Economics of Human Systems Integration: A Systems Engineering Perspective

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Abstract
Human Systems Integration (HSI) is the collection of interdisciplinary technical and management processes for integrating human considerations within and across all system elements. This discipline seeks to treat humans as equally important to system design as are other system elements, such as hardware and software. HSI has been defined by many stakeholders, particularly government agencies that advocate the "total system" approach, which incorporates humans, technology, the operational context, and the necessary interfaces between. HSI considerations include the following nine domains: manpower, personnel, training, human factors engineering, environment, safety, occupational health, habitability, and survivability. This paper introduces one area of a larger research project, sponsored by the U.S Air Force, which seeks to develop an approach for determining what percentage of the overall systems engineering activity should be allocated to HSI in order to effectively consider these nine domains as part of the overall systems engineering effort. We describe previous relevant work, including a case study of our own, related to the development of "HSI Size" as a function of HSI Requirements, and discuss how those requirements can be integrated into a parametric cost estimation model.

Keywords - human systems integration, parametric cost estimation, COSYSMO, systems engineering economics

1 Introduction

Humans are critical to the success at every stage of the life cycle of complex systems. In the defense industry, Human Systems Integration (HSI) is a comprehensive management and technical approach for addressing the human element in weapon system development and acquisition. By taking into account the interests of designers, operators, maintainers and other human stakeholders, HSI can improve system performance and minimize ownership costs. Published case studies and best practices have highlighted the benefits of successful HSI, particularly when HSI is incorporated with other systems engineering activities early in the acquisition process [1] [2].

The work presented in this paper is part of a project to better understand how HSI fits into the larger systems engineering picture. Because HSI is most effective when it is integrated as part of early systems engineering, it can be difficult to generate an accurate estimate of HSI costs and return on investment without taking into account total systems engineering effort. We propose that the cost of HSI can be estimated as a function of the total cost of systems engineering. Additionally, we propose that our understanding of HSI's impact on systems engineering would be furthered by a better appreciation for HSI's impact on the number and complexity of system requirements. We look to a variety of sources to support our conclusions.

This paper is organized into five sections. The first section introduces HSI, its origins, and why understanding its role in systems engineering is critical. The second section documents current HSI policies and practices and provides a brief review of the literature relevant to HSI. The third section describes a case study of a complex system that illustrates a best practice of HSI. We find that both the literature and our own case study support the importance of including HSI in requirements development. The fourth section shows how HSI requirements can be integrated into an existing parametric cost estimation model. We conclude with a description of expert input on our research findings and a summary of our next steps.

1.1 Origins of HSI

HSI has its origins in the field of Human Factors Engineering (HFE), with which it is commonly confused. Human Factors is the science of understanding the properties of human capability and the application of this understanding to the design and development of systems and services. While human factors has arguably been studied since the very beginning of scientific inquiry, the technological advances of the Industrial Revolution drove modern research on how humans could best interact with machines. During this time period, innovations were also made in work and schedule management. At the time, these efforts were known as Industrial Engineering [3].

The challenges and requirements of industry leading up to the beginning of the 20th century grew significantly during the first and second World Wars. In response, the U.S. and UK both funded efforts to understand human impacts on performance [3]. It is difficult to pinpoint the exact "beginning" of the field of Human Factors Engineering, as HFE activity has been documented throughout the 20th century, sometimes under different names [4]. However,

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the Human Factors and Ergonomics Society, with which HFE is commonly associated, was incorporated in 1957 [5].

HFE is the field that Human Systems Integration grew from and continues to be one of its central elements. However, Human Systems Integration as it is practiced expands upon Human Factors Engineering by incorporating a broader range of human considerations such as occupational health, training, and survivability over the system life cycle.

In 1981 and later in 1985, the U.S. General Accounting Office (since renamed the Government Accountability Office) released reports calling on the U.S. Army to improve integration of manpower, personnel, and training (MPT) into its systems acquisitions processes [6][7]. In response, the U.S. Army developed the Manpower and Personnel Integration (MANPRINT) program. The term itself was coined in 1984 and became an official Army Directorate in 1987 [8].

