planning to complete development. **Projected Capability** is the percentage of the requirements the program expects to deliver to the user. When a program begins development, many times meeting the full set of user requirements is an impossible task. The user is reluctant to reduce requirements and is willing to progress with the program to push the envelope of technology despite knowing that a 100% solution is unreasonable. The user is also very unlikely to reduce requirements due to the concern of losing more than an acceptable amount of capability.

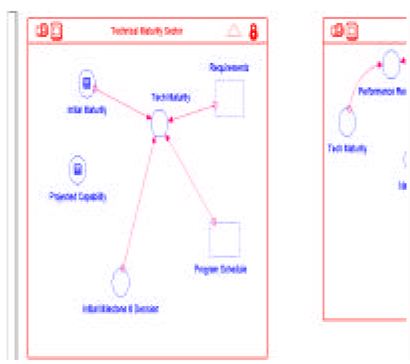

Figure 11. Technical Maturity Sector

Inquiries Sector:

This sector models the inquiries coming into a program office. There are three sources of inquiry inputs: **Planned Inquiries**, **Inquiries Due to Program Performance**, and **Inquiries Due to Customer Satisfaction**. **Planned Inquiries** are formal reporting inquires that each program office is required to perform. Reports such as the Monthly Acquisition Report (MAR), Defense Acquisition Executive Summary (DAES), and quarterly program reviews are examples of recurring reports that engineers support and are included in the **Planned Inquiries**. **Inquiries Due to Program Performance** are non-recurring inquires that are generated when the program is experiencing poor **Business Performance**. The **Inquiries Due to Customer Satisfaction** variable represents the additional inquiries that result from insufficiently supporting the inquiry workload. The Answer Inquiries Factor governs the workload and is calculated by the ratio of **Available Manpower to Answer Inquiries** and **Required Effort Inquires** variables. The **Required Effort Inquiries** is a predetermined value that is dependent on the number of inquires. The more inquires that are received, the more manpower that is required to answer inquiries. If the SPO does not allocate enough engineers to answer inquires, or **Inquiries Out**. **Inquiries Out** represents the remaining factor that increases the number of **Inquiries Due to Customer Satisfaction** and is multiplied by the **Answer Inquiries Factor**.

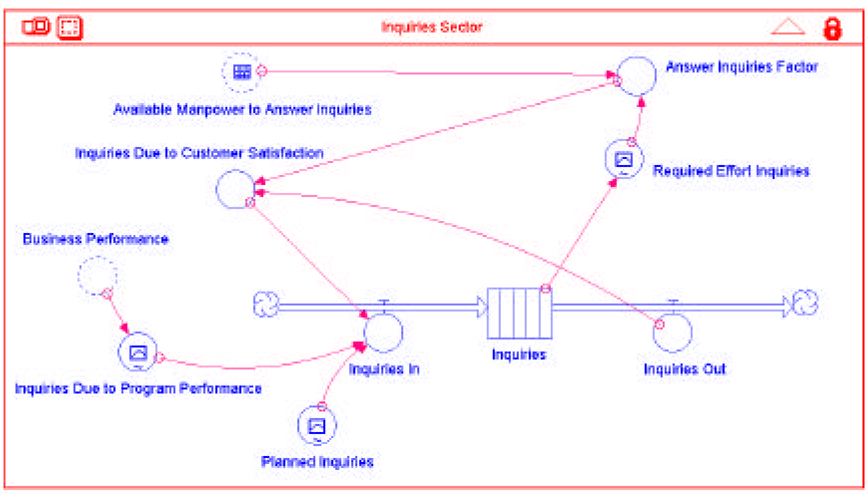

Figure 12. Inquiries Sector

<u>Manpower Sector:</u>

This sector contains the user-controlled input of manpower into the system. The **EN Manpower** variable is the sum of the allocated engineering manpower.

