Cost Estimation as an Intensive Human Interactive System Design Problem

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***Abstract* —**This paper will compare and contrast the difference between Intensive and Non-Intensive Human Interactive Systems. Further, this paper will investigate the role of Governance, Culture, Process and Tools (GCPT) in each of the two systems, Intensive and Non-intensive. Finally, this paper will apply the GCPT Framework to the system of Organizational Cost Estimation and provide examples of results that Raytheon has seen in its effort to improve the accuracy, affordability and accountability of the current bidding/estimation process.

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1. INTRODUCTION - Definitions

We are sitting on the cusp of a transportation revolution. The era of driverless automobiles is going to dismantle the massive Governance structure of driver behavior enforcement. If one views the automobile as simply a Tool to get from one place to another, then there has historically been a multi-billion dollar business surrounding the Governance of the behavior surrounding this transportation Tool called a "car". In the future, if most cars are automated, then speeding infractions will become negligible, drunk driving infractions will be reduced dramatically, even things like parking tickets and driving without insurance will be reduced so significantly with completely automated automobiles that the huge infrastructure of Governance surrounding the Intensive Human Interactive System activity of driving a vehicle will be dismantled.

This dismantling should be expected because the automobile transportation system is moving from one that is considered an Intensive Human Interactive System to a Non-intensive Human Interactive System. An author of this paper has a 9 year old daughter and he suspects that by the time that she is old enough to drive, all she will need to know about driving is how to speak the destination of where she wants to go and the "Smart Car" will be responsible for getting her to the location. In the future, operating a vehicle will be considered a Non-intensive Human Activity.

Continuing with the Automobile Transportation System example for a moment, consider all of the parts that go into the current system. First, there is the Tool, an automobile. The car is the Tool that gets an individual from one place to another. However, before the car can do that, the driver must know the Process of how to operate the automobile and the Process of obtaining the state sanctioned certification to drive the vehicle. Beyond the Process of learning to drive, there is understanding the Culture of how to be a courteous driver in order to successfully operate the vehicle in the community. The police, sheriffs, highway patrol and traffic court systems provide the Governance to insure that the entire System is working.

Consider also what the Automobile Transportation System will look like in 20 years. The system of Governing the human behavior (police, highway patrol, traffic court etc.) is going to be greatly reduced if most cars are programmed to obey the speed and parking laws. How many Department of Motor Vehicle locations will be needed if only a few people need to test for a driver's license? All of the primary components of the Automobile Transportation System (Tools, Process, Culture and Governance) will be vastly different in the future because the System is transforming from an Intensive Human Interactive System to a Non-intensive Human Interactive System.

There is an old saying that goes something like: "Build a better mouse trap and the world will beat a path to your door." Generalizing the "mouse trap" as a Tool, then it follows that the saying could be modified to be: "Build a better Tool and success will soon follow." This paper will investigate the limitations of the "Tools for success" paradigm for Intensive Human Interactive Systems and will provide very specific insight into the application and implementation of Tools in Cost Estimation Systems, although the concepts could be abstracted to almost any organization activity.

Let us begin with some definitions.

Systems Design:

> *Systems Design is an interdisciplinary field of development that focuses on how to design and manage complex capability based systems over their life cycles.*

Cost Estimate:

> *A cost estimate is the approximation of the cost of a program, project, or operation. The cost estimate is the product of the cost estimating process.*

Intensive Human Interactive System:

> *An Intensive Human Interactive System is any organized activity through which complex human interaction, participation and judgment and possibly motivation plays a key role in the outcome of the activity.*

Before moving forward, here are some more examples of Intensive and Non-intensive Human Interactive Systems. The capability to design or test Electronics Hardware is an example of an Intensive Human Interactive System activity. Electronics Hardware design normally depends on a number of contributors providing critical value to the design activity. If the motivation of any one of the contributors suffers, then the entire activity suffers. Most organizations have written Processes covering the Hardware design process. Further, most organizations have adopted at least an informal Culture around training and activities around the "correct way to design hardware". Normally there is an oversight Process through design reviews that Govern the entire process of Hardware design.

The capability of listening to music is an example of a Non-intensive Human Interactive System. Multiple individuals are not needed to provide the capability of listening to music. All one needs to do is either buy a music CD, plug it into the player and enjoy the music or if one chooses to get a little more complex, then one could download the music onto a smart phone and either listen to it through the phone or set up the Bluetooth and listen to the music through a Bluetooth entertainment system. Either way, the system would not be considered an Intensive Human Interactive System.

This paper will investigate and provide results for the robust creation and optimization of an Intensive Human Interactive Cost Estimation System that attempts to accurately forecast costs in which human motivation, judgment (along with human error) and participation play key roles in the successful implementation of the system.

2. Types of Systemic Failures in Human Interactive Systems

At this point it is helpful to introduce a framework for characterizing system failures as a result of human activity or judgment. While there is rich literature that addresses the framework for characterizing system failures as a result of human activity, much of that literature is concerned with human errors associated with knowledge, rules, and skills. That framework carries the assumption that human errors are mistakes by well-intentioned humans.

In an error framework such as this, the focus is on categorization of error context and error proofing within each context. The literature often assumes it is possible for a human to complete the task and that the human desires to complete the task. This assumption of good-intentions is dangerous because it can result in overlooking the importance of aligning and motivating humans, which is far more difficult than training humans.

Innovation adoption models offer insight into the cultural mechanics of helping humans engaged in interactive systems to embrace change. Based on these innovation adoption models, we will define 3 types of human failures in a human interactive system:

1. Soft Human Failure (SHF)
2. Hard Human Failure (HHF)
3. Complex Human Failure (CHF)

A Soft Human Failure (SHF) occurs in systems which minimize human interaction and involvement to “simple” tasks. With these types of tasks, it is reasonable to assume that the average person is capable of correctly interacting within the human interactive system.

A Hard Human Failure (HHF) occurs when a human needs to complete much more intensive and difficult activity in conjunction with the other parts of the system. For instance, sea navigation via sextant requires intensive human activity in coordination with navigational tools. In this case, it cannot be expected that the average person is capable of navigating correctly.

It should be obvious from this discussion that there is no clear dividing line between SHFs and HHFs; characterization of these failures changes over time as our technologies change, and is also dependent upon what one considers to be “simple” or “difficult.” For instance, from the human user perspective, the systems utilized for navigation used to be very difficult to use, but now, via GPS and possibly smart phone technology, the system is considered simple due to the fact that most GPS user interfaces are quite simple. Much more training and understanding is required to mitigate HHFs than SHFs, but both could potentially be overcome with training.

In both SHFs and HHFs, there is an implicit but critical assumption: that the user is motivated to correctly navigate. This leads to a further assumption that the user will reasonably attempt to correctly interact with the other system elements to achieve that goal. However, a navigation failure will also likely occur if the human is not motivated to navigate correctly, or is actually motivated to navigate incorrectly. A failure of this type is characterized in this paper as a Complex Human Failure (CHF).

CHFs are an entirely different class of failures than SHFs and HHFs. CHFs are more closely associated with human capabilities, motivations, desires, preferences, and beliefs. For example, cooking a meal that tastes awful from a published, good recipe could be a SHF or HHF, depending upon whether the recipe calls for simple or highly- specialized cooking skills. It could also be a CHF if the person never *wanted* to cook the meal in the first place. Cooking lessons can possibly solve the former types of failures (SHF and HHF) but will not likely ever solve the latter type of CHF, because this CHF is not fundamentally a knowledge, rules, or skills problem; it is a motivational problem.

Further, CHF modes can exist when, regardless of training, it is not possible for a human to execute the task that is required. For example, a CHF mode may exist if a person has all the knowledge and training they need to complete a task, however completing it may require gathering input from someone who has not completed their input and a system failure occurs due to unsuccessful handoffs between two individuals.

All three of the failure types cited above result in the overall system failing to meet its desired requirements. While SHFs are likely mitigated with things like better user’s manuals, HHFs might require actual hands-on training. However, both are likely mitigated by motivated users getting appropriate information and skills. CHFs, on the other hand, require entirely different types of mitigating activities. In systems with CHFs, designers must figure out how to make users *want* to use their system, or at least protect their systems from people who are not motivated to use them properly.

3. "CAPABILITY" vs "SYSTEM" vs "DEVICE"

Many system designers are trained to believe that the device that they deliver to customers is the "system" and when properly created, that "system" delivers "capability" required by the customer. **However, this is almost never true**.

Most, if not all, items delivered to customers require some sort of human interaction to make them work. Without the proper human interaction, the device cannot alone deliver the capability required. Even the most trivial device must be plugged in and turned on or it does not work. System designers need to understand that the "system" that delivers the required capability consists of a complete set of directives or human interactive activities. If any of the directives or human interactivities are missing, the capability is not likely to be delivered.

"Capability" means the new or improved ability that the end user requires. For instance, the capability to navigate has existed for thousands of years. The methods and tools used, and the accuracy achieved has changed over time, but the capability to navigate has existed for a very long time. Humans once used landmarks, sextants, crude maps, even "bare" GPS coordinates to arrive at their destinations.

