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Systems-Theoretic Process Analysis for Organizational Management

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Abstract

This work is intended to demonstrate how Systems-Theoretic Process Analysis (STPA) can serve as a practical and immediately useful tool for the U.S. Army. Specifically, it is intended to improve outcomes in current and future acquisition programs. To demonstrate its usefulness the Future Combat Systems (FCS) program is examined retrospectively. This work is not intended to study history. It is in tended to show how STPA can improve outcomes in acquisition programs when used proactively. FCS was a highly ambitious modernization effort launched in the early 2000s. It eventually ended in cancellation due to technical, financial and organizational challenges (Pernin et al., 2012, p. 47). This work identifies a number of organizational losses, hazards and system constraints that contributed to program failure. This work will also model the high-level organizational control structure of FCS along with selected features of the mid-level organizational control structure. These structures reveal weak feedback loops, poor communication and other organizational barriers that helped contribute to a cascading series of program break downs. What STPA offers Army leadership is a powerful, accessible causal framework that can expose hidden systemic risks. The organizational control charts that emerge make it a practical and visual discussion tool for briefings, meetings and strategic decisions. This work also attempts to demonstrate that current U.S. Army programs still suffer from organizational challenges, evidenced through a discussion of the Integrated Visual Augmentation System (IVAS) and the XM30 programs. This work demonstrates that by systemically generating and examining organizational control structures, STPA can improve current and future U.S. Army acquisition outcomes by highlighting organizational shortcomings that are not always easily detected using other management frameworks.

Keywords

Program Management, Systems-Theoretic Process Analysis, Organizational Management, Defense Acquisition.

Introduction

Organizational management, the approach to aligning personnel and initiatives to achieve organizational goals, is a short- and long-term challenge that evolves as the goals, risks, issues, and opportunities faced by an organization change. This challenge is pronounced in larger organizations and novel initiatives, and demands a sound approach to practical management. Systems-Theoretic Process

Analysis (STPA) is one such approach from systems engineering that aims to uncover latent and active risks in complex systems (Leveson, 2011). Organizations leverage personnel, hardware (e.g., equipment) and software to accomplish specific goals, and are therefore large, complex socio-technical systems. Viewing organizations as systems allows the application of systems engineering approaches to organizational management; STPA has been successfully applied to organizational challenges (Williams, 2019). This work demonstrates the utility of STPA for analyzing organizations as systems and developing feasible interventions to support organizational success. This paper applies STPA to identify and model the organizational challenges faced by the failed U.S. Army acquisition program Future Combat Systems (FCS), and develops an "idealized vision" of FCS.

The U.S. Army FCS program was initiated in the early 2000s and was intended to revolutionize U.S. Army operations. The main deliverable for FCS was to be a family of integrated, advanced systems to forge deeper connections between U.S. Army operators for the "Army of the Future." Although ambitious, the FCS program ended in cancellation after being plagued with cost overruns, integration challenges, organizational failures and unrealistic scheduling (Francis, 2003). While there are a number of sources that detail technical challenges that the program faced there appears to be fewer that examine the structure of FCS and how this structure also contributed to failure.

STPA, a highly structured engineering framework, was originally developed to uncover risks in complex systems (Leveson, 2011). However, it also proves valuable for organizational analysis by providing a structured approach for understanding organizational control structures and systemic challenges (Barstow, 2023; Dainoff et al., 2022). The organizational control structures also detail decision-making paths and feedback mechanisms within the organization. Causal diagrams and control structure visualizations facilitate rapid transfer and translation of information between key stakeholders, and can be easily discussed by leadership in staff meetings, strategy reviews and briefings. These features of the framework make it differ from traditional risk management frameworks.

