Human Systems Integration Tradeoff Analyses: Lessons Learned in Support of Naval Surface Acquisitions

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Human Systems Integration (HSI) utilizes a variety of analysis methods to evaluate systems with respect to seven key domains: manpower, personnel, training, human factors engineering, personnel survivability, habitability and safety & occupational health. A critical part of the "I" in HSI is the tradeoff analysis where system features and attributes are "traded-off" to satisfy constraints on system life cycle cost, performance, and development/delivery schedule. Members of this panel will discuss general HSI tradeoff lessons learned based on their experiences in support of Naval surface acquisition programs, focusing on the mechanics of initiating and completing HSI tradeoff analyses. These experiences include interactions with people and hardware/software (e.g., data collection, formatting, processing, etc.), timelines/deadlines to complete analyses and make decisions, and any required support activities (e.g., meetings, briefings, etc.). Each panelist will share experiences from the perspective of one of three key acquisition positions for HSI: Technical Professional, Program Manager, or Support Contractor.

INTRODUCTION

The Department of Defense Acquisition System is a multilayered process that attempts to simultaneously coordinate activities between program management, systems engineering, contracting, and logistics. As outlined in the Department of Defense Instruction 5000.02 (2008), a Human Systems Integration (HSI) plan must be included in the acquisition strategy and systems engineering plan for any system to address the following seven HSI domains: manpower, personnel, training, human factors engineering, habitability, survivability (of personnel), and safety & occupational health.

The ultimate goal of HSI analyses is to ensure that as many requirements relative to the seven domains for a system (or system of systems) are satisfied within the constraints of life cycle cost, performance, and development/delivery schedule. However, depending on the requirements and constraints, the analysis needs within a particular HSI domain *or between* domains can be complex and challenging.

Chapanis (1996) describes a general example of tradeoffs in systems engineering as follows: "…suppose Function A can be performed faster on Computer System X, but Function B can be performed faster on Computer System Y…How do you strike a balance between the savings in time versus the cost of errors? Does increased operator comfort increase productivity and, if it does, how can that be translated into dollar savings? Since more highly selected personnel require less training, is it better to spend more money on selection or on training?" (p. 283).

Consider asking such questions relative to multiple systems on a new construction or modification of a U.S. Navy ship. As a true system of systems, a typical ship has machinery spaces, combat systems spaces, a flight deck, and living quarters. Because of this complexity, a variety of HSI tradeoff needs may arise, and are typically context specific.

But how does one conduct a cross domain tradeoff analysis? What are the elements of the analysis process? During this panel discussion, participants will provide lessons learned that address the following key questions:

- How does the acquisition phase or maturity of design affect the nature and impact of conducting tradeoff analyses?
- What factors precipitate a need for a tradeoff analysis?
- What factors influence the technical scope of a tradeoff analysis? How can this scope vary for different types of domain tradeoffs?
- What kinds of people interactions are needed to conduct a tradeoff analysis?
- What analyses require close collaboration with other engineering elements, and how best do you obtain that collaboration?
- What techniques or tools are useful when conducting a tradeoff analysis?
- What are typical implications of tradeoff analyses on engineering decisions/activities? What about implications on program management decisions/activities?
- What kinds of engineering and program management risks relate to tradeoffs?
- Which tradeoffs are most challenging?

NITA LEWIS SHATTUCK

In the area of Defense acquisition, tradeoffs are constantly being made, either implicitly or explicitly. A senior decision

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maker, recognizing the high cost of manpower, sets the manning requirement for a new ship platform at a nominal number. Whether or not it is acknowledged, he has made a tradeoff. In the decision maker's mind, the trade is between cost and manpower – but the tradeoff has far-reaching ramifications that will almost certainly affect other HSI domains of personnel, training, human factors engineering, habitability, survivability (of personnel), and safety & occupational health.