These days, one can simply type the name of a restaurant into a smart phone and the device will provide all guidance necessary to get to the destination. In all of these cases, the capability to navigate existed, but the systems created to enable this capability have varied dramatically, as has the accuracy obtained in navigation. A key differentiator of these systems is the amount of human activity required to successfully navigate. As technologies mature, the navigation systems have become less human intensive, and the failure modes have moved from HHF modes to SHF modes.

Fundamentally, there are four elements which composed the navigation system: Tools, Processes, Culture, and Governance. For instance, in early sea navigation, one required a Tool (sextant), a Process ("sight reduction" instructions), Culture (motivated and trained users), and Governance (multi-celestial body redundancy to reduce errors). In navigating with maps and primitive GPS receivers, one required Tools (GPS receiver and maps), a Process (instructions for using receiver and reading maps), Culture (motivated and trained users), and Governance (perhaps checking landmarks on maps against current actual position).

It is the fundamental premise of this paper that every modern complex system capability that involves Intensive Human Interaction of any sort requires these four elements: Governance, Culture, Process, and Tools (GCPT). These will be explained in detail in a following sections. Within the context of this paper, we will refine the definition of an Intensive Human Interactive System:

> *An Intensive Human Interactive System is defined as system that includes a framework of Governance, Culture, Process, and Tools which together enable a complex capability.*

In summarizing these very important concepts, Non-intensive Human Interactive Systems are comprised of capabilities in which either the user already contains a high degree of motivation to use, or it is so trivial to accomplish, as to make motivation not an issue. An Intensive Human Interaction System is one in which motivation is often closely tied to the success of the activity.

4. Non-intensive Human Interactive Systems

For Non-intensive Human Interactive Systems, a system designer typically is involved in designing products and mitigating SHFs and HHFs associated with using that product. The system designer is not worried about whether or not the user *wants* to use the product or whether there is a complex interaction of various individuals of varying motivation. By the time the system designer is involved, the existence of potential motivated users is already verified, or the interaction with the system is so trivial, that motivation of the user(s) is not an issue. In fact, users of new products are often so motivated to use them that they do not even bother initially reading the training material.

Any techie who gets a new smartphone (or any cost engineer who gets a new cost analysis program) has probably experienced the joy of opening the box and "trying it out" without bothering to read the manual. In other words, system designers are typically involved in the development of products that people want. Their customers are ready to spend money on those products and are highly motivated to use them.

For a Non-intensive Human Interactive System, as long as the product is usable (given the appropriate training materials to mitigate SHFs and HHFs), the system designer's job is done. If a student incorrectly uses a calculator and fails a math test, the systems designer who designed the calculator is not at fault, as it is the student's responsibility to use the calculator correctly. Further, the systems designer never even considers the possibility that the student might not like math, and may not be motivated to use the calculator correctly. The systems designer has the luxury of producing a Tool (and some training material) for a motivated user. The Tool designer is never asked to determine how to motivate consumers to use the Tool, or how the Tool might be optimally integrated into the user's workflow.

5. Intensive Human Interactive Systems

Intensive Human Interactive Systems will certainly have SHF modes and/or HHF modes that will need to be mitigated via training of employees. However, in many cases, Intensive Human Interactive Systems will also have CHF modes: the employees or individuals may not *want* to perform using the new capability that is being provided or the successful introduction of the new capability may depend on the successful interaction of many individuals, any of whom may or may not be motivated leading to a CHF mode.

Imagine an example where an employee is told to use a new Tool or Process, e.g. a cost model. The employee is already familiar with the old Tool. The employee is already motivated to do the work, or analysis. The requirement to use the new Tool and abandon the old Tool may make sense at a corporate or business level. But to the individual user, there is no motivation to change. In fact, it is quite common that the employee will fight to maintain the old Tool.

There is a fundamental difference between someone who is motivated to adopt a new capability, and a person who has a new capability thrust upon him as a requirement of employment. The prior person already understands the value and need for the product, and is willing to personally invest in the product. The latter person likely does not understand why the new capability is important, already has a way to do the job, and has not invested anything into the change. In this case, the motivated user is missing, and without the motivated user, new system adoption and proper usage cannot be expected.

In this case, the system designer needs to be concerned not only about designing a system that is usable (avoids SHFs and HHFs), but also with designing a system that the employees want to (and can) use, and avoiding CHF modes. Tools alone are insufficient in overcoming CHF modes. User training on the importance of the system (Culture) and documentation (Process) to insure that Tools are used correctly and consistently as well as oversight (Governance) is needed to insure that the system is not being gamed by any individual who lacks motivation.

6. The GCPT Framework for Intensive Human Interactive Systems

The GCPT (Governance, Culture, Processes, and Tools) Framework describes the four elements required for any Human Interactive System to achieve its desired capability and attempts to describe the Process for the creation of these elements in a way that is already familiar to the systems designer. However, the power of the GCPT Framework comes into fruition when the required system is an Intensive Human Interactive System where considerations such as user motivation and user confusion need to be taken into account.

It is important to note that in a Non-intensive Human Interactive System, a visual for the GCPT Framework could be employed as "gcpT" where the Tool is the most important part of the Framework and ease of use of the Tool is key to the success of implementing a capability. However, for Intensive Human Interactive Systems, all parts of the GCPT Framework are equally important. An argument could be made even in Intensive Human Interactive System capabilities, that Tools are less important than Governance, Culture and Processes.

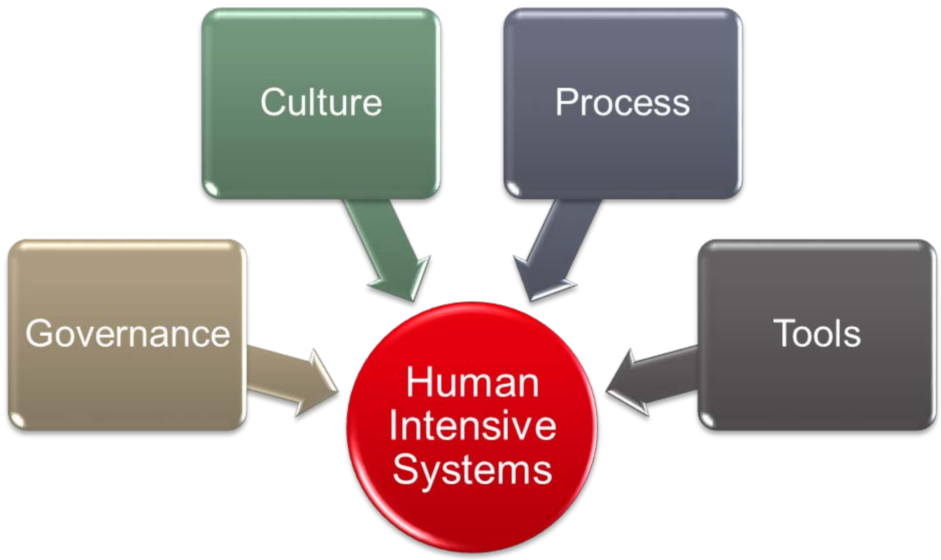

Figure 1. Human Intensive Block Diagram

7. Governance

The first element, Governance, describes the model/method one will use to measure that the system is delivering the expected results during deployment. This is reflected in the top-level system requirements, or capability description. During execution of an internal project delivering an Intensive Human Interactive capability, it is critical that desired business-level success metrics are defined, and that they are measured in deployment to ensure the system is achieving the desired business outcomes. For example, while a web-based tool may be part of the system being developed, the tool itself is not the desired outcome; the desired outcome is a business improvement such as increased efficiency or quality. While the Governance model may seem like a trivial concept, it is critical to system success, as it is the way we measure system success. If there is no measurement, how can it be known if the system is working?

In terms of integrating the use of a Cost Tool into an Intensive Human Interactive System, there must be a Governance model to determine that the Tool is working effectively. It is useful at this point to begin to move away from the language of "Cost Tool" and begin to think in terms of "cost system". The Tool exists, but it is part of a bigger system. The Tool is used to calculate cost. During execution and at the completion, the cost is collected. That cost should be fed back into the Tool to iterate and refine the Tool. In addition, a comparison should be made between the Tool estimate and the final collected cost. Metrics should be put in place to evaluate that comparison and quantify the quality of the estimate. In other words, a closed loop system. Over time the results provided by the Tool should improve. That improvement also should be quantifiable.

8. Culture

The second element, Culture, reflects the need to have people trained to exercise the other system elements in such a way that the system can achieve success. It also reflects, in the case of internal business systems, the cultural will of the employees to make necessary changes in the way they work to ensure system success. This element is concerned with how to make cultural change happen, and how to engage internal users to want to use the new system properly, as well as delivery of appropriate training to users.