This work demonstrates that the STPA approach is valuable, not just when performing historical analysis of a failed program but also on current Army endeavors. Using the lens of STPA, one can see the recent difficulties of the Integrated Visual Augmentation System (IVAS) program with a new and refreshing perspective. Regarding IVAS, early misalignments between leadership, soldiers and developers resulted in costly delays and scope changes (Dodaro, 2023). This highlights how organizational deficiencies can degrade promising concepts, and the continuous nature of organizational management. Therefore, a strategy of applying STPA early in a program's lifecycle could better inform leaders of risks that are challenging to uncover long before issues escalate in cost and complexity. Another challenged program that will be examined is the XM30 program. This program has had several publicized setbacks. When reviewing the literature with regards to the XM30, while also considering the organizational control structures of STPA, finding that the program apparently set rigid requirements ahead of soliciting feedback from soldiers appears highly relevant to this work. These two programs, the IVAS and the XM30, indicate that a strategy of applying STPA early in a program's lifecycle could better inform leaders of risks that are challenging to uncover long before issues escalate in cost and complexity. Continuing application of STPA, e.g., as the organization and/or mission evolve, ensures that emergent issues are identified and mitigated before propagating through the organization.

This work demonstrates that STPA is a straightforward and practical tool Army leadership can immediately leverage to improve program alignment while mitigating risk that will improve return on investment. This high-level view of STPA applications is part of a broader, ongoing research effort to develop an STPA informed framework for large organizational management. Section 2 of this paper provides further details on the FCS program and STPA, and Section 3 highlights the application of STPA to

FCS. Section 4 discusses the utility of STPA for ongoing challenges similar to those faced by FCS, and Section 5 concludes with recommendations for the immediate application of STPA as an organizational management tool.

Background

Army Future Combat Systems (FCS)

The FCS program was an initiative to develop and deploy the weaponry and support systems to support a transformed, strategically responsive, and rapid deployment-focused Army. The roughly $200 Billion pro gram was first envisioned in 1999, and became an official acquisition program in 2003. Aiming to produce a suite of 18 systems networked with each other and warfighters, FCS ultimately failed as ambitious, but vague, system requirements produced few mature technologies and unexpected risks and growing complexity exacerbated unrealistic schedule goals (Pernin et al., 2012).

As FCS became an official acquisition program (i.e., hit "Milestone B"), the U.S. General Accounting Office (GAO) issued a report on the challenges of FCS. Even at this early stage, it was recognized that the schedule, even if extended, was challenging convention built by past programs. Further, GAO assessed that critical technologies had not matured and increased the risk of cost escalation and schedule delays, and proposed three approaches to salvaging investments in the program (Francis, 2003). At the heart of FCS were the Lead Systems Integrators (LSI), Boeing and Science Applications International Corporation (SAIC), charged with integrating over 500 contractors to produce a cohesive battalion of advanced, net worked systems (Klein, 2007).

Even as FCS continued, the concerns mounted across government institutions. Various parties criticized the Department of Defense's (DoD) reliance on just two prime contractors, the rising costs, and the sheer ambition of the program (Klein, 2007). As the costs ballooned from the planned $92 Billion to over $200 Billion, and the 33.7 million lines of code in the original estimate tripled to 114 million, the DoD eventually decided to sunset the program, canceling some projects and rolling others into other DoD programs (Charette, 2009). Approaching 20 years after the end of FCS, the consensus remains that it was an ambitious, and necessary, concept that was doomed by poor planning and execution. Guided by lessons learned from FCS, the drive to develop and deploy advanced systems in support of the warfighter continues through a range of programs including IVAS. However, these new programs continue to face challenges (Roque, 2023). Operationalizing lessons learned requires a systematic, accessible approach that is adaptable to various contexts. STPA is one available pathway to incorporating lessons learned.

Systems-Theoretic Process Analysis (STPA)

STPA, developed by Nancy Leveson, is a hazard analysis technique based on modeling of accident causation. It has been shown to be a useful method for identifying potential hazards in complex systems. A central assumption of the STPA framework is that accidents are caused not only by component failures but also by inadequate control interactions among and between a system's components (Leveson & Thomas, 2018).

STPA is a method within the Systems-Theoretic Accident Model and Process (STAMP) framework, originally developed to effectively assess system safety and reliability in the massively complex and increasingly interactive and digitized systems that are replacing "traditional" mechanical systems (Leveson, 2004). The underlying theory of STAMP is that increasing complexities in systems have outpaced our ability to understand their workings – a point that is increasingly salient given the proliferation of artificial intelligence (AI) systems. As a result, whereas risk and safety analyses typically focus on chains of events (accident sequences) comprised of hardware and/or human failures, STAMP and STPA take the view that inadequate control and enforcement mechanisms in the system are a root cause of system failure (Leveson, 2004).

