Roots of Failure: Technical and Management Process Shortfalls in DoD Software Intensive Systems

A Tri-Service Assessment Initiative™ Systemic Analysis White Paper

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This Tri-Service Assessment Initiative (TAI)™ Systemic Analysis (SA) White Paper is the first in a series of technical reports that describe the TAI findings and analysis of recurring technical and acquisition issues that are negatively impacting the performance of U.S. Department of Defense (DoD) software intensive systems (SIS).

This paper specifically examines the program process shortfalls that materially impact program cost, schedule, quality and the operational capability of DoD software intensive systems. A recent analysis across a number of DoD programs identifies process performance shortfalls as a primary factor in the inability of a SIS program to meet its acquisition objectives and technical requirements. The analysis shows that nine out of ten DoD programs are likely to have technical and/or management process performance issues that are materially impacting their ability to deliver an effective system within established acquisition parameters. When viewed in the perspective of changing technology, revised acquisition strategies, and a more complex development environment, the inability of future program teams to specify, design, integrate and/or implement the management and technical processes that adequately address the specific needs of their programs is likely to increase unless corrective actions are taken.

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Introduction

U.S. Department of Defense (DoD) software intensive system (SIS) development programs pose highly complex technical and management challenges. The associated technical and management processes used to create today's Weapons and C^3I systems are critical factors for developing and delivering quality DoD programs that effectively address defined mission needs. DoD has recognized the importance of this relationship and has instituted policies over the last decade to improve process capability and quality across SIS programs.

Despite an increased process focus within DoD programs, there is a growing gap between program performance requirements and the capability of program teams to realize them.[1] In a recent analysis by the Tri-Service Assessment Initiative™ (TAI) systemic analysis team, process performance shortfalls were identified as a primary factor in the inability of a program to meet its acquisition objectives and technical requirements.[2] The analysis shows that nine out of every ten DoD programs that TAI has assessed have technical and/or management ***process performance shortfalls*** that are negatively impacting a program's ability to deliver an effective system within established acquisition parameters (see the sidebar "Process Adherence vs. Process Capability"). In other words, program teams are unable to specify, design, integrate and/or perform the development processes that adequately support the specific needs of their unique programs. Given the predicted increase in technical and managerial complexity of future DoD programs, the TAI analysis projects that this process related performance gap will widen.

TAI Assessment Findings

DoD SIS programs are marked by their complexity and dynamics. For example, an aircraft development program like the F-22 requires over two million lines of operational software for controlling everything from flight control systems to automatically testing its avionics systems. Several million more lines of support code are required to develop and maintain the operational software once it is deployed. Without software, the aircraft would not only be unsuccessful in carrying out its mission but it literally could not fly. Similarly, the technology embedded in current DoD software intensive systems changes rapidly and numerous times over the program life cycle.

[1] A program team consists of both the government and contractor organizations responsible for acquiring, developing or sustaining an SIS program.

[2] Tri-Service Assessment Initiative and TAI are trademarks of the Department of Defense

Process Adherence vs. Process Capability

The TAI analysis shows that there are two primary types of process performance shortfalls, those related to ***process adherence***, and those related to ***process capability***. ***Process adherence*** is focused on the ability of an organization to adequately define and implement the technical and managerial processes required for its programs. Typically, process adherence adequacy or performance is evaluated against defined process models or standards that a parent organization or enterprise has established as being necessary to ensure program success.[3] Common process models include the SEI's Capability Maturity Model® (CMM), the Capability Maturity Model Integration® (CMMI), and ISO/IEC Standard 15504 for software process assessment.[4]

Process capability is related to the effectiveness of the defined and implemented processes in meeting a specific program's technical and management requirements. In general, process capability refers to how well an organization's process models or standards have been adapted and applied to address the specific characteristics and needs of a particular program.

In a best case scenario, a program's process requirements and the organizational process model or proposed process standard match closely, thereby ensuring an appropriate level of process capability.[5] If this is not the case – i.e., the organizational standard set of processes or the process model does not effectively meet program specific process requirements – the organizational standard or process model must be adapted or modified to meet the process capabilities demanded by the unique technical and management characteristics of the program in question. (See the second sidebar, "Limitations of Adherence Models" for a further discussion of tailoring a process model.)