Regardless of the maturity of the current costing system, some system is already in place. It may be an Engineering estimate, spread sheet, rule-of-thumb, tribal knowledge, an elaborate purchased product, or any combination. Users who are responsible for generating a cost estimate already have their chosen preference, or Tool, and are typically comfortable with their preference. In the case where an alternative way has been identified to calculate cost, it is very important to impress upon the user that there is a new way to do their old job.

The new Tool is "better", more defensible, more reliable, more repeatable, more portable (in the case of retirement or reassignment), but most importantly, the alternative Tool is unfamiliar and new. The Culture must be modified to transition users away from the familiar to the new. One very nice way to achieve this goal is to involve the user early on and to get user's buy-in every step along the way for either development or purchase of the new Tool. Developing a tool in a vacuum will almost guarantee the tool will be rejected by the users. If the Culture is modified correctly, by the time the new tool is ready for use, the users are excited to start.

9. Process

The third element, Process, simply reflects the need for well-defined processes that the overall system executes to repeatedly achieve success. “Process” potentially includes system operational flows, stepwise executable instructions, interaction diagrams, etc. These well-defined processes demonstrate that one can actually achieve the desired capability (sans automation).

For example, in sextant navigation, the navigator must be highly trained in the use of the sextant, the “navigation” stars, and how to make measurements. Additionally, the twenty-two step mathematical process to move from navigational readings to position must be precisely carried out by the navigator. In recent history, when the U.S. Navy still required officers to demonstrate facility with the sextant, a computer was used to automate the twenty-two step mathematical Process. However, without the existence of the Process which is executable on paper with pencil, there is nothing to automate. The Process had to be well-defined, and demonstrated to work manually before it could be coded into a computer.

In the application to a costing system, there are steps to be performed, a Process. With an immature system, the cost might be determined as simply as Engineering estimate. A mature system should have a clearly defined and documented Processes. In the case of a mature costing system, there could be a published, controlled list of qualified bidders, operational flow diagrams, training videos, etc. There could be a documented, published set of instructions. Instructions may include manuals, videos, certifications, and a schedule for certification refresh. The output of the costing Process should be maintained in a controlled location. In general, a cost system Process answers who, where, and how.

10. Tools

Tools are those devices and machines which are built to automate processes. Again, the critical thought is that once a Process is well-defined and demonstrated to work, one can then begin to consider Tools to help automate the process to achieve higher efficiency.

There are a wide variety of Cost Tools. The Cost Tool might be home grown or purchased or a combination. With an immature costing system, the Tool might be as simple as an Engineer’s opinion or tribal knowledge. A mature costing system would include elements called out in the Process. The Tool takes what is known (lines of code, period of performance, key size metrics, scaling factors, mission parameters, etc.) and translates that information into cost (dollars or hours).

The above discussion is not “rocket science”. Anyone who has successfully implemented a major change initiative in a large organization will likely recognize the GCPT framework as a cousin of the “People, Processes, and Tools” and other change management frameworks. However, the full GCPT framework is specifically designed to aid system designers who are used to developing Tools, to embrace all four elements of their system design projects. The framework explicitly requires the development of artifacts to demonstrate that all four GCPT elements are in place, and that SHF modes, HHF modes, and CHF modes have all been addressed in the system development.

11. GCPT Maturity Index

So far, this paper has discussed the GCPT Framework as a binary model: either the Governance, Culture, Processes and Tools exist or they do not. However, this is overly simplistic is real-world systems and capabilities. In real-world systems, each component of the GCPT Framework already exists to some extent, it is just that maturity of any particular component may be less than other components. Typically, in Intensive Human Interactive Systems, much more capital in attention and investment has been placed in the “Tool” part of the Framework such that the Tool is far more advanced in maturity than the other elements of the Framework. However, success in the Intensive Human Interactive System development lies in gaining maturity in all aspects of the GCPT Framework.

There are numerous maturity indexes that could be implemented into the Intensive Human Interactive System. The Capability Maturity Model Integration (CMMI) definitions of maturity are described as follows:

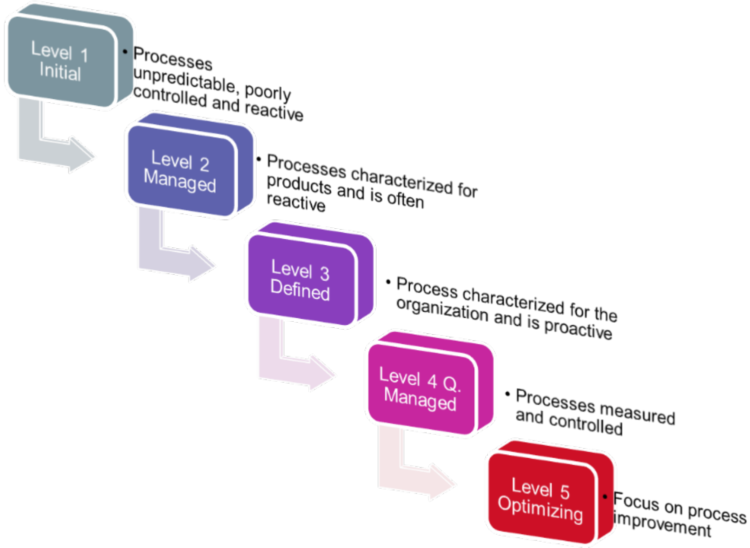

Figure 2. Capability Maturity Model Integration Block Diagram

In addition to CMMI, another common Maturity Index would be the Technology Readiness Level (TRL) Index. Appendix B goes into great detail of a TRL based GCPT Maturity Index that has worked successfully.

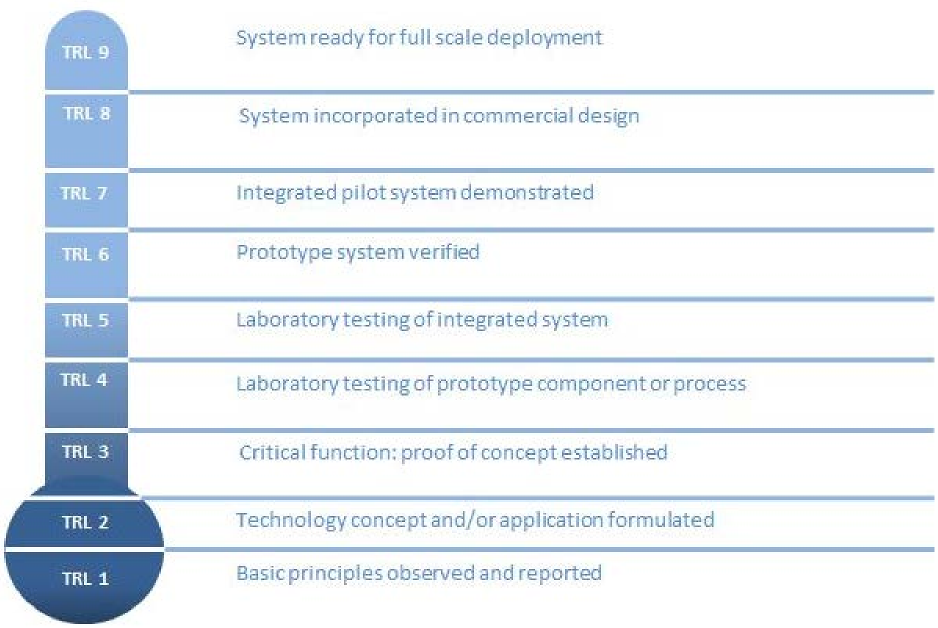

Figure 3. Test Readiness Level (TRL) Block Diagram

12. A Generalized Cost Estimation System Flowchart

Moving to the application of the GCPT Framework to Cost Estimation, the following is a flowchart of an example of a typical Costing System of an Aerospace/DoD system provider.