1.2 The Need for Better Cost Estimation

HSI involves many different fields of study and HSI activities are important at every phase of the acquisition cycle. Because of this, HSI practitioners often vary in their definitions of, perspectives on, and approaches to HSI. The similarity of the designation "Human Systems Integration" to other fields of varying relation, such as Human Factors Engineering, Human Factors Integration, Human Performance Enhancement, Human-Computer Interaction, etc., also causes confusion.

As previously discussed, HSI evolved from the study of Human Factors. Human Factors tools are typically used to evaluate a design later in the acquisition process. Unfortunately, this means that many engineers tend to view HSI as a means of identifying problems with a design, rather than as an enabler of good design [9]. Although HSI analysis in the later phases of acquisition are an important part of HSI success, the research presented in this paper seeks to identify a tool that can be used by program managers (PMs) early in the acquisition process to estimate the costs of HSI. Understanding these costs will allow PMs to better incorporate HSI considerations into their systems and formulate effective plans for HSI activities throughout the acquisition cycle.

2 Current Practice of HSI

HFE and HSI advances in countries such as the UK, Canada, Australia, and New Zealand were important in the evolution of the field [10] but this paper focuses specifically on HSI activity in the U.S. Military.

HSI is addressed in many different military documents at varying levels of detail. The acquisition policy of the U.S. Department of Defense is governed by a series of department-wide issuances collectively known as the 5000 series of publications. The two highest-level documents are DoDD 5000.01, *Defense Acquisition System,* which only states that the program manager shall "apply human systems integration," [11] and DoDI 5000.02, *Operation of the Defense Acquisition System*, which defines HSI and lists its domains[12].

Although DoDI 5000.02 lists 7 domains of HSI, the three military services maintain their own lists and definitions of HSI domains. The differences between services do not indicate disagreement about the meaning and importance of HSI, but rather exist in order to help HSI integrate better into each service's unique organizational structure.

Since the work presented in this paper is sponsored by the U.S. Air Force, we use the Air Force's definition of HSI domains [13]. It identifies 9 domains of HSI:

Manpower—the number and mix of personnel (military, civilian, and contractor) authorized and available to train, operate, maintain, and support each system.

Personnel—the human aptitudes, skills, and knowledge, experience levels, and abilities required to operate, maintain, and support a system at the time it is fielded.