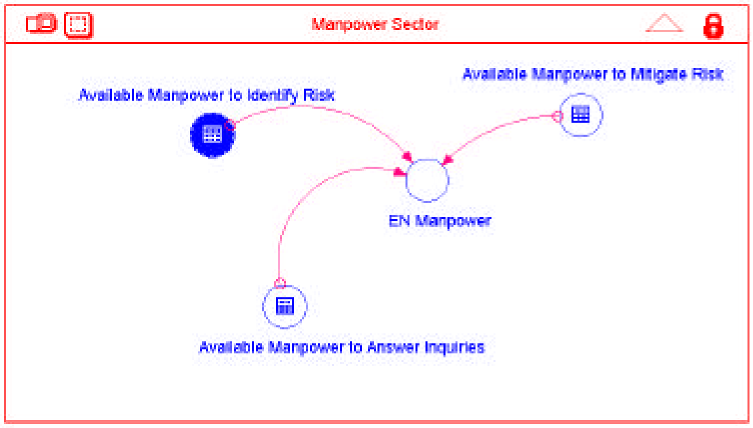

Figure 13. Manpower Sector

Cost/Schedule Performance Sector:

This sector models **Business Performance**, **Program Schedule**, and **Management Reserve**. **Business Performance** is the ratio of **budgeted at Completion (BAC)** and **Management Reserve (MR)** divided by **Estimate at Completion (EAC)** and **Reported Program Risk**, respectively. This ratio determines if the program is executable at the budget determined at the beginning of the program. If the value is less than 1, then the user must determine whether he is going to reduce requirements or seek additional funding. Other information feedback is determined by this variable. If the business performance is poor (<1) then the program could expect an increase in non-recurring taskers.

Program Schedule has an input and an output variable. **Schedule In** is a function of factors that increase a program's schedule. **Reported Risk In** is a variable that increases the schedule if risks are identified late in a program. Early identification of risk does not have a significant impact to schedule, whereas late risk identification is very costly and affects schedule. The other input to **Program Schedule** is the impact that new requirements have on schedule. The **Time Factor New Rqmt and Schedule 2,** in concert with the **New Requirement** input, yields an increase in schedule that is dependent on when a new requirement is added. The later a requirement is added to a program, the greater the impact it has on **Program Schedule**.

Mitigated Risk Out and requirement reduction variables govern **Schedule Out**. The **Mitigated Risk Out** compensates for the **Reported Risk In.** If the SPO allocates the proper effort to mitigate risk, some of the schedule impacts of the risks will decrease. There is also corresponding schedule relief associated with requirements; this is defined by the variables **Time Factor New Rqmt and Schedule** and **Reqt's Out**.

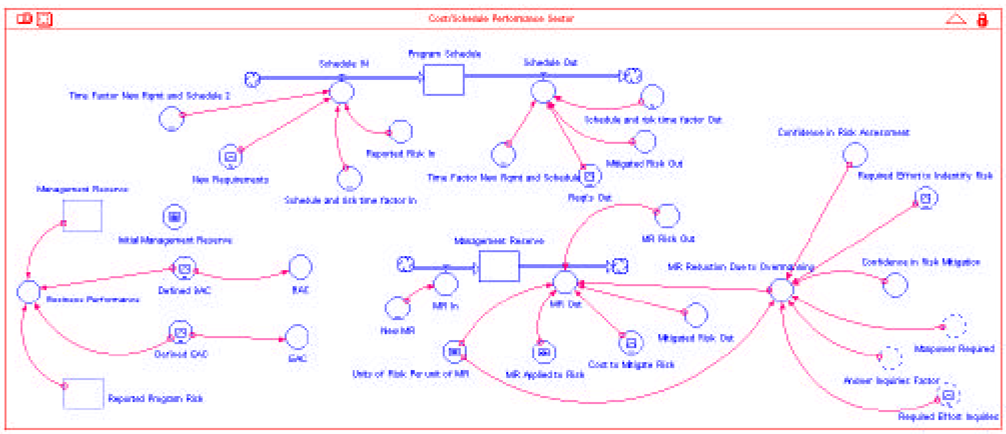

Figure 14. Cost and Schedule Performance Sector

The next key component of this sector is the **Management Reserve** region. Each program allocated approximately 10% of the contract cost for **Management Reserve**. Depending on the risk associated with the program, this variable can be greater or less than 10% and units can be added throughout the life of the program. The variable, **New MR**, is a controlled input.

MR Out represents the sum of the variables that drains the **Management Reserve** stock. These variables include; **MR Applied to Risk**, **MR Risk Out, Cost to Mitigate Risk,** and **Mitigated Risk Out**. **Cost to Mitigate Risk** is a time dependent variable and works in concert with **Mitigate Risk Out**. The two variables together establish that the point in program development at which risk is mitigated affects the cost of risk. The later in development a risk is mitigated, the greater the cost. The variable, **MR Applied to Risk**, is a control that allows the model user to reduce a significant amount of risk in a specific time increment. **MR Risk Out** is same output variable to the **Program Risk** stock. The variable **MR Reduction Due to Overmanning** penalizes the model user for overmanning the program. If the ratio of manpower required versus manpower allocated is exceeded, the program MR is reduced.