Process adherence and process capability are very closely related. A program can be process adherent without being process capable. In contrast, a program cannot be process capable without being at least process adherent. TAI data and analysis shows that both process adherence and process capability are frequently inadequate to deliver a quality program within the overall performance objectives. Furthermore, TAI systemic analysis also indicates that there are multiple causes for these process adherence and process capability shortfalls, which makes their elimination without a concerted effort difficult.

[3] These models or standards are designed to meet general program process requirements, but not necessarily the specific process needs of an individual program.
[4] Capability Maturity Model, CMM, Capability Maturity Model Integration, and CMMI are registered trademarks of Carnegie-Mellon University.
[5] For simplicity purposes, we are assuming a single supplier situation. In multiple supplier situations, the data indicates that it is unlikely that all suppliers' organizational process models will satisfy the program's process requirements.

To successfully develop a DoD SIS program requires a highly coordinated program team made up of dozens of individual government and contractor organizations that are typically dispersed geographically. The "glue" that holds this complex organization together is the technical and managerial processes that bring together the technology, resources, knowledge, and skills to execute the program plan. If the appropriate set of processes is not performed, or worse, if the individual processes are inadequate for supporting the specific development or evolutionary needs of the program, program success is severely compromised.

Over the last four years, TAI, along with its assessment partners, have assessed over 50 major DoD programs that span the range of ACAT levels, platforms, domains, and services.[6] Among the recurring issues that have been identified, TAI systemic analysis indicates that the software, systems engineering, and management processes involved in developing and deploying these software intensive systems are primary contributors to poor program performance.

The pervasive nature of the identified process shortfalls dictated a more detailed analysis to investigate the underlying causes. A detailed review of the assessment data led to the categorization of the causes of both process adherence and process capability shortfalls. The types and relationships of these causative process issues are shown below in Table 1.

Looking at the left side of Table 1, TAI assessments have not identified any individual programs that are missing the most rudimentary technical or managerial processes. Fifteen years of process improvement efforts have appeared to overcome this one-time pervasive problem. All the programs that TAI teams assessed were well aware of the value of well-defined processes, and of the need to map these processes to the defined business needs within their organizations. Further, most of the organizations assessed were actively involved in a structured process improvement program of some kind.

More prevalent were the programs exhibiting ***process adherence*** shortfalls. TAI systemic analysis data show that over 50% of the programs that have been assessed have issues involving process adherence.[7] This means that the assessments identified issues directly related to a program team's ability to implement the technical and managerial process model or standards that the organization has established as necessary to ensure program success. As noted, a program team that is not adhering to its own specified organizational processes is not well-positioned to achieve its program's expectations. TAI assessments show that process adherence shortfalls are most commonly found in the areas of requirements definition and management, risk management, testing, systems engineering management, and technical change management.

[6] TAI's Phase 2 systemic analysis, completed in January 2003, is based on a review of 23 of these assessments.

[7] This category includes programs with software and other processes that did not meet program team policies or proposed standards, for instance, programs that required CMM Level 3 but the program team was only CMM Level 2.

No Defined Processes in Place	Defined Team Program Processes Established						No Accepted Processes Defined	
Rudimentary Processes are Missing	Not Following Accepted Processes		Following Accepted Processes				Emerging Processes	Missing Innovative Processes
	Process Adherence Shortfall Issues		Process Capability Shortfall Issues			Program Team Processes Are Capable		
	Poorly executed Processes	Constrained Processes	Outmoded Processes	Pro Forma Processes	Non-integrated Team Processes	Effective Processes		

Table 1. Types of Technical and Managerial Process Issues Encountered

As illustrated in Table 1, there are two general types of process adherence shortfalls shown in the TAI data. First are the technical or managerial processes that are **poorly executed**, meaning that they are ineffectively implemented or performed for a particular program. For example, TAI has found that poor program team communication plagues many programs, with poor implementations of integrated program teams (IPTs) being a primary causative issue. In one program, over 60 IPTs were created with many program team members assigned to six or more individual teams. Furthermore, these IPTs had the responsibility, but not the authority, for making technical decisions (in most cases only recommendations). As one person on the program succinctly put it, "It takes a long time to make a bad decision" in this environment. TAI has found that many "best practices" such as IPTs, risk management, or measurement are not being implemented properly, and often cause more problems than they solve as a result.