Safety analysis using STPA expands beyond traditional models to incorporate process dynamics like feed back and control structures. This technique is well known for being successfully applied to traditional systems like airplanes or computer networks (Ishimatsu et al., 2010). However, it is less known for being 3 applicable for analyzing the behavior of organizations, although it has been explored for that application (Dainoff et al., 2022; Williams, 2019).

Applying STPA to an Organization

STPA is applicable to a variety of systems and has been widely demonstrated on mechanical systems (Leveson, 2011; Leveson & Thomas, 2018), socio-technical systems (Barstow, 2023), and organizations (Dainoff et al., 2022). Leveson has suggested that organizations are composed of interacting control loops with feedback mechanisms. Viewing organizations in this manner allows engineers to model them as systems with control and feedback mechanisms that can either enhance or degrade progress and operations. Numerous examples of such control structures for a wide variety of systems are provided in Appendix B of the STPA Handbook (Leveson & Thomas, 2018, p. 148). Three specific structures from appendix B are:

- FDA drug approval process including Congress and various regulatory agencies
- Hierarchical aviation oversight structures
- Nuclear power plant safety management systems

These examples span entirely different domains from medical regulation, energy to transportation which underscores the STPA process's capability and adaptability to be a relevant framework that can be applied to complex defense acquisition programs. This contrasts with the typical view of organizations as a hierarchy of various groups working toward a shared goal.

The feedback and control model within the STPA framework has a structured analytical process. The diagram detailed in Figure 1 shows the flow of the process proposed by Leveson (Leveson & Thomas, 2018). If this process is performed adequately, then the result is the identification of unsafe control actions and a newly designed system that reduces the likelihood of the unsafe control actions.

The STPA process begins by identifying and understanding the problem to be solved while also defining what needs to be fixed. One then progresses through the steps in the diagram until a control structure has emerged that illustrates the current organization. Accurately assessing the current control structure is critical for understanding the organization at a deeper level that allows one to begin to address inadequate, unsafe or missing controls. Once the current control structure has been modeled, the results are then analyzed to 4 redesign a more robust organization with a new organizational control structure. Ultimately, the STPA process culminates in a new organizational model with improved or new feedback loops and improved or new constraints that better govern organizational behavior.

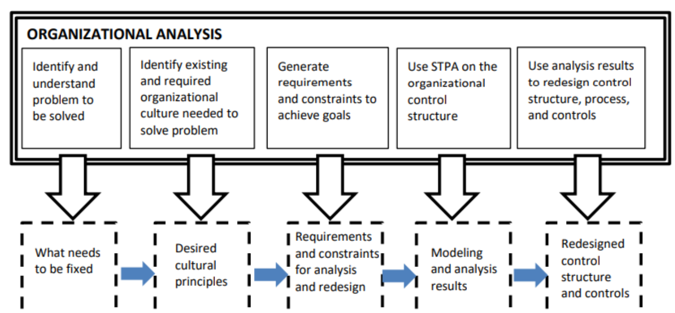

Figure 1. STPA process for organizational analysis (Leveson & Thomas, 2018, p. 86).

This intuitive and visual perspective is particularly valuable in large programs where emergent problems arise that are difficult to detect using traditional failure analysis. In addition to emergent organizational problems, STPA also yields insight when there are multiple leaders with feedback delays and conflicting goals that allows leaders to see causal issues for a wide variety of organizational problems. Thus, by viewing the organization as a system that generates accidents or has diminished performance with flawed control structure, leadership is given a powerful lens for identifying issues and improving governance.

To better illustrate how visual the results become for STPA are, an example diagram of the U.S. Pharmaceutical Approval Safety Control Structure is shown in Figure 2 (Leveson & Thomas, 2018, p. 152). Similar organizational control structures could be assembled throughout the DoD network that would allow leadership in various divisions and programs to gather and discuss the dynamics of their immediate organizations using a valuable approach with insight that traditional failure models have struggled to replicate.

STPA is a powerful framework for examining the variety of issues, like communication breakdowns, that hindered progress in the U.S. Army's FCS program. The next section of this work focuses on STPA applied to FCS from an organizational perspective. The hope is that the reader will be able to conclude that STPA offers a systematic process that evaluates safety, control structures and overall organizational integrity of large-scale programs.