Model Analysis:

Due to the lack of substantial data, the model was not fit for performing critical statistical analysis. The main objective was to determine if the current structure and multiple assumptions yielded a reasonable response. Many scenarios were tested and the model was validated as a good representation of the system structure. I will examine one scenario with varying manning levels.

Adequate Engineering Support:

Below is several graph outputs from the model compared to the predicted behaviors with reasonable engineering manning levels.

As indicated in figures 15 and 16, the behavior of achieved technical maturity vs. time behaved very similarly to the predicted behaviors. Figures 4.3 and 4.4 illustrate the behaviors of program inquiries.

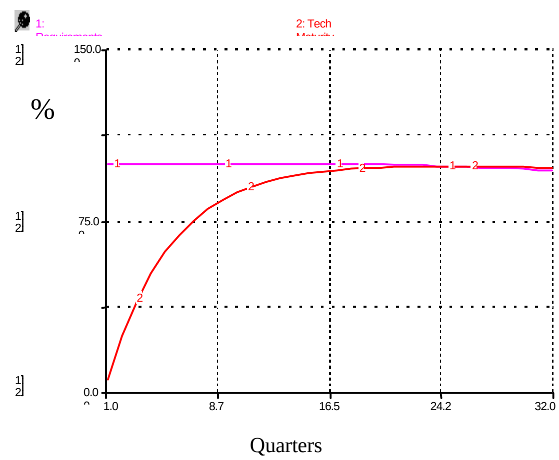

Figure 15.

Simulated Technical Maturity vs Time

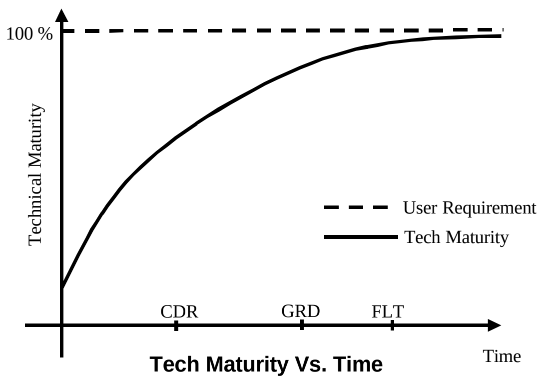

Figure 16.

Predicted Technical Maturity vs. Time

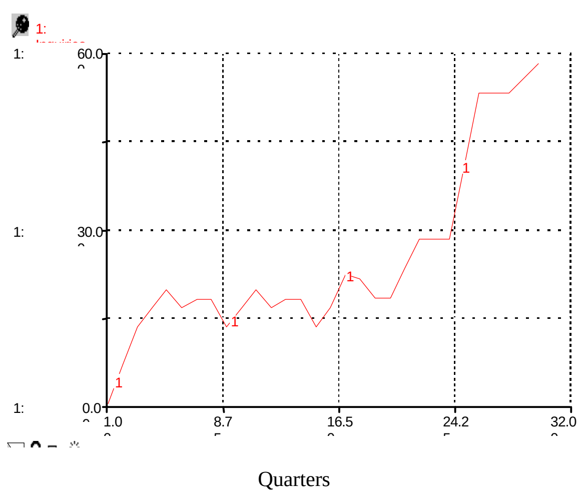

Figure 17.

Simulated Inquiries vs. Time

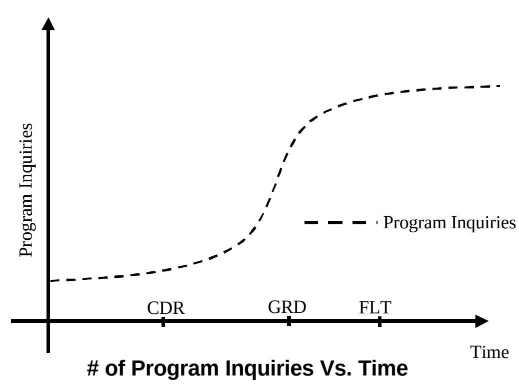

Figure 18.