The second type of process adherence shortfall can be described as **constrained processes**. These are technical or managerial processes that are not fully implemented or executed because the program team no longer supports or funds them. For instance, the full range of software or systems testing that is planned for at the beginning of a program is often not carried out due to later emerging program budgetary or schedule shortfalls. Testing is in effect traded-off against higher-priority program cost or schedule objectives. As a result, errors that should have been discovered during development testing slip into the operational system, causing major problems in the field. As one individual on such a program commented, "My worry is not so much whether we deliver on time, but that should the system fail during its

operational test, will we be able to tell why?"

Programs that exhibit foundational process adherence shortfalls are unable to implement capable, performance satisfying, technical and management processes. However, while acceptable process adherence is necessary, it is also an *inadequate requirement* for ensuring the performance for a given program.

Even when program teams are satisfactorily performing the specified organizational team technical and managerial processes, TAI systemic analysis shows that the processes themselves are often inadequate for the tasks at hand. In other words, there exists a ***process capability*** shortfall indicating that the processes used are ineffective for the situation encountered.[8] As before, several different types of process capability shortfalls have been identified as shown in Table 1.

Disturbingly, in 80% of the programs assessed by TAI where *no* process adherence issues of merit were found, process capability issues were still discovered. While the program teams are generally aware of the need for improving their adherence to a set of defined processes, TAI has found that program team members do not routinely consider their technical and managerial process capabilities either individually or from an overall program team perspective, resulting in *program team* process capability performance shortfalls. In short, the full spectrum of a program team's organizational processes are not rigorously evaluated and then tailored to meet the specific characteristics or requirements of the program in question.

The first type of process capability shortfall is the **outmoded process** problem. This is where a process model, standard or practice may no longer be supported, or a specific process practice is inappropriate for the situation, e.g., it doesn't scale for implementation on a large program. While the TAI data shows several instances of these issues, one extreme situation was related to requirements management. In this particular assessment, the program team was attempting to manually manage over 20,000 software requirements. While process was still "technically" adequate, it was proving to be extremely labor intensive. This manual approach was further complicated by the existence of multiple trouble report tracking databases as well as by a change control approach "stretched" to handle multiple baselines and releases. This made the requirements process extremely error prone, particularly during test when trying to demonstrate requirements traceability. As it turned out, the manual requirements process was instituted during the systems development phase which occurred over twenty years ago, but it had not been changed or updated as the system moved into post deployment support. Consequently, the program had "outgrown" the original process. The cost of changing to a new requirements process was seen as too expensive and time consuming, so the "outmoded" (and ineffective) process remained in place.

[8] We assume that a process adherence shortfall also translates into a process capability shortfall.

A second type of process capability shortfall is the **pro forma process** approach common to many programs. This occurs when a process is adequately defined but performed in a "check in the box" manner. In other words, the process exists on paper, but no one pays much attention to it. A common characteristic of pro forma processes is that their outputs are not utilized to make decisions or to improve how the program is being run. Program risk management often falls into this category. It is "performed" on most programs, but it often does not greatly influence decision making in the program. We found the state of risk management practice in many SIS programs mirrored the remarks of Adm. Hal Gehman, head of the shuttle Columbia Accident Investigation Board when he testified before Congress on the NASA's shuttle risk management approach, "The safety organization is, on paper, perfect, but when you bore down a little deeper, you don't find any 'there' there."

A third type of process capability shortfall identified by TAI systemic analysis is the **non-integrated team process**. This occurs when a program team uses several different and often incompatible processes to achieve the same end. This lack of coordination of processes plagues multiple supplier programs where work items are shared. For instance, in one program, because there was a lack of coordinated configuration management (CM) processes across the program team, the software product ended up being handled and managed differently at different times in the development process. This caused numerous inconsistencies to appear in the system software being produced, which in turn created errors in the system that were difficult to discover and remove. TAI systemic data show that individual team member CM processes are not often coordinated or compared against or what is needed to achieve overall program team success.

Lastly, there is the **emerging process** problem. This occurs when a new or largely revised process is required, but the program team has failed to define it in enough detail so that the process materially addresses the identified risk, problem, or concern. More importantly, an emerging process does not require adherence to an organizational process standard, since the process standard in question may not have been upgraded to include it.

For example, many programs assessed by TAI appreciate that they have to manage changes in technology over the course of their SIS program development and beyond. However, TAI assessments have found that many, if not most programs, are managing technological insertion in an *ad hoc* fashion, rather than through any discretely managed process. As a result, technology updates are introduced haphazardly into the development cycle. Since the process for managing technology insertion is defined at the higher CMM and CMMI maturity levels, it is routinely overlooked.