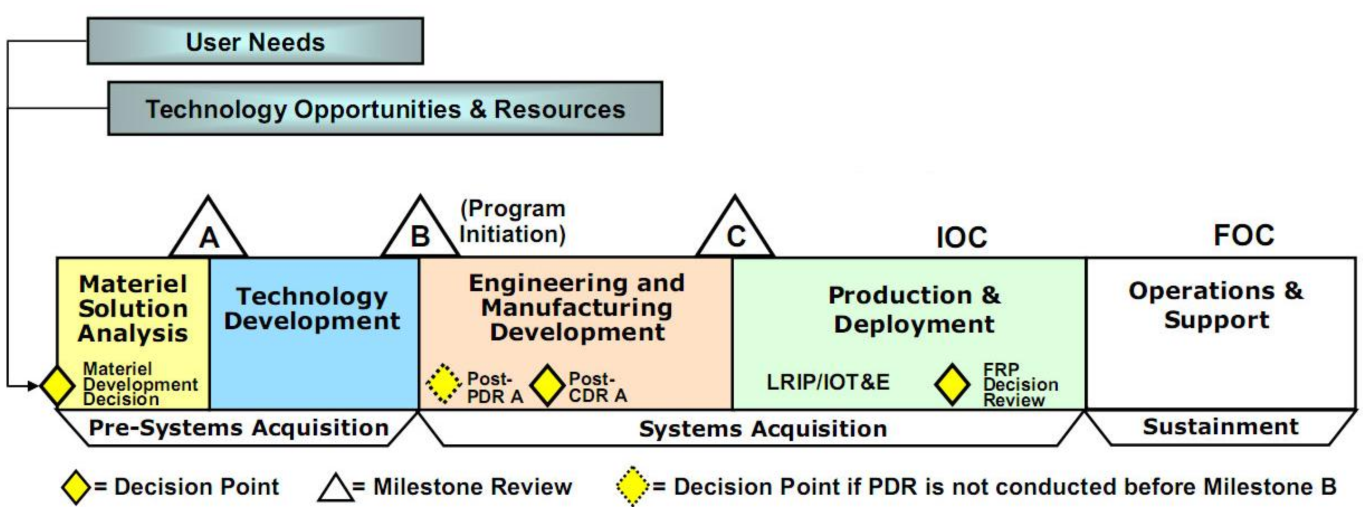

Figure 1 - *The Defense Acquisition Management System, adapted from* [12].

Training—the instruction and resources required providing personnel with requisite knowledge, skills, and abilities to properly operate, maintain, and support a system.

Environment—in the context of HSI, environment includes the conditions in and around the system and the concepts of operation that affect the human's ability to function as a part of the system as well as the requirements necessary to protect the system from the environment (e.g., radiation, temperature, acceleration forces, all-weather ops, day-night ops, laser exposure, air quality within and around the system, etc.).

Safety—the application of systems engineering and systems management in con-ducting hazard, safety and risk analysis in system design and development to ensure that all systems, subsystems, and their interfaces operate effectively, without sustaining failures or jeopardizing the safety and health of operators, maintainers and the system mission.

Occupational Health—the consideration of design features that minimize risk of injury, acute and/or chronic illness, or disability, and/or reduce job performance of personnel who operate, maintain, or support the system.

Habitability—factors of living and working conditions that are necessary to sustain the morale, safety, health, and comfort of the user population that contribute directly to personnel effectiveness and mission accomplishment, and often preclude recruitment and retention problems.

Survivability—the ability of a system, including its operators, maintainers and sustainers to withstand the risk of damage, injury, loss of mission capability or destruction.

Human Factors Engineering—the comprehensive integration of human capabilities and limitations (cognitive, physical, sensory, and team dynamic) into systems design, to optimize human interfaces to facilitate human performance in training operation, maintenance, support and sustainment of a system.

2.1 Early Integration of HSI

The DoD recognizes the importance of the human element to every stage of acquisition. DoDI 5000.02 mandates that "the PM shall have a plan for HSI in place <u>early</u> in the acquisition process to <u>optimize total system performance</u>, <u>minimize total ownership cost</u>s, and ensure that the system is built to accommodate the characteristics of the user population that will operate, maintain, and support the system," (emphasis added) [12]. The DoD recently approved a major revision of the Defense Acquisition System, so some of the language used in DoD 5000.02 conflicts with earlier service-specific publications [14]. However, the basic terminology related to milestones and acquisition phases relevant to the work presented here remained intact.

The U.S. Army, Navy, and Air Force each publishes documents describing how their service intends to carry out the mandate of DoDI 5000.02. Figure 1 depicts the Defense Acquisition Management System and summarizes the different phases of acquisition. As detailed in the next section, publications from each of the U.S. Armed Services also emphasize that HSI effort should begin prior to Milestone A, during the Pre-Systems Acquisition phase.

2.2 HSI Requirements

System requirements have been defined as "a statement that identifies a system, product or process' characteristic or constraint," and as "The need or demand for personnel, equipment, facilities, other resources, or services, by specified quantities," [15][16]. Requirements are iteratively refined during the Pre-Systems Acquisition phase of acquisition. Several publications from the U.S. Military explain its view of the role of HSI in requirements definition.

The Department of Defense emphasizes the importance of "capabilities-based" requirements definition [15]. The Defense Acquisition Guidebook, a detailed online guide that is considered to be part of the DoD 5000 series of publications, devotes a chapter to HSI. Of HSI requirements, it states: "HSI capabilities in the Capability Development Document should be specified in measurable, testable, performance-based language that is specific to the system and mission performance." The Guidebook also discusses in detail how to develop requirements in each of the domains of HSI and uses the term "HSI requirements" to refer to these requirements in general [18].