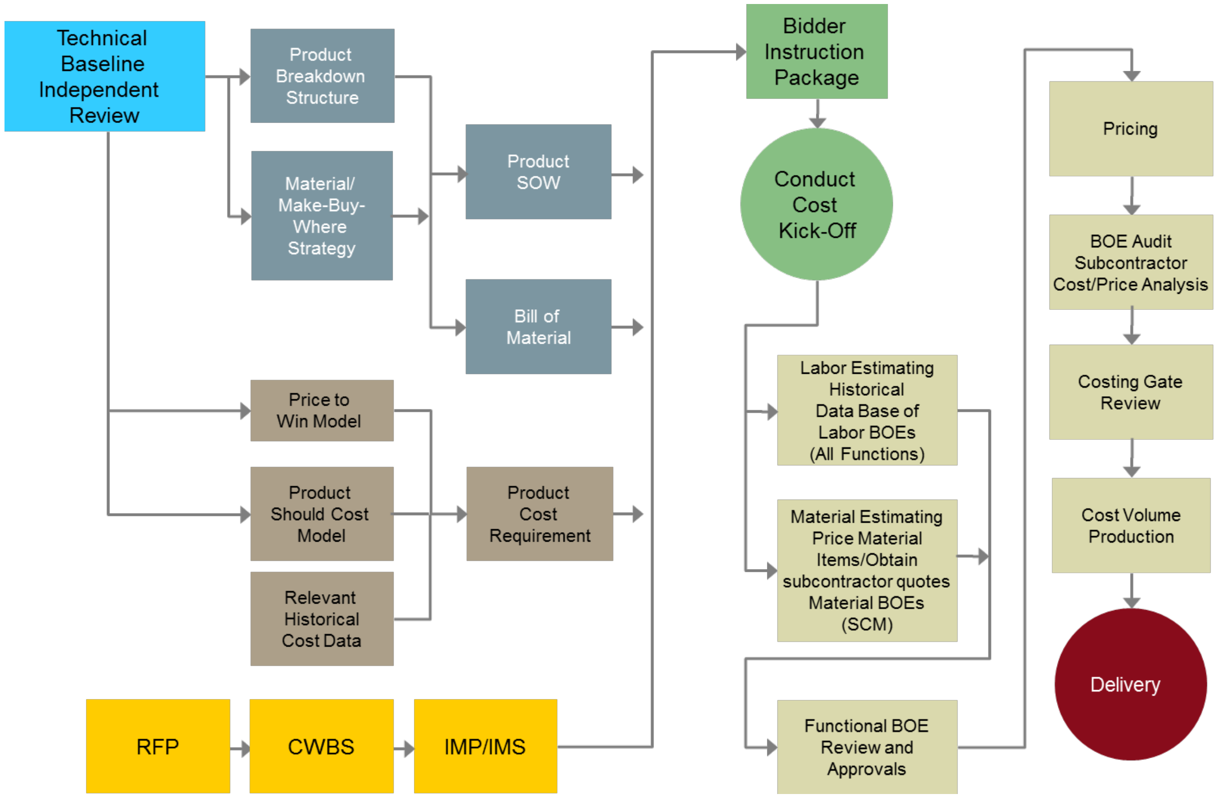

Figure 4. Cost Estimation System Flowchart

Without going in depth through the details of each and every block of the flowchart, what is clear is that many steps of this cost estimation flowchart are human intensive where final decisions are based on the complex activities of individuals. Many executives and institutions abstract the activities and make the often faulty assumption that because there are processes and tools in place, the results of the activities are reliable.

Flowchart Element	Intensive Human Interactive Activity	
Technical Baseline Independent Review	Significant	Multiple people, multiple perspectives, multiple opinions.
Product Breakdown Structure	Significant	Although a standard may exist, to be applicable for the current Program, a manual process of tailoring must occur.
Material/Make-Buy-Where Strategy	Significant	Manual Process to collect the data and create decision making tree. Includes review of results and decisions
Priced to win model	Significant	Multiple people, multiple perspectives, multiple opinions.
Product Should Cost Model	Significant	Multiple people, multiple perspectives, multiple opinions.
Relevant Historical Cost Data	Significant	Each Program may have its own PBS. Therefore the cost collection vs. cost archival may be different. Untangling the data is typically significant.
RFP	Not significant	Requires limited human activity. Primarily an automated computer run.
CWBS		
IMP/IMS	Significant	Although a standard may exist, to be applicable for the current Program, a manual process of tailoring must occur.
Product SOW	Significant	
Bill Of Materials	Significant	A new Program may be similar to a

		historical Program. But any differences requires significant human interaction for identification
Product Cost Requirement	Significant	
Bidder Instruction Packages	Significant	
Conduct Cost Kick-Off	Significant	Multiple people, multiple perspectives, multiple opinions.
Labor Estimating	Significant	Multiple people, multiple perspectives, multiple opinions.
Material Estimating	Not significant	Requires limited human activity. Primarily an automated computer run.
Functional BOE Review and Approvals	Significant	Multiple people, multiple perspectives, multiple opinions.
Pricing	Not significant	Requires limited human activity. Primarily an automated computer run.
BOE Audit	Significant	Multiple people, multiple perspectives, multiple opinions.
Costing Gate Review	Significant	Multiple people, multiple perspectives, multiple opinions.
Delivery	N/A	

Looking at all of the very complex Intensive Human Interactive activities, it is probably a wonder that any one proposal ever gets completed by any Aerospace company. Generally, as most people know who work on these activities, proposals are spearheaded by highly motivated individuals who compartmentalize short comings in any one proposal while understanding that often success is defined as completing the bid “at the right number” as opposed to completing the “right” bid at the “defensible number”.

Further, not only are many of the blocks within the Cost Estimation System Flowchart part of an Intensive Human Interactive System, but each block in the Flowchart depends on the input from an Intensive Human Interactive Sub-system. For example, the Labor Estimating depends on the input from a set of historical “similar to” actuals of a Final Cost and Size Collection Sub-system. The Final Cost and Size Collection Sub-system is also an Intensive Human Interactive System where many of the contributors are not motivated to participate to the extent needed for the successful collection of data.

Ultimately, the Governance, Culture, Process and Tools (GCPT) need to be evaluated for maturity for each of the Intensive Human Interactive activities within the Cost Estimation Flowchart. Some of the high level questions that need to be answered such as: do the existing Tools support the Process? Is the Process documented and has the process been reduced to some type of check sheet? Is there Training (Culture) that not only addresses how to complete the check list but also addresses the importance of why following the Process is so important? Are there a “set of eyes” that insure (Governance) that the System is working and that the system is not “being gamed”?

13. Key Sub-System Components Supporting the Cost Estimation System Flowchart

As Figure 5 illustrates, in addition to the Cost Estimation Flow Diagram, there are a significant number of Costing Sub-systems necessary that will feed the individual blocks of the Cost Estimation Flow Diagram. For example, there is a “Cost Modeling and Analysis” sub-system block that supports the “Labor Estimating and Basis of Estimate” block in the Cost Estimation Flowchart when Labor Estimation methods include parametric analysis. As Figure 5 shows there are a number of support Costing Sub-systems and each one is an Intensive Human Interactive Sub-system.

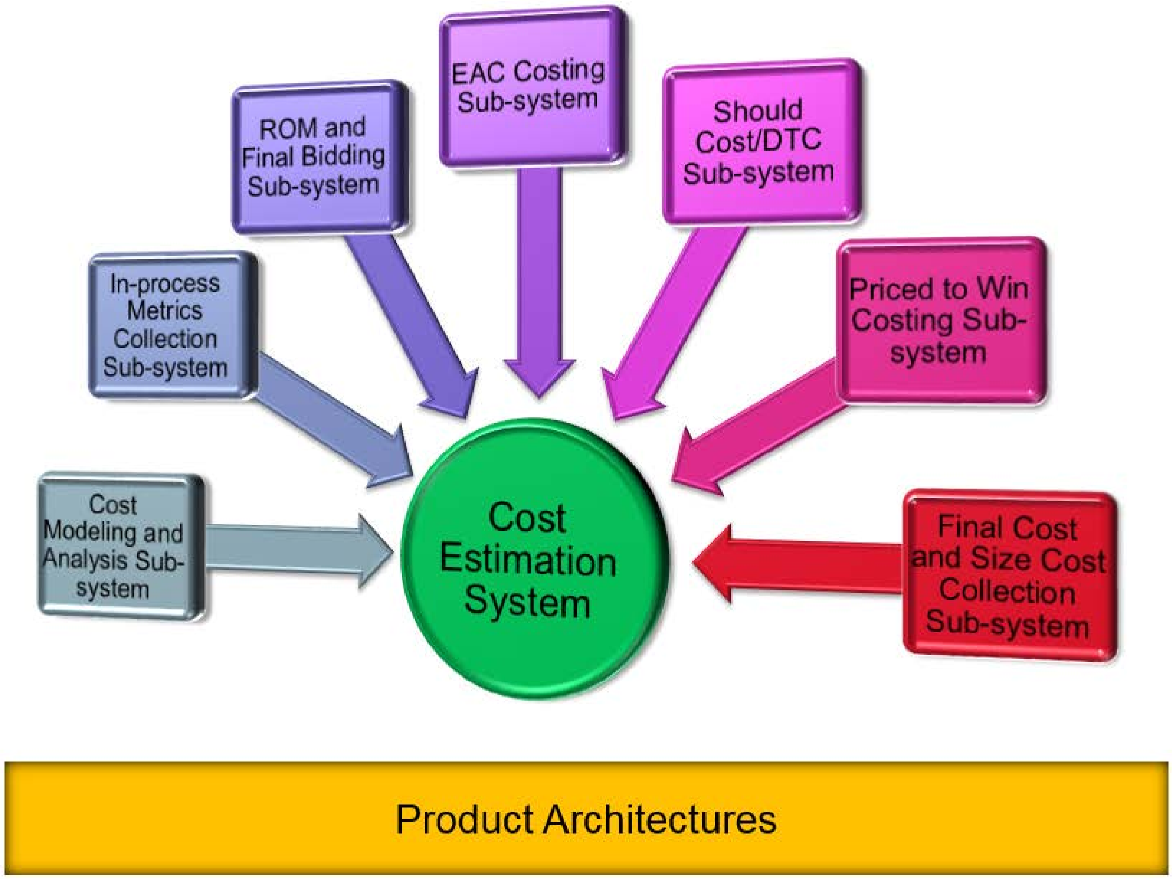

Figure 5. Cost Estimation Sub-System Diagram

For most Aerospace Companies, archiving a set of reference Product Architectures is key to the success of any Costing System. No matter how much an Aerospace Company spends on Tools and Training, without a significant database of Reference Architectures, the Costing System falls apart. What is a Reference Architecture?