When taken together, process adherence or process capability issues have been found to exist on nine out of every ten programs assessed by TAI. We expect our results are typical across most DoD SIS programs. Furthermore, while some process deficiencies have more impact on performance than others, it is common for

a single program to have multiple technical and managerial process shortfalls occurring simultaneously. On average, a program will have process adherence shortfalls in two process areas, while process capability shortfalls are seen in five process areas. Additionally, technical process deficiencies tend to occur at about twice the rate of management process deficiencies. It is not an exaggeration to state that process performance shortfall issues are seriously impeding successful program execution.

Finding Implications

One can draw several implications from the TAI systemic findings. A criticism sometimes leveled at the military is that it tends to fight the last war. While the military campaigns in Afghanistan and Iraqi have seemed to avoid a repeat of this syndrome, DoD SIS programs do not appear to have learned to avoid a similar problem when it comes to process performance. The TAI systemic data indicates that new SIS program teams often proceed with processes that were applicable to the previous SIS program they were involved in – not the one they are currently working on. Many new SIS programs pose innovative process challenges that are unrecognized as needed until well into the program (in effect, they are emerging processes as shown in Table 1), by which time it is too late. The current data suggest that 10 – 20% of previously applicable technical or management processes typically are not appropriate or effective for new SIS program starts. This unrecognized process need is especially true in SIS programs where interoperability, systems of systems, family of systems, or network centric warfare requirements are very high. As an example, TAI has found that *interoperability systems management* is an emerging program team process that is desperately needed but missing on many SIS programs.

Second, most adherence-oriented process models or standards are organization-based. That is, the technical and management models that form the basis for organizational process definition and improvement and are assessed against are based on a generalized organizational standard of what "most" projects require, not on what any specific project requires. While these process models are *intended* to be adapted or modified to meet specific program needs, TAI data suggest in practice that they often are not (see the sidebar, "Limitations of Adherence Models"). It appears that many organizations simply apply their standardized approved corporate process to meet *all* of the diverse programs in their portfolio. Given the high degree of technical and acquisition change that a DoD program or project is subject to, the inability or unwillingness to adapt defined organizational processes to meet a program's specific characteristics, constraints, and requirements, results in significant performance shortfalls.

Limitations of Adherence Models

As is well known, the SEI's CMM has been the favored model against which organizational adherence to software engineering processes are measured against. Attaining CMM Level 3 has been the target maturity level DoD programs expect their supplier software development organizations to reach. We have found in our assessments that there is a strong expectation by SIS program team managers that by achieving CMM Level 3, many if not most of the problems associated with software development on a SIS program will be controlled.

While the use of the CMM Level 3 as a goal to reach has greatly improved software development in DoD SIS programs, it does not guarantee in and of itself that software development on a SIS program will be problem or risk-free. Many SIS program managers do not understand the limitations of the CMM, and therefore, assume results that the CMM never promises nor can deliver.

As members of the SEI's CMM process team like to point out, some models are useful, but all models are wrong. CMM is a model, and in many SIS development situations, it is "wrong." As a model, it is necessarily limited in its scope. It is important to remember that the CMM model is aimed at improving an organization's software development process, not the development process of any specific program. The CMM assumes that for an individual program, the organization's standard software process (OSSP) will be tailored to meet the individual program's requirements.

Unfortunately, our assessments have found that tailoring of the OSSP (by which we include the methods/procedures/techniques that implement that process) is often not the case in practice. What usually appears to happen is that the OSSP is used "as is" in an SIS program and little tailoring is performed. This is acceptable if the OSSP and the program specific software process (PSSP) needs are in close alignment. However, this alignment is unlikely to happen in the general case.

For an organization's CMM Level 3 process to meet specific program process requirements, for example, a careful evaluation of the program's context of application and a tailoring of the implementation or application of the process to that context is required. While the organization's generic process – e.g., requirements management – may be adequate to meet the program's process goals for this practice area, the actual procedures for implementing the requirements management process may not be efficient or effective for the program's situation.

More importantly, the evaluation must identify program process areas that are not only beyond the current capability of the OSSP but are out of the CMM or CMMI scopes. "Best practices" sometimes are used to fill in for these out-of-scope processes, but the quality of their implementation vary greatly.

Currently, there is no formal evaluation method that routinely assesses the management and technical processes required by the SIS program team as a whole. TAI data shows that this issue also needs to be addressed if SIS programs are to increase their chances of success.