In 2003, the Government Accounting Office (GAO) (since renamed the Government Accountability Office), published a study titled *Setting Requirements Differently Could Reduce Weapon Systems' Total Ownership Costs* that recommended making "requirements to include total ownership cost goals and readiness rates for any major weapons system as performance parameters equal to any others," [19]. Though the GAO's recommendations were mostly directed toward the DoD's *Guide for Achieving Reliability, Availability, and Maintainability,* we found that they also directly applied to Human Systems Integration in general [20]. This relationship is corroborated by our case study work. We found that many HSI activities were done as part of an Air Force Reliability, Maintainability & Supportability (RM&S) program prior to the formalization of HSI in the Air Force.

In 2005, the U.S. Army published a comprehensive MANPRINT handbook for PMs. The handbook explains the MANPRINT-related activities suggested and required of PMs during each phase of development, starting prior to Milestone A and continuing in accordance with the Defense Acquisition Management System and Joint Capabilities Integrated Development System. The Handbook lists specific MANPRINT activities important to requirements development [21].

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While the MANPRINT currently offers the most complete guidance on specific HSI-related actions during the acquisition process, the Navy and Air Force have worked quickly to produce guidance tailored to their own services. The Navy is developing a three-volume HSI guide based on the high-level guidance provided in Secretary of the Navy Instruction (SECNAVINST) 5000.2D, *Implementation and Operation of the Defense Acquisition System and the Joint Capabilities Integration and Development System.* The second volume in the series states "The PM must initiate an HSI effort at the earliest stages of the acquisition process," [22].

The Air Force is developing both a Handbook as well as an HSI Development Guide based on capability-based requirements. The Development Guide describes HSI activities, capabilities, requirements, and responsibilities that all must be considered early in acquisition [10][23].

Several sources of HSI analysis outside the military have been influential to the development of policy. Harold Booher's oft-cited 2003 *Handbook of Human Systems Integration* presents lessons learned from case studies of HSI as well as the opinions, observations, and advice of HSI experts [24].

The International Council on Systems Engineering's (INCOSE) Systems Engineering Handbook includes an appendix dealing with HSI that advises "it is critical to include HSI early in concept development and continuously through the development process to realize substantial Life Cycle Cost (LCC) savings" [15]. The appendix suggests several early HSI actions in particular, such as initial capabilities studies and HSI modeling and simulation.

2.3 Observations

The literature presented in the above sections serves two purposes. The first is to familiarize systems engineers with the current practice of Human Systems Integration, particularly how it fits into policy relevant to systems engineering as a whole. The second is to highlight the concept of an "HSI requirement" as it exists in the literature. Judging by the context of documents reviewed, an HSI requirement can be understood to be any requirement that belongs to a domain of HSI. However, no effort is made in any of the documents to explicitly state the difference between an HSI requirement and a "non-HSI" requirement or whether that difference has any effect on the systems engineering effort needed to meet a requirement.

While some practitioners would argue that the distinction between the two types of requirements is merely semantic and would be understood implicitly, the lack of clarity poses a challenge to developing effective cost estimates. The level of detail of a requirement and the number of HSI domains that requirement affects can have a significant impact on the effort necessary for its completion. This is evident in several industry examples where HSI is a key consideration. The next section provides an example from a U.S. engine manufacturer.

3 Case Study: The Pratt & Whitney F119 Engine

This section documents HSI activities done during the development of Pratt & Whitney's F119 engine, shown in Figure 2. The engine powers the $143M Lockheed Martin F-22 Raptor fighter aircraft [25]. The F-22 raptor fulfills the air superiority role in the U.S. Air Force by using a package of technologies to deliver "first look, first shot, first kill capability in all environments" [26]. Although the Air Force HSI Office was not formalized until 2007, much of the work done on the F-22 and F119 in the 1980s and 1990s spans the domains of HSI, making the F119 a successful example of HSI in the Air Force.