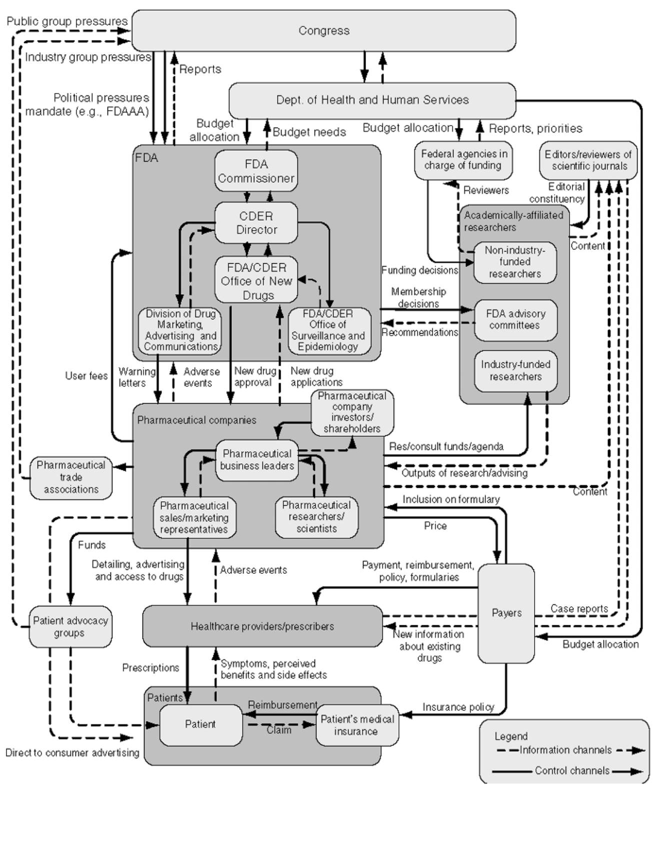

Figure 2. Control structure for U.S. pharmaceutical approval (Leveson & Thomas, 2018, p. 152).

Application of STPA to FCS

The FCS program is an example that systems engineers can learn a great deal from. It was a program with a level of organizational complexity that was challenging with regards to oversight and organizational adaptability. It was initiated in the early 2000s. FCS intended to transform the Army's battlefield capabilities via an integrated array of manned and unmanned systems. Unfortunately, after a few years of effort and billions in spending, the program was canceled. There have been previous studies that have focused on maturity of technology, challenges of requirements and scheduling issues. This specific work will apply STPA and examine the organizational control structure that contributed to program risk.

To follow the STPA framework an understanding of how a system should behave needs to be compared to how the system actually behaved. In the case of FCS, an idealized model of what the organization should have been like needs to be compared against what the organization was. To fabricate the idealized view of how FCS should have functioned, multiple sources have been considered. Two companies, with interesting foundational philosophies have been chosen for examination. The first is Koch Industries' Principle-Based Management (PBM) framework (Koch Industries, n.d.). The second is INFICON's governance framework (INFICON, n.d.). Both yield insight into what "good" organizational management philosophy looks like. The third source of consideration for forming the idealized behavior for FCS is the reforms that are currently taking place within the U.S. Navy (Escalante, 2021); (Chief of Naval Personnel, 2024); (Grady, 2025). Taking all three of these sources together it can be concluded that an idealized acquisition environment must emphasize the aspects listed in Table 1.

Requirement	Source
Warfighter-informed design	(Koch Industries, n.d.)
Agile environment for decision-making with decentralized decision-making and employee empowerment	(INFICON, n.d.)
Workforce integrity and fiscal responsibility	(Koch Industries, n.d.)
Leadership accurately informed about risk	(Grady, 2025)
Environment embraces learning and cross-functional collaboration	(Chief of Naval Personnel, 2024)
Transparent communications	(Escalante, 2021)

Table 1. Requirements for idealized FCS organizational control.

However, the FCS program's organizational environment was characterized by rigidness, siloed development and risk aversion. Feedback from soldiers was not high enough priority, learning based on iterative progress was too limited and accountability from authority was often ineffective. There was also an environment where program progress became a higher priority than transparent reporting. In addition, oversight mechanisms were often not effective enough (Pernin et al., 2012, p. 163). These organizational shortcomings ultimately contributed to FCS's cancellation. To support this organizational analysis, a set of eight high-level system constraints (SC), shown in Table 2, have been identified using the STPA framework that have been found primarily in (Pernin et al., 2012). Had FCS enabled these constraints, the program may have prevented many of the losses it encountered (Table 3).