Predicted Inquiries vs. Time

Figure 19 shows **Management Reserve** versus **Remaining Risk** over time. The behavior represents a successful program where the difference between the **Management Reserve** and the **Remaining Risk** represents the amount of funds remaining during the development program. The two peaks on the **Remaining Risk** curves represent risk discovery in the system. According to the predetermined inputs, the engineering manpower identified risk in a timely fashion.

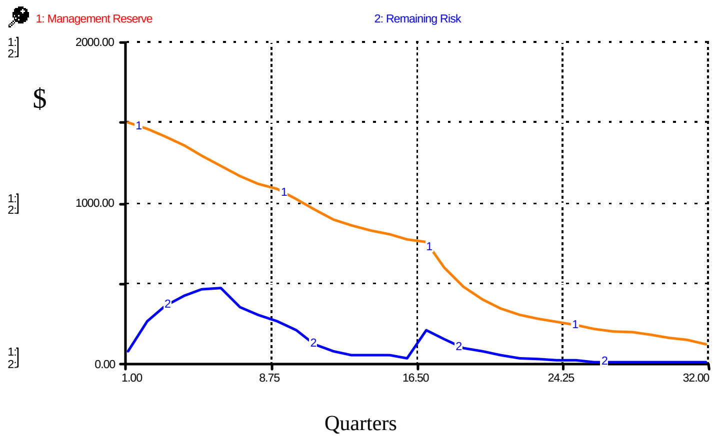

Figure 19. Management Reserve and Program Risk over Time

Too Few Engineers:

The next graph represents a program office that has no engineers supporting the development activity. The program office is relying on the contractor to identify and mitigate risk. With all the variables remaining unchanged from the previous example, with the exception of reducing manpower, the results are seen in Figure 20.

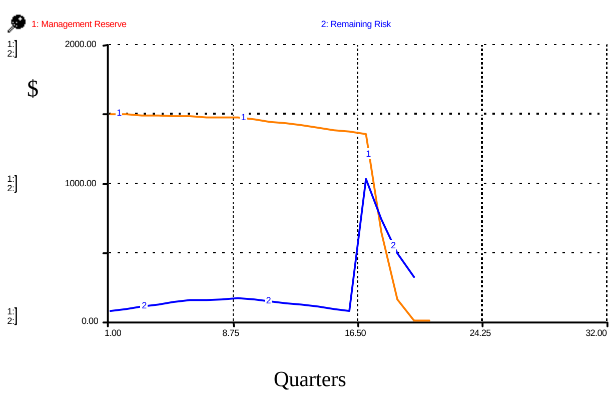

Figure 20 Management Reserve and Program Risk Performance with No Engineers

The results are as expected. The **Management Reserve** burndown is much slower, due to the very slow identification of risks represented by the **Remaining Risk** curve. The sudden peak a time=16, represents the contractor's identification of risks. The model is parameterized so that at the halfway point the contractor begins identifying risk. The program goes unexecutable at approximately time (T) =17, when the management reserve fails to cover the program risk.

Too Many Engineers:

The next graph represents the behaviors of Management Reserve and risk in a program office with too many engineers. The behavior is the opposite of the previous example. **Management Reserve** experiences a steep decrease due to the early identification and mitigation of risks, and the extra costs of extra manpower. At T=16 there is only very slight increase to the **Remaining Risk** due to fact that contractors has very little risk to identify. Interestingly, the program becomes unexecutable at T-17 because the risk, though small, exceeds the remaining management reserve. The system model behaved as predicted by demonstrating the adversarial effects of overmanning.

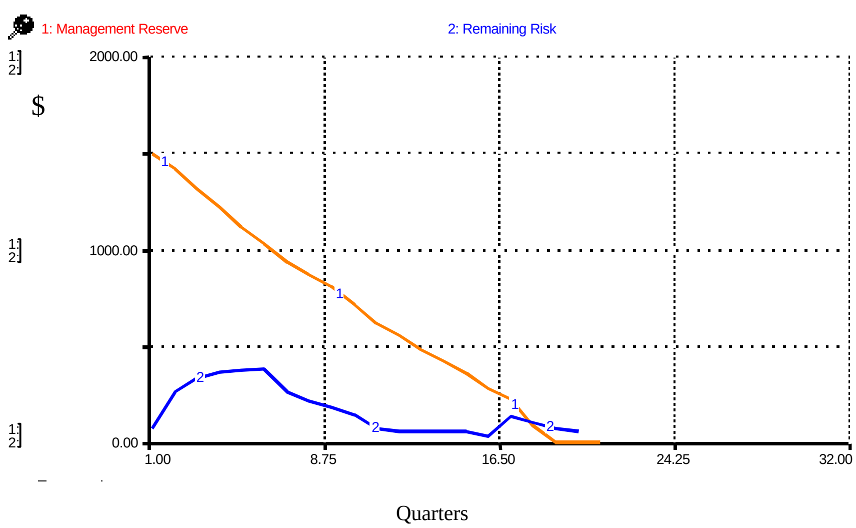

Figure 21.