The case study was designed around three central research questions:

(1) How did Pratt & Whitney predict how much HSI effort would be needed?
(2) How much did HSI effort eventually cost?
(3) How did HSI fit into the larger systems engineering picture?

Since historical data on specific costs associated with HSI activities were not available either because data were not kept or records could not be found, we depended on Pratt & Whitney employees involved in the development of the F119 to build an understanding of these questions. We conducted a series of interviews with Pratt & Whitney engineers who played key roles in the HSI aspects of the F119 in both technical and management roles.

3.1 Reliability, Maintainability, & Supportability

The Defense Resources Board approved the creation of the Advanced Tactical Fighter (ATF) program in November of 1981 to create a military jet that would be able to guarantee air superiority against the Soviet Union. The fighter was meant to replace the F-15 Eagle, which had previously filled this role. A team composed of Lockheed, Boeing, and General Dynamics competed against Northrop Grumman to develop the fighter. In 1991, the ATF contract was awarded to the Lockheed team's F-22, powered by Pratt & Whitney's F119 engine. Then Secretary of the Air Force Donald Rice noted that an important consideration in the awarding of the contract was the fact that the F-22's engines offered superior reliability and maintainability [27].

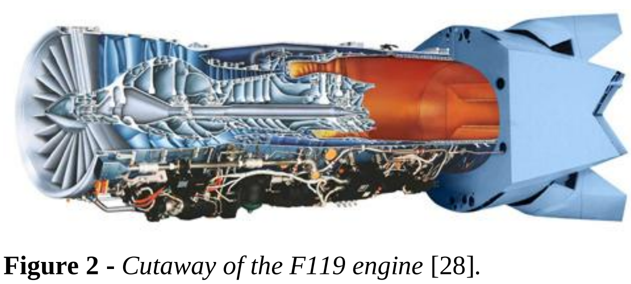

Figure 2 - *Cutaway of the F119 engine* [28].

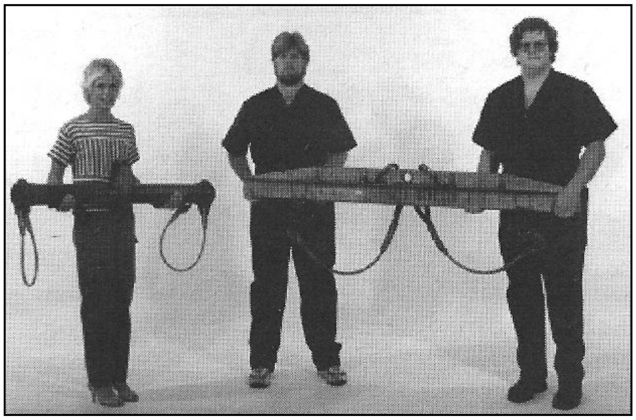

Figure 3 - *Tool design to accommodate maintainers* [29].

The Air Force placed an emphasis on reliability and maintainability from the beginning of the ATF program as well as the Joint Advanced Fighter Engine program (JAFE) – the program to develop the engine for the ATF. In June of 1983, four general officers representing the Army, Navy, and Air Force signed a joint agreement in order to "emphasize to the DoD and defense contractor communities the critical importance of improving operational system availability by making weapon system readiness and support enhancement high priority areas for all our research and development activities" [30]. Later that year, Colonel John Reynolds, then director of JAFE, sent a memorandum to participants in the program, including Pratt & Whitney, asking them to consider that over 50% of Air Force budget was then devoted to logistics, and that the problem would only worsen [31].

To address this increase in logistics cost and determine ways to develop creative solutions, the Air Force created the Reliability, Maintainability & Sustainability (RM&S) program in 1984 [29]. Besides reducing life cycle cost, the RM&S program also sought to address the reliability and durability problems that had plagued the previously built Pratt & Whitney F100 engine, which powered the Air Force's F-15 eagle. The Air Force emphasized improved RM&S not only on the F119 engine, but on development of the F-22 as a whole. Specific supportability goals for the F-22 were announced as early as 1983 [32].