Constraint ID	System Constraint
SC-1	Must establish and maintain vertical communication. (Pernin et al., 2012, pp. 133, 162–163).
SC-2	Must establish and maintain clear roles, responsibilities, and expectations across stakeholders including Lead Systems Integrator (LSI) and subcontractors (Pernin et al., 2012, pp. 133–134).
SC-3	Must ensure early engagement maintained by stakeholders (Pernin et al., 2012, p. 163).
SC-4	Cost estimates must align with a realistic scenario that can be executed. (Pernin et al., 2012, pp. 117–120, 163).
SC-5	Must use funding model and oversight that adapts to uncertainty and changing battlefield (Pernin et al., 2012, p. 163).
SC-6	Must have an effective control system to enforce program constraints. (Pernin et al., 2012, p. 163).
SC-7	Needs a structure that allows subject matter experts to make timely informed decisions, keeping in mind schedule, integration, and requirements. (Pernin et al., 2012, pp. 158–159, 163).
SC-8	Needs to embrace and enforce modular interfacing between LSI and subcontractors (Pernin et al., 2012, pp. 158–159).

Table 2. System constraints for Army FCS program.

Each of the above system constraints can also be associated with organizational losses. To illustrate how this is done, SC-1 will be examined. This constraint was often violated in the lifecycle of FCS. This resulted in delays of communication between the Office of the Secretary of Defense (OSD) and Program Manager and Leaders in the Army (Pernin et al., 2012, pp. 133, 162–163). Using the framework of STPA the breakdown of vertical communication contributed to several organizational losses, detailed in Table 3.

All of these losses can be associated with missing or unsafe control actions within vertical communication of the FCS program. An example is that overly ambitious requirements were not vetted by leadership. In addition, the roles were unclear and hindered escalating issues that were encountered as well as degrading the ability to execute ((Pernin et al., 2012, p. 134). Since this vertical feedback loop was weak or sometimes non-existent, oversight became more reactive, and trust began to erode yet program momentum needed to keep pace even though there were unresolved issues. This STPA analysis has allowed the authors to link losses together to a contributing failure mode due to a poor organizational enforcement of SC-1. This ex ample shows some of the value that can be gained by examining acquisition programs using STPA.

Using the constraints for a foundation, an STPA-informed control structure was constructed (see Figure 3). This diagram models the FCS program from a high-level. The diagram illustrates Congress and the Office of the Secretary of Defense (OSD) down through the organization to subcontractors and end-users. In addition, reporting and control flows can also be seen along with feedback channels that were either weak, delayed or missing. For example, RAND documents that communication that was vertical within FCS was oftentimes delayed until problems became critical (Pernin et al., 2012, pp. 236–238). This example directly relates to SC-1. An early STPA analysis could have anticipated this hazard and recommended mandatory, routine reporting pathways for critical issues. Another example shown in Figure 3 is the feedback arrow from Army Test and Evaluation Command (ATEC) box to the Program Manager box. RAND (Pernin et al., 2012, p. 243) found these feedback channels were often filtered and delayed when reaching the program manager even though they had been formally put in place. This diminished their value for timely action to correct issues. Within the STPA methodology, this represents a weak control feedback loop that could have been strengthened via reporting timelines and explicit constraints. Each arrow in the diagram is associated with decision rights, oversight or accountability. Lastly, the diagram has been analyzed using the eight system constraints that were previously detailed in Table 2.

Loss ID	System Loss	Associated System Constraints
L-1	Loss of, or failure to generate, feasible program requirements.	SC-1, SC-2
L-2	Loss of trust from high-ranking stakeholders.	SC-4, SC-6
L-3	Loss of program viability resulting in cancellation.	SC-3, SC-5
L-4	Loss of technical expertise from program.	SC-7
L-5	Loss of trust within program stakeholders, contractors, and/or employees.	SC-1, SC-3, SC-8

Table 3. System losses for Army FCS program.