Consider the case in which the manning requirement is set at an arbitrarily low number for a ship class. This decision affects the performance of the entire system in both direct and indirect ways. The work on the ship, including standing watch and maintenance, is fixed – although it varies with ship activities and evolutions. With fewer sailors onboard, there are fewer bodies available to do this fixed amount of work. Consequently, the sailors must work longer hours to accomplish the work, resulting in cumulative fatigue and an ever-increasing sleep debt.

While this may seem to be a small problem, the downstream effect of the manning decision may be that sailors choose not to work on this platform, making retention and promotion a challenge. In order to keep sailors on the ship, pay bonuses must be offered—offsetting the original cost-saving effort. The sailors on the under-manned ship may be so tired and sleep-deprived that they make mistakes or fail to perform the required maintenance, resulting in costly mishaps and safety issues. In emergency conditions, such as that experienced by the USS *Cole*, there may not be enough able-bodied sailors to perform critical tasks such as firefighting, resulting in a threat to system and personnel survivability.

Because manning levels for the ship have been minimized, the ship has fewer qualified watchstanders – making it ever harder for junior sailors and officers to get the training and experience required for qualification and promotion. The need to perform multiple jobs (i.e., the 'hybrid sailor') creates more pressure on training and performance; over-tasking of the individual sailor is common. The resulting decline in morale will certainly impact the level of motivation and individual sailor performance and will ripple through overall system performance. Ships will fail inspections and readiness levels will be compromised, all resulting from a simple tradeoff decision to cut back on the number of sailors.

HSI offers the opportunity for an early exploration of decisions such as those described in the previous example. Making the implications of tradeoff decisions available for decision makers to consider will result in better-informed and more innovative material and non-material solutions for acquisition challenges.

Biography

Dr. Nita Lewis Shattuck is an Associate Professor at the Naval Postgraduate School in Monterey, California and the founder of the Human Systems Integration graduate degree program. She holds faculty appointments in the Operations Research and Systems Engineering Departments and the MOVES Institute where she teaches human factors engineering and human systems integration courses, directs thesis research, and pursues her research interests in human fatigue in operational settings, individual and team performance. She has her Ph.D. in Behavioral Science from the University of Texas School of Public Health.

JOHN WINTERS

The top-level objectives of HSI are optimizing total system performance and minimizing total ownership cost. The terms minimize and optimize do not translate well into requirements documents, so the working-level HSI or domain practitioner must establish lower-level objectives to address. Success in making a domain tradeoff requires scoping the tradeoff to these and other constraints.

First, the tradeoff needs to fit the program's organizational, contractual, and political framework. The HSI focus on total ownership cost and total system performance is common to systems engineering, which illustrates the need for tight integration of HSI with systems engineering aspects of the program. The components of the tradeoff – in particular the costs incurred and savings realized – need to be within the authority of the part of the organization making the tradeoff. The tradeoffs that are most likely to succeed are those whose costs and benefits are fully within the established systems engineering scope or the authority of the Program Manager, and all relevant domains must be in concurrence.

The hierarchy of the Department of the Navy illustrates the difficulty in making tradeoffs between acquisition cost and manpower, as the responsibilities for acquisition and manpower in the Navy reside with separate Assistant Secretaries of the Navy. Contractual limitations to be considered include (1) the Statement of Work or Work Breakdown Structure of the project, and (2) the contractual deliverables. Any significant work or product that needs to be traded off – as an addition or a subtraction – needs to be aligned with these constraints.

Second, the tradeoff must be scoped to the right timeframe. Typically, any cost incurred for a tradeoff must be recoverable within the near-term funding cycle for a Program Manager, which would typically be two or three years. Also, program schedule may not be a variable that can be traded off, particularly for ship systems. For most ship systems, their completion or delivery dates are tied to construction or overhaul periods for ships, which are not under the control of the Program Manager and are unlikely to be altered. The financial costs and benefits of HSI may also be associated with different timeframes. Valerdi and Liu (2010) present three levels of HSI cost, beginning with the cost to carry out HSI as part of systems engineering, which would include the cost of defining requirements or conducting a tradeoff analysis. The second level is the cost of satisfying those requirements in the design, and the third level is the long-term total ownership cost or savings of the earlier HSI investment (or lack thereof). Costs within individual domains can be difficult to predict, and differing timeframes only makes these costs more difficult to trade off against one another.