3.2 HSI Early in Acquisition

The major requirements for RM&S came directly from the Air Force. The JAFE program in particular was intended to improve RM&S by "reducing the parts count, eliminating maintenance nuisances such as safety wire, reducing special-use tools, using common fasteners, improving durability, improving diagnostics, etc," [32]. While General Electric made significant RM&S improvements to its F120 engine during this time period, Pratt & Whitney centered its competitive strategy on RM&S superiority.

One of the most important requirements for the F119 was that only five hand tools should be used to service the entire engine. All Line Replaceable Units (LRUs) would have to be "one-deep", meaning that the engine would have to be serviceable without removal of any other LRUs and each LRU would have to be removable using a single tool within a 20 minute window [29]. Maintenance would have to be possible while wearing hazardous environment protection clothing. Maintenance tasks would have to accommodate maintainers from the 5th percentile female and 95th percentile male as shown in Figure 3, in addition:

"Built-in test and diagnostics were integrated with the aircraft support system, eliminating the need for a special engine support system. Lockwire was eliminated, and torque wrenches were no longer required for "B" nut installations. The engine was designed with built-in threadless borescope ports, axially split cases, oil sight gauges, and integrated diagnostics. Other improvements were a modular design…, color-coded harnesses, interchangeable components, quick disconnects, automated integrated maintenance system, no component rigging, no trim required, computer-based training, electronic technical orders, and foreign object damage and corrosion resistant. These advances were intended to reduce operational level and intermediate level maintenance items by 75% and depot level tools by 60%, with a 40% reduction in average tool weight," [32].

Pratt & Whitney conducted roughly 200 formal trade studies as contracted deliverables for the Air Force. Pratt & Whitney engineers also estimated they had conducted thousands of informal trade studies for internal use. These trade studies used evaluation criteria including safety, supportability, reliability, maintainability, operability and stability, and manpower, personnel, and training [33]. Performing these trade studies helped Pratt & Whitney determine how to achieve the Air Force's requirements and which requirements, if any, would need revision.

These activities were only possible using the Integrated Product Development (IPD) concept. Whereas on previous projects, engineering groups at Pratt & Whitney each worked in their own respective disciplines, under IPD, teams of engineers from varying disciplines were able to provide design engineers with the perspectives they needed to see the full impacts of their design decisions.

3.3 Continuing Accountability and Enforcement of HSI

Adoption of the Integrated Product Development concept brought various stakeholders together early in the design process and ensured multidisciplinary input through design and development. As a matter of policy, whenever a design change needed to be made, the originating group would submit the change to be reviewed by a Configuration Control Board (CCB). CCBs were composed of senior engineers from multiple engineering groups. At CCB meetings, each group with a stake in a particular design change would explain the impacts of that change to the chair of the CCB, typically a design engineer. The chair

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would then weigh the different considerations of the design change and either approve/disapprove the change or recommend further analysis be done.

In instances when Air Force requirements needed to be changed, the originating group would submit a Component Integration Change Request (CICR), which would then be internally debated much like with design changes. CICRs were typically initiated when it was determined that a particular requirement might not be in the best interests of the customer or when one requirement conflicted with another. Once a CICR was finalized internally by all of Pratt & Whitney's engineering groups, it was presented to the Air Force, which would then make the final decision on whether a requirement could be eliminated, modified, or waived.

The processes for design and requirement change ensured that the work of one group did not create unforeseen problems for another. However, change requests were typically made in response to problems that arose during development. Although reacting to and fixing these problems was important, it took proactive leadership to make sure HSI principles were being followed even when no problems were apparent.

3.4 HSI Efforts Lead to Competition Success

In 1991, both Pratt & Whitney and its competitor General Electric were awarded contracts worth $290 million to complete the engineering and manufacturing development (EMD) phase of competition for the F-22 propulsion system. The companies were given independence as to the number and types of tests that would be run on their engines, while the Air Force provided safety oversight [32].