Then, STPA was used for evaluation of unsafe control actions, poorly formed constraints or degraded feedback loops that enabled risk to cascade through the program. For one example, the failure to enforce SC-3 contributed to a poor alignment with regards to battlefield needs. A second example is that there were lapses in SC-8 that resulted in integration delays between subcontractors. A third example is that SC-1 and SC-2 cascaded and resulted in gaps in program oversight compounded by delays in issue resolution. Eventually trust within Congress (L-2) resulted in program cancellation (L-3).

STPA provides a methodical way an organization can be understood and how multiple control failures in the organization can lead to undesirable outcomes. This brief example, where unclear roles and poor or missing feedback loops, reinforces the value of STPA application to systems of all types, even at the level of DoD acquisition.

Discussion: Modern Day Organizational Failures in the Army

The FCS program yielded insight into the consequences of organizational issues in acquisition programs. Yet, nearly two decades later, there are still similar struggles that are ongoing in other Army programs. For example, delayed feedback, unclear authority, poor enforcement of constraints and conflicting objectives. This means that these types of failures are not only historical in occurrence. Instead, they are recurring aspects of Army programs that could lack adequate management frameworks for early detection and mitigation. However, STPA offers an approach that could reveal these organizational control flaws proactively during the program lifecycle.

One recent program that seemingly had these types of challenges is IVAS. Its aim is to improve battlefield awareness using an all-in-one display that was to be worn by soldiers. It encountered serious issues during testing and initial use. System usability problems were amplified by insufficient soldier feedback. As one reviews the current status of this program while using the lens of STPA, interesting details begin to emerge. For example, it is reasonable to assume that STPA, if used adequately by the program, could have identified organizational issues such as when the Army got ahead of itself and issued Microsoft a production contract weeks before discovering that the technology was not ready for soldiers (Roque, 2023). Another indication of organizational challenges was a mid-course shift in the acquisition strategy. This mid-course correction without closing out known issues, such as low-light performance, suggests organizational instability stem ming from inaccurate or delayed information reaching higher levels of the program (Guertin, 2023).

Had the Army proactively modeled the control relationships among Army leaders, end-users and developers, program leadership could have visualized absence in the program's control structure and corrected missing or inadequate feedback loops. This proactive analysis could have prevented missteps in the acquisition process before cascading and causing more substantial problems later.

Another interesting case to examine while utilizing the STPA framework is the XM30. This vehicle under went a name change from Optionally Manned Fighting Vehicle. There is no admission known by the author's that the name change was due to an effort to revitalize a struggling program. There was a pattern of organizational challenges that is suggestive of a rebranding effort by the Army possibly due to the original name, OMFV, being associated with failures (Freedberg Jr., 2020) (U.S. Army Public Affairs, 2020).

The XM30 is currently intended to replace the Bradley Fighting Vehicle (Judson, 2020). However, progress has been plagued by procurement resets and shifting requirements (Eggler, 2024). Reports have pointed to unrealistic timelines with unclear needs. Some of the challenges seem to stem from overly rigid requirements being put in place prior to feedback from soldiers and the operating environment. (Freedberg Jr., 2020) The failure to initialize and maintain stakeholder alignment and prematurely locking in the design, the program created a scenario that easily fell into poor alignment and program resets. This program has had many challenges. However, it also is a candidate program where the framework of STPA may have revealed inadequate control structure within the XM30 program if it had been proactively utilized early.

These two modern examples show that even in ongoing Army programs, organizational challenges persist. It seems that both IVAS and the XM30, at times control actions were issued in the absence of adequate feedback. System constraints were also seemingly vague or poorly enforced. In addition goals had a way of becoming misaligned over time. Thes organizational hazards are known to be highlighted by the STPA framework. If Army leaders begin to proactively analyze acquisition programs using organizational STPA, risk of costly, cascading, organizational issues could be greatly reduced.