Third, the tradeoff must specifically address a program priority. It will be difficult to illustrate how a tradeoff minimizes total ownership cost or optimizes total system performance, but it is much more straightforward to tie a tradeoff to performance requirements, to manpower and personnel constraints, or documented program risks. Associating a tradeoff with a program risk is one of the fastest ways to get approval because it addresses something of direct importance to the Program Manager. Domains differ in their relevant data and areas of interest, meaning that trades have to be made in different "units of measure." Translating the impact in each domain to program priorities improves the viability of the tradeoff.

Finally, making a tradeoff requires relevant supporting data. Since people are inherently the most variable part of the total system, different decision makers will have different predictions or assumptions about how they will impact performance. The proclivity for armchair performance prediction from outside the HSI community can be best discouraged by collecting the relevant data or completing the relevant analyses. Performing the analysis work may require a specific contractual deliverable. The results then need to be condensed or translated into a format that is relevant at the level of the individual with authority for the tradeoff.

Biography

John Winters is a Senior Human Factors Engineer at BCI, where he serves as the Dahlgren, VA Division's Program Director for HSI. Over the last dozen years, Mr. Winters' primary area of work has been the support of major ship and combat systems efforts from the program, systems command, and research perspectives.

JAMES A. PHARMER

Although practitioners in the HSI domains have made great strides in gaining acceptance into the system acquisition process, the role of these practitioners is not often readily apparent to the practitioners of more traditional engineering and program management disciplines. In other words, the traditional acquisition community is generally aware of the requirements to "do HSI" but still often at a loss for the best way to integrate this new discipline (or set of disciplines) into the process. Therefore, it is incumbent on the HSI practitioners to provide some education to these practitioners on the value provided by including HSI considerations into the conventional cost, schedule, and performance tradeoff process.

Unfortunately, two issues arise when trying to provide this "education." First, hard and fast requirements for HSI are still in the beginning stages of development. Despite support for HSI at high levels within the Department of Defense and other governmental organizations, the requirements for a Program Manager are still somewhat ambiguous. Program Managers know that they are required to fund professionals in the domains, but many do not know how to utilize them. Therefore, an assertion that HSI has value to the program meeting a higher level requirement is difficult to defend if the program is technically meeting the requirement simply by funding HSI practitioners.

Second, because HSI is still in its infancy, there are few, if any, major acquisition programs that have fully implemented HSI considerations into the acquisition tradespace and progressed into operations and sustainment of the designed systems. The paucity of data from programs that have "walked the talk" limits the ability to study its impact across the lifecycle. For this reason, an assertion that HSI has value cannot easily be communicated in terms of returns on investment from cost, schedule, or performance standpoints, precisely the language that is important to a Program Manager.

Since HSI requirements are not often clear and there is scarce data on its return on investment, HSI practitioners need to educate traditional acquisition professionals through actively participating during the systems engineering process. This means educating themselves on the factors the disciplines, both internal and external to HSI, are considering. For example, for many Navy assets (ships, aircraft, etc), a key consideration is overall weight, which adds to fuel costs, and structural engineering, and material costs. Therefore, a human factors, habitability, training, or manpower "solution" that adds weight (cost) can be a difficult challenge unless it can be justified by a large performance payoff.

Knowing the performance requirements, and whether or not the program is on a path to meet them, can provide leverage to the argument for the HSI solution. Since cost is often the most important consideration, a "solution" couched in terms of a reasonable prediction of increased performance that does not increase acquisition cost or schedule is perhaps the most powerful argument. The point is that if the HSI practitioner understands the constraints placed on the individual on the other side of the tradeoff discussion (e.g., a weight limitation), an HSI solution can be developed that recognizes that constraint as a limiting factor. Traditional systems engineering tradeoffs between such disciplines as hardware and software engineering are performed in this way. Participation in this same process by HSI practitioners makes the job a little more challenging but it is the essence of the systems engineering tradeoff process.