Management Reserve and Program Risk Performance with Too Many Engineers

Early Requirement Changes

The next scenario examined the effects of requirement changes early in the program. The parameters were reset to the adequate manning level described above. For the scenario, a 50% increase of requirements was added to the program in the first 8 quarters of the development cycle. Figure 22 illustrates the system behavior. The three step-like jumps at T=2, T=4, and T=6 represent increases in the requirement. The early changes to the requirements has little effect on the **Technical Maturity** which matures before the end of the program.

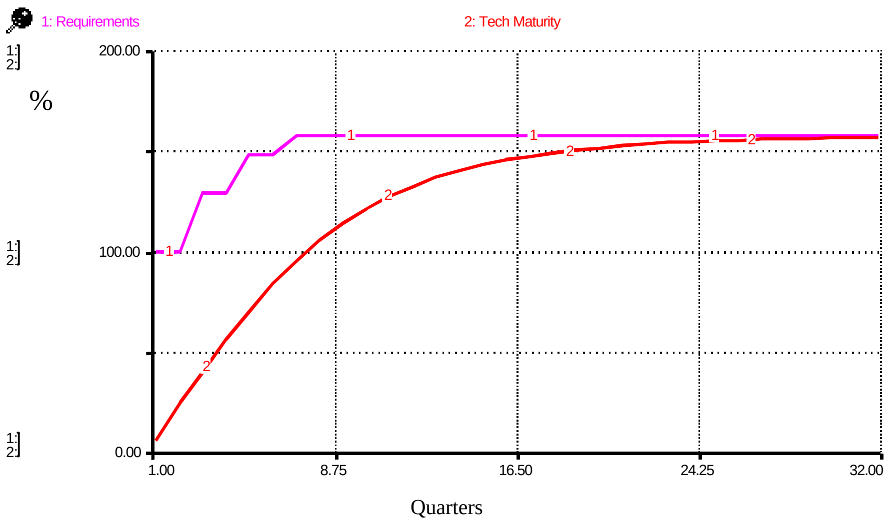

Figure 22 Tech Maturity and Requirement Behaviors with Early Increase in Requirements

Figure 23 illustrates the **Management Reserve** and **Risk** behaviors. Even with a 50% increase in the requirements, the program is executable.

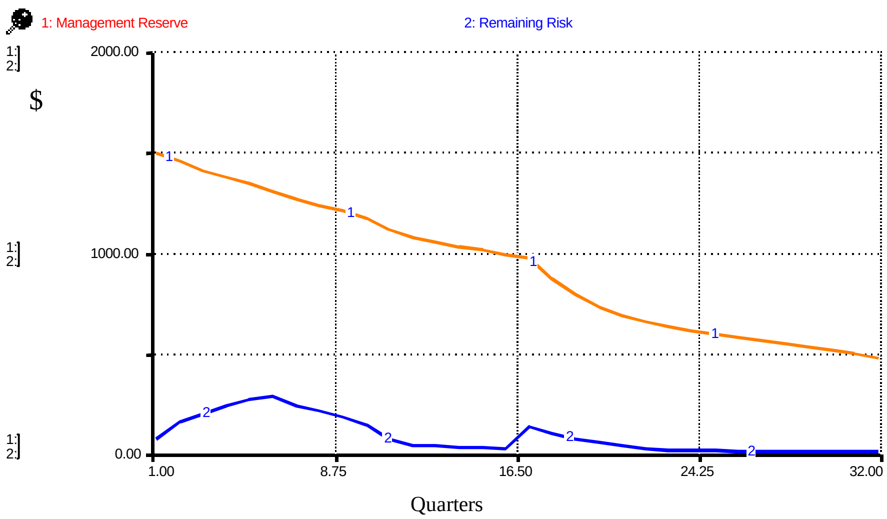

Figure 23 Management Reserve and Program Risk Behaviors with an Early Increase in Requirements

Late Requirement Changes:

The next scenario investigates the effect of late requirement changes in the last quarter of the development phase. The results are significantly different than early changes. Figure 24 illustrates increases in requirements at T=22, T=24, and T=26.