GE chose to emphasize the performance of its F120 engine over RM&S, though the F120 did meet the Air Force's RM&S requirements. The F120 was tested in both Lockheed's YF-22 and Northrop Grumman's YF-23 prototypes, demonstrating better maximum speed and supercruise than Pratt & Whitney's F119 in both cases [32].

Despite the F120's superior performance in the air and higher thrust-to-weight ratio, on April 23rd, 1991, the Air Force chose the combination of Pratt & Whitney's F119 and Lockheed's YF-22 to be developed into the F-22. Pratt & Whitney had repeatedly demonstrated a better understanding of the Air Force's RM&S needs, investing more time and money into demonstrations and internal efforts than its competitor. By 1991, the Air Force's RM&S program was less focused on reducing downtime and more concerned with life cycle costs. Pratt & Whitney had presented a management plan and development schedule that the Air Force considered sensitive to their needs [32]. On August 2nd of 1991, contracts worth $11 billion were awarded to Lockheed and Pratt & Whitney [27]. Pratt & Whitney's portion was worth $1.375 billion alone [32].

3.5 Case Study Conclusions

The case study showed that while Pratt & Whitney was responsible for the successful application of HSI during the design and development of the F119 engine, the company's actions were driven by Air Force policies and funding.

In conversations with Pratt & Whitney engineers, we were told repeatedly that by the time HSI requirements were integrated into the engine by Pratt & Whitney, the cost of specific HSI activities could no longer be distinguished from other systems engineering costs. Pratt & Whitney estimated the cost of the F119 using their records of costs from a previous engine. When new requirements needed to be met in response to RM&S concerns, the projected cost of those requirements was simply added to historical costs. However, no effort was made at Pratt & Whitney to label work related to HSI as such.

The Air Force's early and continuing emphasis on RM&S was captured via requirements. Although even in 2003 the GAO was still advocating for more equal consideration of reliability and maintainability in requirements definition, our case study showed that the Air Force already understood this principle a decade prior [19]. We concluded from our case study that it would be necessary to look at original U.S. Air Force requirements and capabilities for the F119 to better understand the impact of HSI on cost.

4 Parametric Cost Estimation and HSI

A parametric cost model is defined as "a cost estimating relationship (CER) used to estimate a specific aspect of a project or product," [34]. These models are often implemented in sophisticated software applications in which the CER is not apparent to the user but the model parameters can be adjusted to perform a cost estimate. Parametric models in engineering management serve as valuable tools for engineers and project managers to estimate engineering effort. Developing these estimates requires a strong understanding of the factors that affect the phenomenon being modeled, the assumptions of the model in use, and the units of measure provided by the model.

Parametric cost estimation is not the only tool available to PMs to estimate cost. Other cost estimation techniques include *Analogy, Bottom-up/Activity-Based Costing, Top-Down/Design to Cost, Expert Opinion,* and *Heuristic* approaches [34]. However, the more cost estimation techniques used, the more supportable the estimate. The Parametric, Analogy, Expert Opinion, and Heuristic methods can all be used early in the acquisition process. However, the analogy method works best when historical data from a similar project is available and the Expert Opinion and Heuristic methods are less reliable when a proposed system includes new technologies or methods that experts may not be familiar with. Parametric cost estimation is particularly useful when little historical data is available and the system being designed incorporates complex or risky elements.

4.1 The COSYSMO Model

The Constructive Systems Engineering Cost Model (COSYSMO) is a parametric model used to estimate systems engineering effort. Since COSYSMO was designed to estimate systems engineering effort early in the acquisition process, it is an ideal model to incorporate HSI considerations.

The Cost Estimating Relationship (CER) of COSYSMO, reproduced here as Figure 4, is an equation where:

PM = effort in Person-Months
A = calibration constant derived from historical project data
Size = determined by computing the weighted sum of the four size drivers
E = economy/diseconomy of scale; default is 1.0
n = number of cost drivers (14)
$\mathbf{EM}_i$ = effort multiplier for the i_{th} cost driver; nominal is 1.0.

