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Hilbert's Problems III

Time is a Flat Circle

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5/16/2023

The opinions and views expressed herein are my own, culled from observations made during my long tenure as a proud member of the cost-analysis profession. Given the personal nature of the narrative, the views are not necessarily shared by any government or industry organization, any employees therein, or any past or current client.

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Abstract

The cost community stands at an inflection point. Revolutions in telework, data science, and artificial intelligence are opening doors to never-before collaboration and innovation. Indeed, businesses around the world are testing some of the new, exciting technologies to save time and money, such as automatic image generation, report synthesis, and even automatic composition of reports and e-mails. Rest assured reader that, I, Peter J. Braxton, am writing here, and not a bot – at least not yet!

A word of caution, however. The new tools might *not necessarily* inform us about things we don't know. They're better interpreted as useful in helping us do our jobs better (more efficiently and effectively). There's no short cut to achieving expertise in the discipline of cost analysis. Hard work, study, and hands-on experience will always be required.

At any rate, given the on-going revolution in technical capability, where do we stand now in the community? The time seems particularly propitious to revisit the "*Hilbert's Problems II*" ICEAA paper, after a decade, and reassess the topics of *Professional Identity*, *Cost Estimating Techniques*, *Cost Estimating Implementation*, *Cost and Schedule Risk Analysis*, and *Integration with Other Disciplines*.

This think-piece summarizes recent progress in our discipline and presents challenges for future research, in the best tradition of Professor Hilbert, such as exploring the frontiers of digital engineering, Agile software development, AI, and machine learning – and, more specifically, their application to cost analysis.

Keywords: *Cost Management, Methods, Program Management*

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Introduction

This paper is a deeply personal essay about the current state of the cost-estimating community from my particular vantage point. It is intended to be more constructive than the typical mid-life crisis and to present a coherent vision for the road ahead for our beloved profession still deciding what it wants to be when it grows up.

Hilbert's Problems for Cost Estimating

In 2007, with scarcely a decade of experience in the field, I co-wrote the somewhat presumptuous paper "Hilbert's Problems for Cost Estimating." The inspiration was David Hilbert's famous list of 23 unsolved problem in mathematics, which he posed to the world at the cusp of the 20th century. I intended to spur research – including my own – into perhaps equally daunting challenges for my own unique discipline. Many of these challenges were analytical in natural; but since cost analysis is an empirical field, a proof from first principles was not always possible. (Even mathematics, the *Queen of Sciences*, is subject to Gödel's *Incompleteness Theorem.*) Other challenges were structural or cultural in nature. The paper drew heavy interest and seemed to achieve its aim of spurring discussion if not always focused research.[1]

Hilbert's Problems Revisited

In 2013, the conference returned to New Orleans after a half dozen years in what proved to be both a happy and unhappy occasion. On the positive side, the hard-won merger of the International Society of Parametric Analysts (ISPA) and the Society of Cost Estimating and Analysis (SCEA) to form the International Cost Estimating and Analysis (ICEAA) was finally a reality. On the negative side, we were suffering the backlash of the GSA Western Region debacle,[2] and government attendance at the conference – vital for the long-term health of the association and the community at large – was at an all-time low. Not coincidentally, this was about the time that the long-

[1] It did generate at least one "Answer Paper," by David Peeler of the U.S. Air Force.
[2] General Services Administration. The conference included the presence of a paid clown, and drew heavy criticism in the media and in Congress.

standing Department of Defense Cost Analysis Symposium (DoDCAS) went into abeyance.

Thus, it was that the Sequel Paper, "Back to the Big Easy: Hilbert's Problems Revisited" fell on deaf ears, or, more precisely, fewer ears. But, alas, it did garner enough attention to win a generous Best Paper in the Management Track.

Grandson of Hilbert

Perhaps the proverbial third time is the charm. Rather than take the tack of the previous paper, which significantly expanded the list of problems across a half dozen categories and over-reached in the area of literature search, this current paper takes a step back and views the community from the perspective of a traditional SWOT analysis: Strengths, Weaknesses, Opportunities, and Threats.

In attempting to think strategically about the profession and where it currently stands, this line of inquiry owes much to the *ICEAA Strategic Plan*, crafted under the leadership of ICEAA Past President and current Technomics Technical Director, Mr. Rick Collins. A complete cross-indexing of this paper to that document and to the two previous *Hilbert's Problems* papers is left as an exercise to the student.

"If thou wert my fool, I'd have thee beaten/
Thou shouldst not have been old before thou wert wise."
-William Shakespeare, King Lear

Prologue

From Expert Opinion to Data-Driven Analysis

Early in my career, I joked that many stakeholders seemed to think (or at least act like) we analysts were possessed of a Cost Estimating Book of Answers and could simply turn to page 562 and find the precise cost for the system we were estimating. Perhaps this analogy was inspired in equal parts by the cantankerous Good Magician Humphrey, the Magician of Information, in the seemingly interminable series of Xanth novels by Piers Anthony, and by the Sears & Roebuck catalog. When it came to proposal estimates, the reality was not much better.