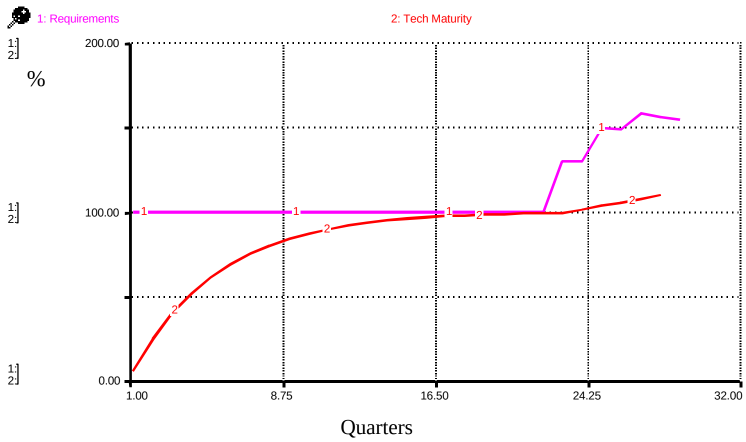

Figure 24. Tech Maturity and Requirement Behaviors with Late Increase in Requirements

Figure 25 goes unexecutable at T=25, when the risk exceeds the management reserve available. Notice that the program actually goes unexecutable after only a 25 % increase in the requirements.

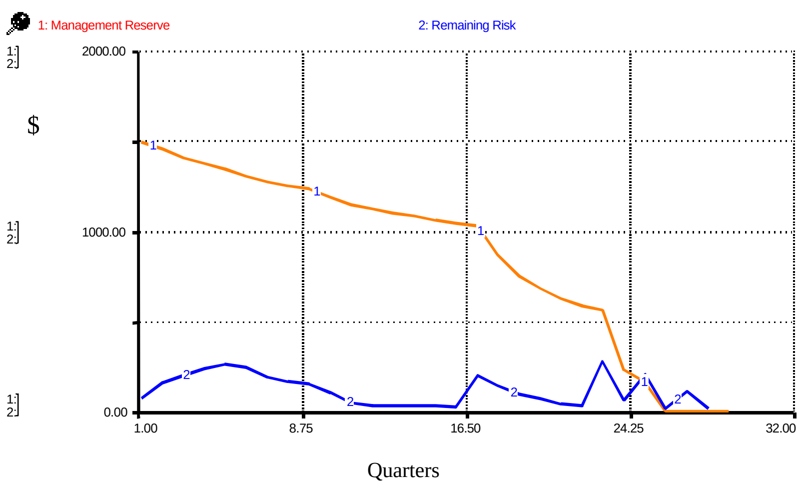

Figure 25 Management Reserve and Program Risk Behaviors with an Early Increase in Requirements

As expected, late increases in requirements have a grave impact on the performance of a program.

Sensitivity Analysis:

Once the extreme conditions were tested, we tested different policies and performed sensitivity analysis. To perform sensitivity analysis for this model, variables were individually manipulated while keeping all other variables constant. If the dynamic behavior of the model changed significantly, it was determined that the variable was a critical variable. The results of the sensitivity analysis determined that manpower selection for each of the three control variables, Manpower to Mitigate Risk, Manpower to Identify Risk, and Manpower to Answer Inquires, were significant factors in the model.

During the sensitivity analysis two manning scenarios were explored. The first looked at the ramifications of adequately manning the engineers who identify and mitigate risk in the beginning of the program, and then removing them at the midway point.