A Reference Architecture is a foundational product which provides the basis of future product developments that are similar. For Aerospace companies, the Reference Architecture is the primary "similar to" product used in the Basis of Estimate for a bid. An example of a Reference Architecture is the Radar of a fighter aircraft. If the Aerospace Company that developed the Radar for a fighter aircraft were to bid another Radar for a future fighter aircraft, there is a high probability that the Aerospace Company would use actual costs and Product Breakdown Structure of the previous Reference Architecture as a "similar to".

The "Cost Modeling and Analysis Sub-system" (Figure 5) is an Intensive Human Interactive System. In most cases, the analysts and modelers are highly motivated, however the experts and responsible technical individuals are not highly motivated to develop an advanced Cost Modeling system. In fact, many experts and responsible individuals see an advanced Cost Modeling system as a threat to their job security. This job security threat provides many opportunities for CFM's.

The In-process Metrics Collection System is an Intensive Human Interactive System. The next section of this paper goes into great detail of the GCPT Framework for this System. Ultimately, the greatest motivation hurdle that In-process Metrics Collection faces is that many of the individuals tasked with collecting the data believe that the data is a monumental waste of time. These individuals often believe that the time spent on collecting the data should be spent improving the execution of the projects on which they are collecting the data.

The ROM and Final Bidding System is an Intensive Human Interactive System, especially for large bids. Aerospace Companies are often called on to bid multi-billion dollar activities and the sheer number of experts required makes it an extremely complex activity. Adding to the complexity is the value that each expert places on risk. Many experts will only bid a project with a cost associated with 100% guarantee of success. Other experts will bid more aggressive and some will bid so aggressive that the basis for the bid is completely unknown.

Final Cost and Size Cost Collection System is an Intensive Human Interactive System. This collection occurs after the project is complete and programs rarely have the money left over to complete this task and individuals want to move on to their next challenge. The lack of importance of the activity placed by the program and the lack of guaranteed future work are de-motivating factors to any individual tasked with collecting the Final Costs and Size.

14. An Example of GPCT for In-Process Metrics Collection

The successful application of the GCPT Framework occurred in the design of an In-Process Metrics Collection System put into place as a result of senior leadership setting a goal of improving engineering productivity by 10% each year for 5 consecutive years (compounded 61%) productivity improvement across varied engineering efforts.

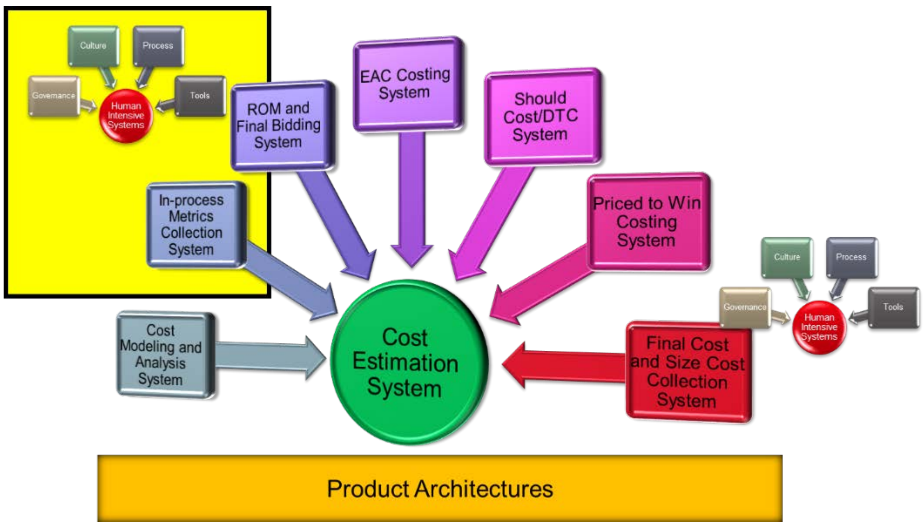

Figure 6. GCPT Framework for In-Process Metrics Diagram

The GCPT model was deployed to drive system success. Most importantly, however, the GCPT model was used to defer Tool development entirely, despite demand from the user population to immediately develop a "productivity Tool." It was also used to develop and execute a plan to create capability around measuring and improving productivity.

The Governance model was developed to ensure that the system components were created with high likelihood of system success upon deployment, as well as to ensure the system was performing as expected post-deployment. The first Governance artifacts developed included a glossary (to create common language and understanding), a process for mathematically calculating productivity in two acceptable ways, and twelve requirements that must be met in order to enable the capability to calculate productivity. Productivity metrics were defined which enabled disparate productivity factors to be combined into an overall engineering efficiency index.

Next, all of this was communicated to discipline-level teams. All team members were coached until they thoroughly understood the objectives of the effort. A rubric was created to measure each team's capability against the twelve requirements that needed to be met. Monthly detailed meetings occurred between the principle investigator and each team lead to agree on grades for each of the twelve requirements. Progress against these twelve requirements was then presented to the executive leader each month; the executive leader continually reinforced the need to reach the desired objectives, and helped to drive each team to a successful implementation.

While top level processes were developed to compute the engineering efficiency index, each team was left to create sub-processes that were meaningful and executable by them. The teams repeatedly requested the development of an enterprise level tool to hold all compiled data, however no enterprise tool was developed. Because each team had different needs, they each developed different Processes, Governance, and Cultural models for collecting data. Because there was no central overarching Process imposed on each team, there could be no central tool created at the enterprise level; this would have violated the fundamental rule that Tools are only created to make processes that already work more efficient. Instead, each team developed their own proto-Tools, aligned with their Processes, Cultural, and Governance models.

Each team eventually completed the necessary steps to enable the calculation of productivity, and the engineering efficiency index began being reported in January 2010. To date, almost five years later, the engineering efficiency index shows an increase in productivity of 65% (figure 1). This index indicates exemplary focus and achievement in reducing the costs associated with new engineering designs.

Productivity improvement results varied across the teams (table 2), with some teams demonstrating marked improvement in productivity, while others teams showed flat or declining results in any given year. Ultimately, each team was successful in significantly improving their productivity; the difference between teams being how soon each team was actually able to embed productivity improvements into their engineering Culture.

The progress each team made was linked to several key factors. If the team decided to embark upon centralization of the task, either by putting data collection into a single person's hands, or by immediate development of an automation proto-Tool, the team typically delayed the institutionalization of productivity improvement into their Culture. Typically in these cases, managers or other users of the centrally created data complained of data inaccuracies, or that they did not receive the data needed to calculate productivity for their particular case. These leaders also typically failed to recognize that they needed two fundamental things: productivity improvement, and the ability to measure it. Instead, they tended to focus on the difficulty in acquiring good data, and didn't invest energy into actual productivity improvements.

Those teams which showed significant improvement typically put the task directly into the hands of each manager, and emphasized the need to make improvements and measure them. Each manager needed to independently pull his own cost and progress data. If that proved difficult, each manager was (self) incentivized to make the job easier by intelligently structuring job charge numbers and by developing consistent methods of measuring job progress. These managers were forced to engage all necessary participants in this effort, and to show them why it was important, get their ideas on how best to implement a solution, and get their feedback and buy-in. Once this was achieved, the chance of CHFs occurring in this Intensive Human Interactive System was dramatically reduced.

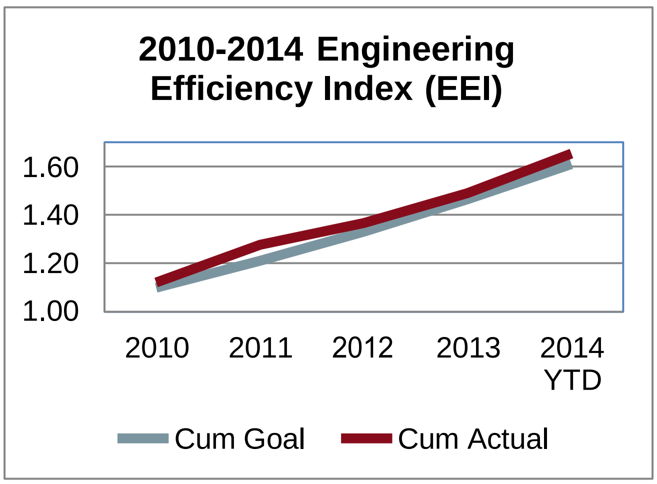

Figure 7. EEI over five year period

While this is the largest (and most important) success of the GCPT framework to date at this company, the framework has been routinely used across the engineering organization for every improvement initiative carried out over the past five years. These have included efforts as small as a few hundred hours, to efforts as large as several million dollars (over three years). Of course, not every project has demonstrated the same consistency of results; but in every case, the GCPT framework has been a useful tool for ensuring that all four elements of internal systems are considered.