Furthermore, proposal evaluations of adherence to program process standards are generally made against organizational-based process adherence requirements, not project-specific capability needs. As a result, the evaluation of process adherence can discourage a complete evaluation and tailoring of process standards to meet specific program needs. In other words, bidders on SIS programs end up proposing the use of their "standard" processes rather than processes that are tailored to program they are bidding on. Unfortunately, "one size does not fit all," and a "best practice" for one program may not work at all for another.

Third, there appears to exist a fundamental disconnect between what process adherence and process capability themselves mean. Process adherence is mistakenly seen by too many program teams to automatically equate to process capability. There is little recognition by these program teams that adherence to a process model equates to capability only when the process model and the program technical and managerial objectives and constraints match extremely well. Since this is rarely the case in practice, there will almost always be a shortfall in process performance if the process model is not adapted to the situation.

In addition, there is little thought of how the individual processes of the multiple members of a program team may clash or conflict with one another. The program team must recognize early that all of its individual technical and management processes must be tailored first to the specific circumstances, and then adherence to that tailored process must be enforced. Too many programs reverse the sequence. A program team must measure a project's likelihood of success on ***both*** process capability as well as project adherence.

Conclusions

For an SIS program to be successful, many things need to be performed well. A program can fail if any single critical process is performed poorly. As DoD SIS programs become more complex as the future military environment becomes more inter-operative, the managerial and technical processes required for successful program execution need to keep pace.

From the TAI systemic analysis, several conclusions can be drawn:

- Process improvement efforts have overcome the past major problem of program teams missing rudimentary technical or managerial processes. No longer is process adherence the long pole in the tent affecting a program teams' capability to execute to plan. It is now time to focus on process capability rather than process adherence.

- SIS program teams must be educated in the difference between process adherence – following some process – and process capability – the true effectiveness of that process. Knowing the difference can be the difference between program success and failure.

- SIS program teams need to evaluate the full spectrum of technical and managerial process requirements, and then tailor their organizationally-based adherence models to meet specific program needs. Careful

attention must be given on how to deal with process areas that are outside either the level of adherence or the adherence model itself.

- SIS programs should be encouraged to assess their process capability. The TAI data suggests that process capability be evaluated at request for proposal and at major milestone reviews at the very least. One approach is to make use of Independent Expert Program Reviews (IEPRs) and other performance based assessment methodologies to assess a program's process capability.

- Individual program team members need to ensure collectively that their technical and managerial processes meet the needs of the program and not necessarily just the needs of individual program team members. Too often program team members simply adhere to their process model, standard or individual best practice without understanding how their process may clash with another team member's processes, or whether or not it is adequate for the specific program in question.

- DoD must work to establish innovative process practice to deal with the future complexity of SIS acquisition, development and deployment. Innovative processes to deal with the implications of creating force interoperability, networked assets, and the like, must be undertaken immediately.

Future software intensive system complexities will put more pressure on not only software but systems engineering and managerial processes. They will need to be more capable, coordinated and team integrated. The gap between program expectations and the ability of program teams to produce such systems will continue to grow unless some actions are taken to solve the process performance shortfall problem in a systemic fashion.

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Tri-Service Assessment Initiative

Systematic Assessments of Projects/Programs

Established in 1999, the SIS TAI is an OUSD(AT&L) sponsored and Tri-Service endorsed initiative that provides:

- A robust and flexible assessment methodology to identify program strengths and areas for improvement
- A means to leverage expertise and collaboration across DoD, Government agencies, FFRDCs and industry to improve program performance
- A source of lessons learned to share with Program Managers, DoD, and Industry to improve software intensive systems acquisition

TAI Independent Expert Program Review (IEPR) assessments span programs across all ACAT levels, covering a wide variety of domain areas and lifecycle phases.

Systemic Analysis (SA) of Assessments

TAI analyzes and identifies the technical, organizational and management issues, risks and problems that recur across the base of over 50 assessed programs ranging from $200 million to $5 billion in software development value. Through its analysis of these "systemic issues" TAI strives to understand the underlying causes of DoD software acquisition problems so that they may be either avoided or their effects minimized in current or future DoD software intensive acquisition programs.

The SA work to date indicates that there exist a significant number of repetitive "cause and effects" issue patterns. Through its automated database, TAI has the capability to:

- Identify the issue trends and patterns
- Quantify the identified systemic patterns
- Relate their occurrences to different program characteristics and acquisition considerations, such as program type, service, lifecycle phase, etc.