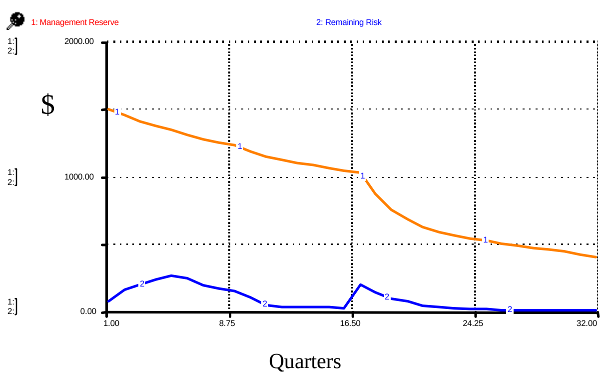

Figure 26 Management Reserve and Risk Performance with Adequate Manning

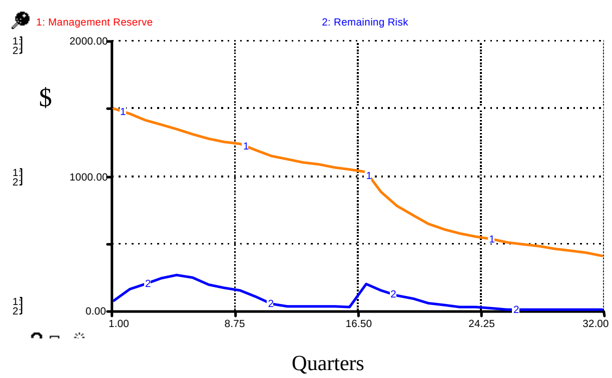

Figure 27 Management Reserve and Risk Performance with Adequate Manning time T=16 and no engineering manning T>16

The results demonstrated that the system is not sensitive to the removal of engineers who identify and mitigate risks after the midway point of a program development. This does not say to remove the engineering workforce completely, because engineers are still required to broker information to the stakeholders and to communicate with the contractor. However, the SPOs might consider reallocating the engineering workforce to shift focus from risk identification and mitigation, to other areas.

The next scenario looked at the behavior of the system if the program has too few engineers at the beginning of the program, and then increases engineering staff at the midway point. Increasing engineering manpower did not improve the system risk performance. In fact, the program became unexecutable at T=20, see figure 29, versus the no engineering model which remains executable until T=24.

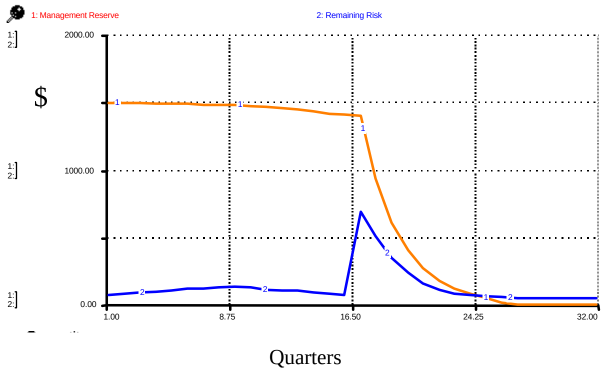

Figure 28 Management Reserve and Risk Performance with no manning

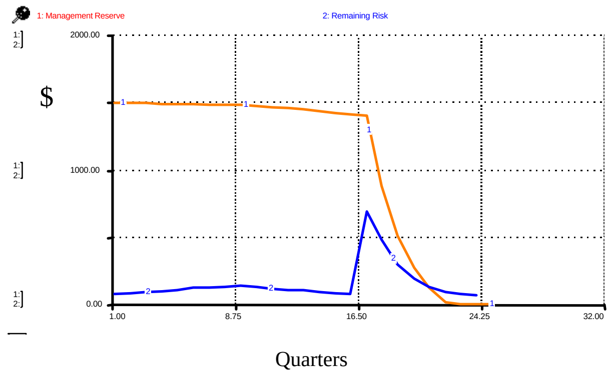

Figure 29 Management Reserve and Risk Performance with No Manning T=0 to T=16 and Adequate Manning T>16

This result is a bit counterintuitive. One might think that adding engineering support to a program would improve performance. However, the late addition of government engineering manpower would also increase the contractors engineering manpower. The added expense would causes the management reserve spending to increase at a faster rate.

Also, as mentioned in the section above, the system is sensitive to the changes in requirements. Early increases of requirements, does not affect the program. Late increases of requirements have grave consequences to system performance.

Conclusion/Recommendations:

The exercise of generating the model has yielded a much greater understanding of the system. The systems experts have agreed that the basic structure of the current model is sound, and the boundary definition and the degree of aggregation provides insight into the system.

The system experts were very pleased with the results of the model. The largest USAF organic engineering organization has adopted the model as a baseline. The entire process enabled the system experts to see the system in a new light. The rigorous information gathering and the formal modeling process led USAF leadership ask the right questions. Each expert has expressed that there is value in pursuing a systems approach to solving the manpower problems over traditional empirical manpower models. They plan to further refine the existing model to better understand the critical dynamic relationships and will pursue better parameterization.