Biography

Dr. Jim Pharmer is a Senior Research Psychologist in the Weapon System HSI branch at the Naval Air Warfare Center Training Systems Division where his work primarily focuses on the development and application of Human Systems Integration principles for major Navy acquisition programs. He holds a Master of Science in Engineering Psychology from Florida Institute of Technology and a Ph.D. in Applied Experimental Human Factors Psychology from the University of Central Florida.

DENNIS WHITE

There are actually two layers of HSI Tradeoff Analyses: 1) within the domains of HSI and 2) between the Human, Hardware and Software systems. The Navy's HSI community has successfully performed tradeoff analyses across the domains (for example, trading workflow complexity with personnel selection), and has been integral to some system/subsystem tradeoffs. But often, the success of implementing the results of tradeoff analyses requires the use of two fundamental skills to successfully implement tradeoffs: communication and compromise.

Communication involves the imparting or interchange of thoughts, opinions, or information by speech, writing, or signs. The real impacts to system design occur around the table where all players are participating – and communicating. As is often stated, the Program Manager's concerns revolve around cost, schedule and performance (order of importance may vary). The Human Systems Engineer is, at the end of the day, a Systems Engineer, because HSI is an integral part of the systems engineering process used in the acquisitions (Secretary of the Navy Instruction 5000.2, 2008). Therefore, the Human Systems Engineer must be able to translate and communicate the value of human performance design options that support operational requirements and user needs into metrics that the Program Manager and other members of the system engineering team will understand.

Two different analyses on two different ship designs in the recent past illustrate the success – and failure – of successfully engaging the program leadership. In the first example, naval architects argued against a two-story high Ship Command Center on the basis of structural integrity and constructability. Although human performance analysis and other design experience showed the value in increasing situational awareness, communication and execution, this had to be explained in terms Mission Performance, which included time to execute, and the difficulty to achieve the same level of performance in a single story design option. By understanding the naval architect's problem and design space, the HSI team was able to successfully present (and win) the argument for a two story command center.

The second example involved a study looking at reducing workload through machinery space design with the goal of reducing manning. The difficulty in translating workload to manpower to sailor billets to dollars rendered an answer that leadership just couldn't grasp on a single PowerPoint slide. The analysis was good, the communication was not, and no impact was made to the program.

Compromise (a settlement of differences by mutual concessions) is another skill necessary to impact design. The key objectives are Total System Performance and Total Ownership Cost across the hardware, software, and people, including user preferences. US Navy Ship and Ship systems (propulsion, ship control, weapon systems) have key parameters, including weight, balance, displacement and power. Recognizing that some things are indeed negotiable, and knowing which parameters absolutely cannot be compromised, allows the Human System Engineer to collaboratively engage the rest of the design team to meet these objectives. This may include 'compromise' on the analysis itself: no program has enough money to do everything desired, and the successful engineer will craft an effective analysis that answers the questions and meets cost and temporal constraints.

For example, in a recent ship design, one organization proposed a high fidelity simulation of a command center to determine the layout of people and equipment. The program had neither the consoles (final design has just been settled, but nothing manufactured) nor the software (ship construction requires a very early lead time, often before software systems are complete or designed). Another organization proposed a lower fidelity option to focus on the problem at hand: optimizing the layout of people and equipment based on requirements and anticipated functionality. The low fidelity option was funded, and made significant contributions to the final approved layout of the command center. Would the high fidelity option have provided better analysis? Absolutely, but it would have been two years after the ship was already under construction.

Biography

Dennis White is the Head of the Human Systems Integration team at the Naval Surface Warfare Center, Dahlgren VA, managing a team of Human Systems Engineers that focus primarily on US Navy and US Marine Corps programs. In addition to a Navy career including both officer and enlisted, he has 15 years experience in user-centered design, including expertise in command center design (afloat and ashore) and human performance and manpower modeling. He has been the Government HSI lead for numerous programs and efforts, including the NAVSEA Manpower & Personnel Technical Warrant Holder.

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