15. An Example of GPCT for a Final Cost and Size Collection System

Another example where the GCPT Framework has proved very successful is in the activity of collecting Final Costs and Size of the Projects that have been completed.

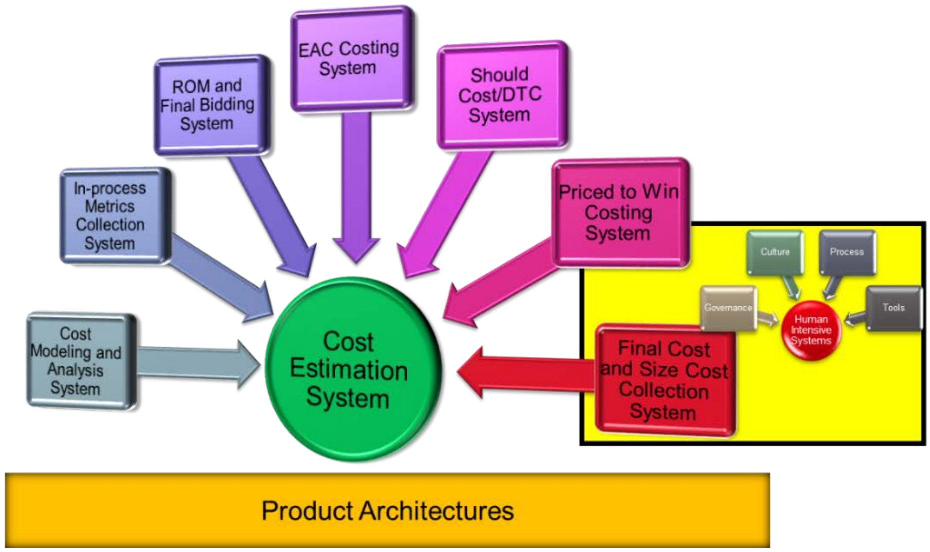

Figure 8. GCPT Framework for Final Cost Collection Diagram

As many in the Aerospace industry know, collecting a final cost and size criteria for programs is extremely difficult. Collecting final cost for systems is usually the easy part of establishing a final close-out. There is normally a very detailed accounting that preserves program costs in order to bill customers. Understanding the final size of a job and how much reuse was involved is almost always a challenge.

All of the authors in this paper have been involved in some degree is addressing the difficulty in convincing the workforce to be mindful of collecting the final size and costs of any and every job that has been performed. As in most Aerospace companies, the very survival of the company depends on the ability to bid actuals of "similar to" programs and products. It has been these author's experience that no matter how loud the table pounding gets, the job of final cost and size collection often remains undone.

Why is this failure to collect final cost and size of a program (project) so common? One of the reasons is because no one really wants, or is motivated, to go back and figure out how many drawings were delivered or how many terminations were delivered on a project. After all, the job is already complete and most people would rather move on to the next challenge.

Also, there is a HHF mode in that understanding what makes any one particular project big or hard or more costly is very difficult to define. Even if one had the motivation to collect the final size and cost of a project, being able to quantify exactly what makes any one particular project big is beyond many individuals skillset. For example, how would one determine what makes a particular box of electronics that processes Radar signals more expensive than another box that processes Radar signals? Maybe one could look at how many electronics modules are included in the electronics box. Alternatively, maybe one would have to collect the speed and complexity of the data paths. There could be many variables that describe the "bigness" of the Radar processing electronics box and knowing the right variables to collect would normally require the analysis of an expert.

So how did our company achieve success? Our first step was to teach the work force what kind of data was needed. Teaching the workforce is part of the "Culture" of the GCPT Framework. This required statistical analysis of every product that was produced by the company and Key Sizing metrics established for each product that was produced. These Key Sizing Metrics were then socialized with the experts and consensus was eventually achieved that the Key Sizing Metrics were indeed causal to the cost of the associated product development.

The next step was to establish in the development Process that no job was "done-done" until the cost and size collection was performed. This had to be carefully negotiated with program areas because there is always a cost element to cost and size collection and programs do not see the direct benefit. Ultimately, the programs are contractually required to execute the Processes that are tailored and as long as the Process step of collecting size and costs is not tailored (it rarely is) then the negotiations for who will be paying for the final cost and size collection run fairly smoothly.

The third step was to build Tools to make the size and cost collection as painless and as effortless as possible. However, the Tools themselves required training (Culture) and documentation (Process) and oversight (Governance) in order to insure that they were being used correctly. Because the organization was over 1000 Engineers, it was imperative that the Tools be collaborative. Microsoft Sharepoint was chosen as foundation for the collaborative Tools used to collect the data.

Fourthly, training (Culture) was provided for all of the personnel that were required to collect the size and costs. However, all of these steps would have been wasted on failure if not for the final Governance step. The watershed event that made the entire system work and successful was a simple cost collection “stop light” system (Governance) that was presented each month to the Organization Director during the Management Review (See Appendix C: Example of Completed Projects Governance). Each Department Manager reported each month to the Organization Director the color status (Red, Yellow and Green) of all completed products in terms of cost and size collection. The color status did not turn Green until a Cost Collection Form had been filled out and approved by Finance that the final cost and size match the accompanying narrative.

To further illustrate the success of the system, over the last 4 years our organization has collected the cost and size (in Effective Lines of Code and other parameters) of over 100 Field Programmable Gate Arrays (FPGAs). These are the foundation Digital Design components and form the basis for our extensive parametric analysis system.

16. SUMMARY

In summary, this paper has described that with Intensive Human Interaction Systems simply providing a better Tool or better instructions to an existing Tool is not sufficient to overcome most failure modes. Adding the organizational construct of Governance, Culture, Process and Tools (the GCPT framework) provides the necessary elements to insure that a new or upgraded capability that involves an Intensive Human Interaction System, such as an upgraded costing system capability, can be successfully implemented and absorbed into the Culture of an organization.

It is important to note that it is almost universally the experience of the authors that whenever a new or upgraded capability is rolled out for an organization that the focus of the roll out is on Tools. Most of the investment is spent on Tools and yet the success or failure of the implementation of the Tool within the organization often has less to do with the Tool and more to do with the Governance or Culture (training, socialization etc) or Process surrounding the use of the Tool.

While this paper has focused on Costing Systems, the application of the GCPT Framework is nearly universal as it relates to nearly any Intensive Human Interactive System.

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BIOGRAPHY

Dr. Robert Wright *received B.S., M.S., and Ph.D. degrees in Physics from the University of California at Los Angeles in 1988, 1990, and 1994. He has been with Raytheon Space and Airborne Systems in El Segundo, California since 2003. His current role there is as the Director of Engineering Operations, where he oversees the internal operation of the engineering organization, including development of strategy, execution of improvement initiatives, and oversight of the operating budgets. He has previously managed software and hardware development groups, overseen IRAD portfolios, and began his career as a semiconductor research scientist at The Aerospace Corporation*

Mr. David Scott *received his B.S. and M.S. degrees in Industrial Engineering from the University of Arkansas at Fayetteville in 2003 and 2005. David has been with Raytheon Space and Airborne Systems in Dallas and McKinney, Texas since 2005. His current role is a Senior Engineering Excellence Project Lead. His efforts focus on creating lasting change for improvement initiatives to achieve the Engineering organization strategy. He has previously served as an Integrated Product Team Leader for a suite of Multi-Spectral Targeting Systems, served as a Six Sigma Expert, managed the McKinney Texas Logistics Operations organization, and started with Raytheon in Logistics Distribution Management.*

Mr. David Bloom *graduated from the University of California at Davis in 1983, Mr. Bloom has worked for the Naval Weapons Center, Lockheed Martin, Lawrence Livermore National Labs and since 2008, for Raytheon Space and Airborne Systems (SAS). Mr. Bloom is currently the Cost Estimation Subject Matter Expert (SME) for the Hardware Engineering Center (HWEC) of SAS. He has developed parametric models for all SAS Electronics Products and helped transform the culture of the organization in the use of parametric bidding methodologies. Mr. Bloom has patents and software copyrights along with a number of publications ranging from electromagnetic boundary value problems to cost estimation. In 2006, he won the International R&D 100 Award for innovating a cost effective Gigapixel Camera for persistent surveillance applications.*

Mr. Danny Polidi *received a B.S. and M.S. degree in Electrical Engineering from the California Polytechnic State University, San Luis Obispo, CA in 1990 and 1991. Upon graduation, started working at Space Systems/Loral on high frequency, microwave designs for space applications. Later, at Radian Technology, he became the Product Manager of the Digitally Tuned Oscillator Product Line where he was responsible for designing new circuits, writing code, and production. At NANOmetrics, Danny managed all Electronic Engineering activities. From 2004 – present he has worked at Raytheon as a Section Manger, Team Lead, Cost Account Manager and has been certified as a Program Manager.*