Since system dynamics modeling is an iterative process, the next step would be to revisit the critical relationships and reach a consensus of the linear and nonlinear dynamic relationship through interviews and data gathering.

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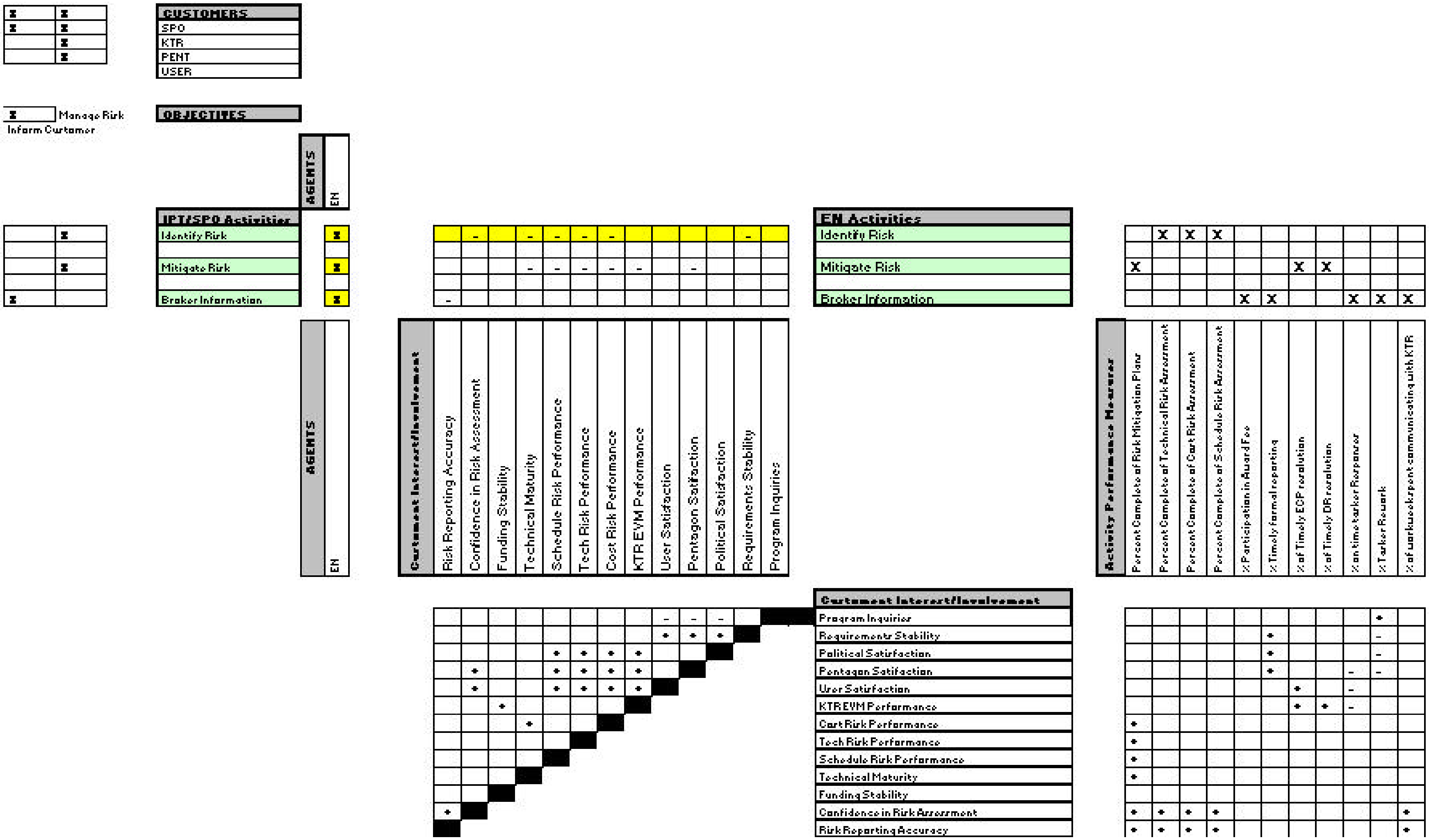

Management Causal Matrix of Government Engineering Support for a Development Program