In cutting my teeth on Basis of Estimate (BOE) reviews in various business segments of the Northrop Grumman Corporation, I became well versed in the allusion to (and hence the illusion of) a *basis*. *What is your estimate based on?* Program X. Or better yet, simply "data."

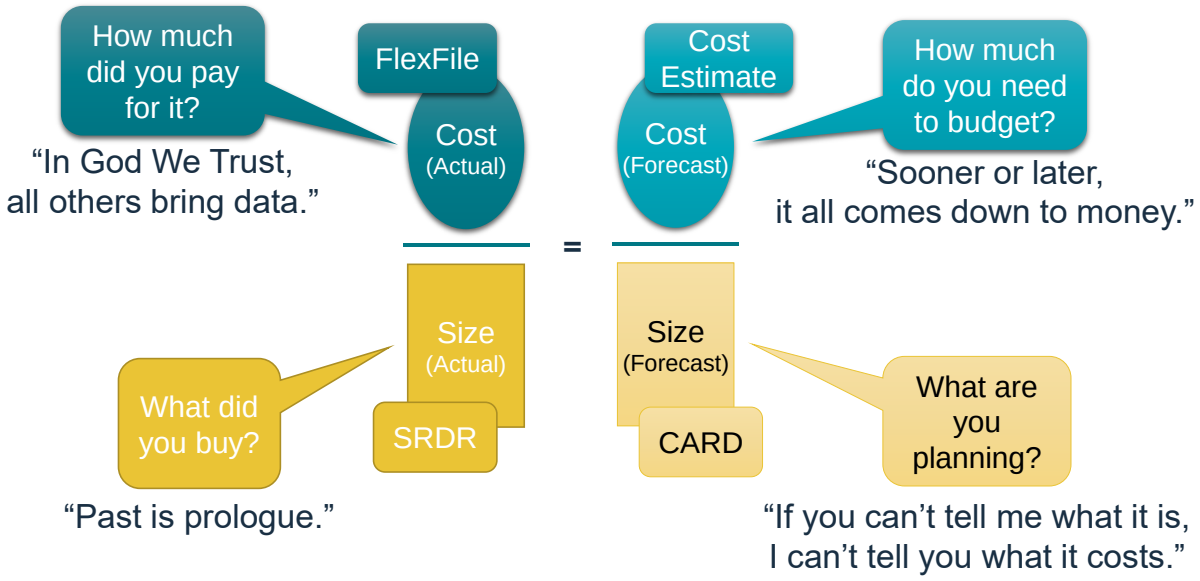

Figure 1: Cost Analysis in One Picture

I was recently reminded that the term "data" is often used imprecisely.[3] To a cost estimator, "data" usually refers to historical actuals as depicted on the left-hand side of Figure 1. What were the actual return costs (and achieved schedule) for a system, in the numerator; and what is the as-built technical description of that system (depicted as software size), in the denominator. To the program management community, "data" often means the plans for the future system, future contracts, Agile Development Solution Epics from some distant release that are now only a gleam in a software architect's eye.

To complicate the two different perspectives of data, what we *planned* to get is not always what *we got*, and what we plan *to get* is not always what we'll *receive*.

"The best laid plans o' mice and men/ Gang aft agley."

-Robert Burns, "To a Mouse"

Strengths – A Foundation, a Vision, and a Calling

Our tired joke is that, when asked in grade school what we wanted to be when we grew up, none of us said, "Cost estimator!" Yet here we are. However accidentally (or Providentially?!) we stumbled into the profession, I for one have stayed in large part due to the opportunity to root around in fascinating and challenging data sets, attempt to distill them into insights, and convey those impactful insights to decision-makers.

[3] With deference to Kevin Cincotta, we leave for other venues the debate on whether "data" are plural or singular.

Data (In God We Trust…)

> *"In God we trust, all others bring data." -W. Edwards Deming,*
> *as cited on the door of then-USD(A&S) Frank Kendall's office*

The strength of cost estimating has always been its grounding in data-driven methodologies. In defining the "Big Four" cost estimating techniques in Module 2 of the Cost Estimating Body of Knowledge (CEBoK), we took pains to require data as the basis for all four, and we relegated Expert Opinion to the outer darkness, where there is wailing and gnashing of teeth. More constructively, we acknowledged the proper role of the subject matter expert (SME) under the umbrella of Expert Judgment, and a middle ground of Expert Testimony. The three expert-categories are listed in Table 1 in ascending order of preference.

Table 1: The Roles of the Expert in Cost Estimating

Expert Role	Definition	Mnemonic
Expert Opinion	The estimate springs fully formed from the head of the SME like Athena from the mind of Zeus; no evident basis	"I Reckon"
Expert Testimony	Where accounting and other data systems fail, those who worked historical programs can provide approximate LOE, cost, duration, etc.; aka Anecdotal Actuals	"I Recall"
Expert Judgment	The expert uses domain knowledge and insight into program context to artfully apply data-driven methods; beware cherry-picking!	"I Recommend"

With the Data Science revolution and the explosion of data and methods that it entails, we can say with a straight face, "We were the Data folks before that was a thing."