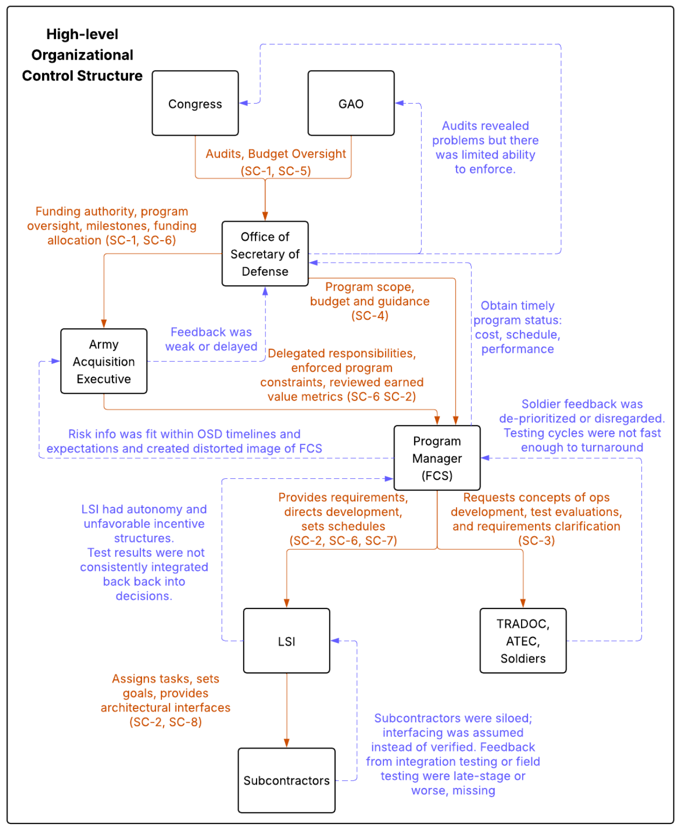

Figure 3. High-level organizational control structure for FCS.

The recurring presence of similar organizational challenges in modern programs bolsters the conclusion of this work. That is, STPA could provide a proactive and low-cost technique. One that is capable of high lighting and mitigating organizational issues in acquisition programs. STPA could offer

Army leadership a new capability that greatly improves the outcomes of acquisition programs.

Conclusion

Any institution should always be improving the return on their resources invested. The U.S. Army is no different. Therefore, the Army should seriously consider utilization of STPA in order to mitigate the risk of current and future organizational acquisition failures.

This work applied STPA to the FCS program. This application was not a historical academic exercise but a case study to demonstrate how STPA could reveal easily unnoticed organizational risks. The types of risks that can be challenging for traditional acquisition management frameworks.

FCS had common, yet significant challenges such as poor feedback loops, lack of feedback from soldiers and not considering changes needed due to evolving battlefield needs. These challenges are not unique to FCS. What has been demonstrated here is applicable to a wide variety of organizations that manage high risk, complex systems. This includes other branches of the military, civilian infrastructure programs and federal agencies. Just as Leveson (2011) has detailed, the same control structure concepts and hazard identification techniques scale across domains. For example, energy, aerospace and transportation. Systems where multiple decision levels and feedback loops must interact effectively. Applying STPA retrospectively, like this study has done for FCS, illustrates a framework that is transferable and has the ability to proactively identify weak control and feedback loops within organizations. This allows a broad range of organizations to put constraints in place before costly failures occur. These types of program weaknesses are still present in modern acquisition programs. Within the Army, one such example is the Integrated Augmentation System (IVAS). This Army program has exhibited the familiar feedback and control challenges. This reinforces the mindset that Army leadership needs better visibility into organizational structure to improve program outcomes.

STPA offers a straightforward, systems engineering centric framework to understand acquisition endeavors using visual organizational control structures with a wealth of loss information and organizational constraints. The diagrams and tables that result are intuitive enough for Army leaders to use in real-world decision-making. This could add a great deal of value to staff meetings, milestone reviews and various briefings.

Applying STPA in a proactive fashion, the Army can identify and resolve root causes misaligned teams and various other organizational failures before they materialize and require more resources to correct. The cost of trialing STPA within a current or upcoming Army program is low compared to the losses it could prevent if effectively executed. Wasted funds, schedule delays, degraded stakeholder trust and diminished warfighter readiness are all issues the U.S. Army likely wants to avoid. STPA is a useful tool that the Army could start using now as an enhancement, rather than replacement, of existing management frameworks.

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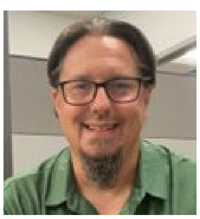
Biography



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