Ms. Wanda Grant *graduated from Pratt Institute with a B.S. Degree in Electrical Engineering in 1979. In 1982, Wanda received a M.S. in Electrical Engineering. Wanda is currently the Center Operations Manager and Chief Process Engineer for Raytheon Space and Airborne Systems (SAS) Hardware Engineering Center (HWEC).*

Appendix A: GCPT Thought-Driving Questions

G Governance	C Culture
System Conops - Who performs tasks / management during the project? During Deployment? During Sustainment?	How do you plan to assess the effectiveness of training provided to the user community? How do you know when your efforts are successful?
After the project effort is concluded, what ensures that the change/results continue?	What reward/recognition models to drive the right behavior in people do you plan to employ?
How pervasive is your management system / metrics ? (% of business affected, % of Full Time Equivalent heads impacted)	Do you have a plan for capturing and transferring knowledge? How do you know that it is happening?
What is the plan to integrate performance metrics and monitoring into the organization as a part of the business or organization's standard metrics?	Development of a lessons learned capture method? Incorporation method? (design team, stakeholders, users)
Regulation of the change - metrics and management in sustainment. How do you know that you are achieving the intended benefit? Who is responsible for further changes to increase intended benefit?	Do you know what other initiatives or barriers might affect the teams effectiveness? (structural, technology, policies)
Can you clearly articulate the deliverables, results, and artifacts that will show that goals have been met? (evidence for: performance, safety, cost, quality, maintainability, operability, reliability)	Can you clearly articulate the cultural change that you are trying to achieve?
How do you know if your project is on track to deliver the intended results? Do you have leading indicators for success?	How do you plan to help personnel affected by the change understand why the change is needed? And what is expected of them?
Does the desired change produce results at a pilot level? Is the pilot representative of a larger deployment environment? If not what changes are needed?	Changes in an organization shift resources away from some area of focus and towards others. How are resources shifting as a result of this effort?
What is the plan to monitor and document results, including financial impacts?	How do you intend on getting personnel affected to <u>want</u> to embrace the change?
Have you clearly documented the objectives of making the improvement?	Who is fighting you, who is supporting you, and what you need to do to build support and devise strategies for change?
What do you expect to achieve when your project ends THIS YEAR? What does your project enable for future years?	What level of buy-in do you have from stakeholders, decision makers, key user community personnel, and affected personnel? (people will support that which they help create)
What leadership engagement is needed for success? Now? In the Future?	Has a proto-type proven successful? Has buy-in from stakeholders been achieved?
What allocation of resources is needed to ensure success? (leadership, personnel, etc..)	Have you developed a communications plan to stakeholders, leaders, and impacted / user community? (during and after efforts)
Can you articulate the value of the project from the perspective of your function, the company's customers, or the company's shareholders?	Can you articulate the environment in which the work is to be conducted with respect to acceptance or resistance to change?
How do you plan to create engagement and momentum for your project with leaders, stakeholders, execution team, and affected community?	what are you doing to ensure that the customer / users needs/objectives are understood, agreed upon, and incorporated in the project or effort?
Has project been vetted through the organization for a collaborative business focused solution?	Can you clearly articulate the environment in which the system will be deployed/used or the change will take place?
What networks of contacts and relationships at all levels within and outside the company are needed to ensure success?	What are the human failure modes associated with your system?
Describe how you plan to influence stakeholders, leadership, and decision makers, and gain their confidence?	
Are you able to articulate your project plan? (schedule, milestones, stakeholders, team, resources, customers, cost, sponsors, measures of success)	
Can you clearly articulate the plan to stay on schedule and on budget throughout all lifecycles of the effort? (risk & opportunity assessment, resource loads, schedule margin, trade offs)	

P Process	T Tools
What is the actual process flow? How is it documented? How do you intend on changing it?	Are tool specific requirements / changes identified?
What is your plan to communicate to people WHAT to do, and HOW to do it?	Can a preliminary tool or prototype be created / used to determine viability of solution?
Are the process requirements defined? Are the process changes identified?	What are the results of the preliminary tool pilot? Does it meet expectations of the design team? Stakeholders intent?
Has a process flow of the key steps been created? What is different from current state?	Is the finalized tool design completed?
Based on a trial run (pilot) of the new process were there any new discoveries? Did everything work as designed or are changes needed?	Is the final tool design built and tested by a development team?
What actions should be taken to ensure that the new process is utilized? Is compliance management designed in?	What is needed to put the tool under configuration control?
How do you plan to ensure that project implementation gets deployed across the business unit / enterprise?	What is needed to get adoption by the global user community?
Does your plan include detailed command media / documentation in addition to the "generic" framework of how work is to be done?	Is the process clearly documented and communicated that this tool is intended to improve efficiency?
What processes are you responsible for? Who are the process owners? Are process owners bought into the proposed change?	What materials, equipment, information, hardware, software, policies, and procedures are needed to be successful?
What are the strengths and weaknesses of the current processes? How does the change affect these?	Does your project depend on capital expenses or connect with an existing capital plan? Future capital plan?
What processes have the highest priority for improvement?	What is the demand for this product? (% of business affected, % of Full Time Equivalents heads impacted)
What are the critical factors that determine process performance?	Is your improvement project dependent on another project or tool completing?
How do we avoid sub-optimization?	What actions are being taken to reduce or eliminate the opportunities for errors or defects with the solution once it is deployed?
What countermeasures will be put in place to keep us from going back?	Has specialty engineering been considered in the solution? (reliability, maintainability, survivability, safety, Ergo/Human factors, supportability, security)
Have you determined how much of the project effort has to be done face-to-face vs virtually?	What specifically is needed? How do we do it? There may be more than a single solution.
Are the project tasks to be completed continuously or will there be gaps in activity?	what interfaces are required, both internally and externally, that will be required interactions with the proposed solution to be successful?
Does the process solution account for variation? (personnel, equipment, hardware, software)	
What are the company, regulatory, or environmental constraints?	
Have you identified all areas where human interactions, decisions, or inputs are critical?	
How will you make your system as error proof as possible to human errors?	

Appendix B: The GCPT Capability Matrix

Being a first-hand witness to many unsuccessful attempts to develop tools (rather than systems), Dr. Wright developed the GCPT framework along with the GCPT matrix (table 1), as an aid in communicating desired outcomes, planning change efforts, and tracking progress against plans. As a requirement of every approved improvement initiative, the principle investigator is required to complete the GCPT matrix to demonstrate completeness in thought around the four required elements of improvement.

The GCPT matrix provides clarity of thought in two dimensions. First, the matrix provides a detailed understanding of each of the four elements, and how they are related. Second, the matrix provides a thought framework for the time evolution of the maturity of each of the four elements.

The GCPT matrix incorporates ideas drawn from both the Department of Defense (DoD) funding framework and from the NASA Technology Readiness Level (TRL) concept for technology maturation. The matrix uses commonly understood terminology as a basis for describing a phased approach to improvement efforts. The first two columns outline "colors of money" used by the Department of Defense to fund efforts from "basic research" through to "operational systems maintenance;" there are 6 categories of interest listed here. These provide broad, general categories to describe the way money is spent in the DoD to mature products and technology. The third and fourth columns outline the NASA TRLs. These break down the categories listed in the first two columns into 9 levels (the author has added a 10th level to map to deployed systems). These TRLs and descriptors demonstrate the formal process NASA uses to mature technologies from "basic principles" to "proven systems." The DoD categories, the NASA TRLs, and the mapping between DoD categories and NASATRLs is taken directly from information available online. [7]

The incorporation of the DoD and NASA TRL models into the GCPT framework is an important enabler in helping engineers to think critically about maturation of the GCPT elements within a context that is familiar to them. Many engineers are already familiar with thinking about technology maturation; the GCPT framework simply helps engineers to think about governance, culture, and processes in the same way they already think about tools and technologies.