The 4 size drivers and 14 cost drivers of COSYSMO and their relative weights were defined using surveys of industry leaders. The nominal value of each of the 14 cost drivers is defined as 1.0. The nominal value represents the average value of a given cost driver across industry.

Ratings other than nominal, ranging from very low to in some cases extra high, can be assigned to each of the cost drivers. For more accurate results, the numerical values corresponding to the level of each cost driver can be calibrated to a given organization. Cost driver estimates are assigned by experts familiar with the system in question.

It can be empirically shown that developing a satellite ground station represents a larger systems engineering effort than developing a toaster. In order to differentiate the two, four size drivers were developed to help quantify this difference. The role of size drivers is to capture the functional size of the system from the systems engineering perspective. They represent a quantifiable characteristic that can be arrived at by objective measures (i.e., physical size).

Since the focus of COSYSMO is systems engineering effort, its size drivers need to apply to software, hardware, and systems containing both. The set of size drivers that affect systems engineering effort were defined to be: (1) *Number of Requirements,* (2) *Number of Major Interfaces,* (3) *Number of Critical Algorithms,* and (4) *Number of Operational Scenarios*. Of these four, *Number of Requirements* has been the most controversial and volatile. This is due in part to the different types of requirements (i.e., functional, operational, environmental) that are used to define systems and their functions, the different levels of requirements decomposition used by organizations, and the varying degree of quality of requirements definition (how well they are written).

$$\mathrm{PM} = \mathrm{A} \times \mathrm{Size}^{\mathrm{E}} \times \prod_{i=1}^{n} \mathrm{EM}_i$$

Figure 4- *COSYSMO Cost Estimating Relationship (CER).*

COSYSMO defines the *Number of Requirements* size driver as:

"*the number of requirements for the system-of-interest at a specific level of design. The quantity of requirements includes those related to the effort involved in system engineering the system interfaces, system specific algorithms, and operational scenarios. Requirements may be functional, performance, feature, or service-oriented in nature depending on the methodology used for specification. They may also be defined by the customer or contractor. Each requirement may have effort associated with it such as verification and validation, functional decomposition, functional allocation, etc. System requirements can typically be quantified by counting the number of applicable shalls/wills/shoulds/mays in the system or marketing specification. Note: some work is involved in decomposing requirements so that they may be counted at the appropriate system-of-interest,"* [34].

We have highlighted many of the issues of counting requirements in our review of literature relevant to HSI requirements and in our case study of the F119 engine. However, the U.S. Military has shown an effort to improve the consistency and quality of requirements definition in its acquisition process with the publication of the various documents described in section 2. Therefore, we believe that with some effort, we will be able to incorporate HSI into the *Number of Requirements* size driver of COSYSMO.

5 Conclusions and Next Steps

We discussed some of our preliminary findings in January 2009 at a meeting of the INCOSE Human Systems Integration Working Group. The HSI experts and practitioners present at the meeting agreed that the concept of an "HSI requirement" is neither standardized nor universal. We collected their input including various recommendations on how to incorporate HSI into COSYSMO's *Number of Requirements* size driver. We intend to continue to collect expert opinion on this topic. The experts also recommended further study into the other cost and size drivers of COSYSMO, including the *Number of Major Interfaces* parameter and how it could be modified to capture HSI considerations.

Since we already have data on the design and development of the F119 engine, we intend to review requirements and capabilities documents from early in the F119 program to create a quantifiable link between early HSI efforts and eventual program success. We also intend to gather the input of industry and military experts on the best definition

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of an "HSI requirement." That understanding will allow us to assign the appropriate weight and rating scales to HSI requirements in COSYSMO.

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The views expressed in this article are those of the authors and do not reflect the official policy or position of the United States Air Force, Marine Corps, Department of Defense, or the U.S. Government.

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