Appendix B Table 1: The GCPT Matrix

Research Type	Research Description	TRL	TRL Description	Description when TRL reached	Focus of effort to reach TRL	Governance	Culture	Process	ProtoTools (Eng Dev'd)	Tools (IT Dev'd)
6.1	Basic Research	1	Basic principles observed and reported	Problem and Potential Solution Identified	Preliminary identification of problem; potential solutions identified	Problem identified; potential solutions identified; potential ROI identified				
		2	Technology concepts or applications (or both) formulated	System Trades Conducted, Point Design Selected	System trades; indentification of point solution	Problem and potential solutions well-defined and documented; System trade study complete; System point solution formally identified				
6.2	Applied Research	3	Analytical and experimental critical function or characteristic proof of concept (or both)	System Design, CONOPs, Failure Modes Documented	System conops; System decomposition; system and product rqmts development	System elements defined; product rqmts defined; system performance rqmts defined	Cultural change rqmts defined; cultural elements identified; change toolkit templates completed	Process rqmts defined; Process changes / developments identified	Tool rqmts defined; Tool changes / developments identified	Tool rqmts defined; Tool changes / developments identified
		4	Component or breadboard validation in a laboratory environment	Critical Elements Designed and Checked Out	Preliminary design of products	Critical elements poc demo	Discussions and preliminary buyin with stakeholders	Process conops, flow, key steps defined; Successful preliminary review	Preliminary tool prototype or mock-up; Tool-process preliminary integration flow	Preliminary tool prototype or mock-up; Tool-process preliminary integration flow
6.3a	Advanced Technology Development	5	Component or breadboard validation in the relevant environment	Critical Elements Tested in Simulated Env	Final design of products; preliminary system performance analysis	Critical elements advanced poc demo	Discussions and detailed buyin with stakeholders	Process conops, flow, steps defined; successful design review	Tool design complete; tool tested by developers; successful review	Tool design complete; tool tested by developers; successful review
6.3b	Demonstration and Validation (DemVal) Activities	6	Demonstration of system or subsystem model or prototype in the relevant environment	All GCPT Tested in Simulated Env	System performance demonstration; deep stakeholder engagement	Components shown to meet performance rqmts; System meets expected perrormance	Stakeholder engagement plan in place; POC with pilot stakeholders successful	Stakeholder review and approval of process; process meets performance rqmts	Stakeholder review and approval of tool; tool meets performance rqmts	Stakeholder review and approval of tool; tool meets performance rqmts
6.4	Engineering and Manufacturing Development	7	Demonstration of a system prototype in an operational environment	All GCPT *Engineering Models* Piloted Successfully	Preliminary (Test) Deployment to small number of pilot areas; system performance documented; deployment via experts / design team	System shown to meet performance rqmts; deployment plan/metrics defined	Proto training proven effective; stakeholder engagement effective; Lessons learned incorporation plan	Process successfully piloted; preliminary process performance metrics reported	Tool successfully piloted; may include significant use of experts	Tool successfully piloted; may include significant use of experts
		8	Actual system completed and "flight qualified" through testing and demonstration activities	All GCPT *Final System Elements* Piloted Successfully	Deployment to small number of areas; deployment via experts / design team; Focused training for operational deployment	System shown to meet performance rqmts	Final training proven effective; stakeholder engagement effective; lessons learned incorporation in place	Process fully integrated into IPDS; Process released into management system; Process rqmts compliance demonstrated thru user deployment	Tool released, under configuration control, referenced appropriately within mangement system; Tool usability demonstrated via users	Tool released, under configuration control, referenced appropriately within mangement system; Tool usability demonstrated via users
		9	Actual system "flight proven" through successful mission operations	All GCPT in LRIP	Limited deployment according to written deployment plan; deployment via operational team	System performance metrics recorded and monitored as part of standard metrics set	Final training proven effective; stakeholder engagement effective; lessons learned incorporation in place	Process fully integrated into IPDS; Process released into management system; Process rqmts compliance demonstrated thru user deployment	Tool released, under configuration control, referenced appropriately within mangement system; Tool usability demonstrated via users	Tool released, under configuration control, referenced appropriately within mangement system; Tool usability demonstrated via users
6.6	Operational Systems (Maintenance)	"10"	System Deployed, Operational, and Effective	All GCPT in Production / Sustainment	Ongoing pervasive deployment and maintenance	Ongoing deployment; Ongoing performance measurement	Minor Training Package Updates as necessary	Minor updates as necessary	Minor updates and bug fixes as necessary	Minor updates and bug fixes as necessary

These first four columns in the GCPT matrix together represent government/industry thought frameworks for systematically advancing the state of a system from preliminary thoughts around the problem through to the fielded system.

The fifth through eleventh columns are the creation of the author. The fifth and sixth columns in the matrix represent the thought that should go into creating an internal improvement effort. The fifth column ("description when TRL is reached") lists "in a nutshell" what should be achieved when the initiative has reached any given maturity level. The sixth column ("focus of effort to reach TRL") describes the activities on which the investigator should focus effort in order to achieve the TRL. It is these two columns that intimately relate the GCPT framework to the TRL framework.

The final five columns treat each of the GCPT elements individually (two columns are dedicated to tools). Each column lists some of the expected outcomes in the development of the four GCPT elements as one progresses through increasing maturity levels. Each element has a dedicated column which focuses thought specifically on the maturity of that element. There are two columns dedicated to tools; one is specific to engineering-developed tools, while the other is specific to IT-developed tools. The engineering-developed tools (proto-tools) column exists to demonstrate how proto-tools (spreadsheets, simple software codes, etc) may be developed to demonstrate early tool effectiveness. The second, IT-developed tools column exists to demonstrate how formal (read-as "expensive") tools may be formally developed to demonstrate enterprise- wide effectiveness.

An important relationship between the four GCPT elements is described with the red arrows on the GCPT matrix. Recall the premise that tools should only be developed once a process has been well-defined and proven to work effectively. The arrows indicate the preferred maturity level of the process elements before tool elements are developed. In other words, proto-tool design should not begin until the process element has reached maturity level 5. This results in process being carefully vetted (at least through simulated use) before engineering proto-tool enabler development can begin. The longer arrows indicate that before formal IT- developed enterprise tools can begin design, process maturity should be demonstrated through piloting (level 7), and if engineering proto-tools have been developed, they should have also reached the piloting stage (level 7). These arrows serve as a reminder that process development should always progress ahead of tool development.

A second important relationship exists between the four elements. The elements are presented left to right in the order of governance, culture, processes, and tools. This order represents a dependency relationship from right to left. In other words, it is possible that one might create a project just to build a governance model; perhaps the enterprise is already doing “the right things” and all that is needed is a measurement system to demonstrate this. However, if one believes that cultural change is a required element, it may be possible to do this without process or tool development, but one must have new governance models if cultural models are changed. Likewise, if new processes are developed (tools need not be), one also expects new cultural change and governance models will be required. Finally, if one expects to develop a tool, one must also develop new processes to work with the tool, cultural change models, and governance models. This right to left relationship signifies that, for any column that is being actively developed, all columns to the left must also be developed, but columns to the right do not necessarily need to be developed.

To use the GCPT framework, the investigator is presented with a blank matrix template (all content in boxes below governance, culture, process, and tools columns are removed). The investigator then completes the matrix by entering items into each box to indicate which artifacts will be developed at each maturity level to ensure that stage of the development is complete. For example, the investigator may recognize that his cultural model requires new processes to be accepted by users, and would then specifically insert that acceptance as a step in his cultural maturation. Additionally, the investigator is asked to indicate the date each box will be completed, and the estimated labor hours required to complete each box. The completed matrix then serves multiple functions: As a communication device to show project plans, as an earned value tracker during execution, and as a process tracker, to ensure that elements are developed in the correct order.

As new engineers are asked to use the GCPT framework, the same question themes occur over and over. In order to make the GCPT framework more accessible to leaders who must apply it, a set of GCPT thought-driving questions was developed (Appendix A). While these questions are not specifically tailored to maturity levels of each GCPT element, they are nevertheless useful in ensuring that engineers have thought about what exactly they need to create, and how exactly they intend to create and deploy it.

It is important to note that a single GCPT matrix is required for every improvement cycle of a system. Each GCPT matrix records the progress to be made in each development spiral of a multi-spiral effort. For example, one may roll out a system for improving engineering design across the business, and the entire suite of capability might take many years to complete. However, if different capabilities are to be released over time, each of those distinct capabilities will need to consider all elements of GCPT in order to roll out that capability effectively.

Appendix C: Example of Completed Projects Governance

HWEC Completed Products Status Scorecard Instructions

Click on this link to view and update your completed products: Update Completed Products (Hyperlink Removed)

Click on this link to view the Scorecard (Hyperlink Removed):

Click on this link to view Completed Products Year End Status Report (Hyperlink Removed). This is the report we review at the beginning of the year with Engineering Leadership. Please make sure all fields are completed.

FAQs:

How do I go from color to color?

To get from RED to YELLOW: Fill in all of the following fields:

SAP Contract #, Project Definition, NWA(s), Actual Start Date, Actual End Date, Actual Metric Value, Actual Labor Hours, Actual % Reuse *(for how to determine the final 'RAW' KSM value, refer to the instructions in the document library below)*

To get from YELLOW to GREEN:

Finance must pull the cost data from BW. This Excel file will be sent to the owning SM.

The owning SM must unmix and untangle the cost data according to the file process and provide the rationale behind the unmixing and untangling of the cost data and then Finance will review the cost analysis and the rationale.

If this file provides an auditable rationale to go along with the cost data then Finance will check the box in the **Checked by Finance** column.

SM please attached the final finance file to you product record

To get from GREEN to BLUE:
Wanda Grant must verify that the product's data is either in SBT or marked as impound.

David Bloom must verify that the product's data is in either the pending or current version of the Cost Model or marked as a no-go.

Once these two conditions are met, Wanda Grant and David Bloom will fill in the checkboxes in the columns **Dispositioned by Wanda Grant and David Bloom.**