Visualization (The Gift of Sight)

Similarly, while we may not have been literally first in line for the renowned Edward R. Tufte *Visual Display of Information* seminars, the community embraced early on the tools of numeracy, sanity-checking, and communication that are statistical graphics. We learned never to argue about learning-curve parameters or CER statistics without first looking at a graph. Some of our misspent youth went to wrestling with Microsoft Chart, and we are now delighted to have at our fingertips tools with much greater power, not to mention better aesthetics.

While Business Intelligence (BI) at its best incorporates other important features such as data wrangling, the most visible (pun intentional!) component are the infographics it produces. Having a dashboard is no defense against poor data (i.e., GIGO, aka garbage in, garbage out), nor ineffectual graphs and charts, but living in a world where decision makers expect to *see* your answer beyond just a table of budget numbers has empowered and invigorated the cost analyst.

Prophecy (Speaking Truth to Power)

In the tradition of Old Testament prophets or virtuoso musicians, who are but vessels for the divine Word or the sublime music they convey, we estimators seek not so much to defend our estimates but to present estimates that are themselves *defensible*, standing on their own merits. That being said, the truth we so clearly see in the data as independent and impartial third parties – as much as we humanly can be – is too often obscured by subconscious biases, wishful thinking, endemic optimism, or (occasionally) willful deception. It is our calling to seek out the signal in the data and convey it as clearly as we can. We "speak for the data," and help the data speak for themselves.

"You can't handle the truth, counsellor!"

-Jack Nicholson as Colonel Nathan Jessup, A Few Good Men

The Cost version might be "You can't *afford* the truth, Program Manager." Estimators are often seen as barriers to progress, but it is important that we present ourselves not

as pessimists but realists. To counteract the prevailing optimism of PMs – would we want them to be any other way? – our realism may have the illusion of being overly conservative. We must convince PMs that risk, like history, is not just something that happens to other people, or they will be "doomed to repeat it." In doing so, we must be righteous but not sanctimonious; zealous but not zealots. "You're part of the solution, or you're part of the problem" is often thrown at us, but we need to turn that on its head. Finding adequate budget for a program may be a challenge, but that *is* the solution, or at least an important consideration. It's limping along with an underfunded program that is the problem.[4] I've found it useful in working with program offices to refer to the independent cost function as the "adversarial ally." We are trying to help the program succeed with a little tough love to get them through their milestone decision.

I have recently enjoyed working with a bright young analyst who goes by Cassie. I told her that her given name, Cassandra, is the ultimate cost estimator name. We went so far as to write that priestess of Troy into CEBoK Module 1, as legend has it that she correctly predicted her people's downfall but was cursed never to be believed. Cassie says she'll have to get a "*Told-ya-so*" tattoo some day….

A key asset for cost estimators is a strong sense of *Mission*, both the mission of estimating itself but also the ultimate mission, the *raison d'être*, of the organizations we support. I've found that cost analysis draws fervent adherents from across the political spectrum; from patriots who support a strong military to pacifists who support a focused and cost-effective military so that money can be spent on other priorities; from liberal spenders who see value in a wide array of federal programs to fiscal conservatives who wish to force tough trade-off decisions to maximize best value.

Put another way, there's a strong need for sound cost analysis in both up and down markets.

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[4] Christian B. Smart, *Solving for Project Risk Management: Understanding the Critical Role of Uncertainty in Project Management*, McGraw-Hill, 2021. See Chapter 7, "Trying to Do Too Much with Too Little: The Importance of Portfolio Planning."

Weaknesses – Narrow-Mindedness, Isolationism, and Fear of Change

Maybe I'm just projecting, as a world-class procrastinator[5], but it seems that we can chalk up many of the cost community's difficulties to being "too busy." When cost organizations are not properly resourced, a negative feedback loop is created wherein recurring activities – completing estimates and assessments – consume the majority of time and energy. Where there has not been adequate investment in data, these estimates take longer, because analysts are having to "beg, borrow, and steal" to scrape up adequate data on which to base an estimate. Where there has not been adequate investment in methods, similar inefficiencies occur. While necessity – or desperation! – is the mother of invention, and applied estimating at its best can spawn some of our most innovative methods, new methods development is often better conducted in a cost research environment, where sufficient time and effort can be spent iterating and testing new approaches. It was just such cost research efforts that many of the original Hilbert's Problems were intended to inspire.

Jim Fiume, then Director of the Office of the Director of National Intelligence (ODNI) Cost Analysis Improvement Group (CAIG), had a rule of thumb that a cost organization's resources should be evenly split between applied estimating and investment in data and methods. The latter are classic Stephen Covey *Fourth Quadrant* stuff: important but not urgent work that tends to be marginalized if not effectively managed.

"You can't start a fire/ You can't start a fire without a spark…"

-Bruce Springsteen, "Dancing in the Dark"

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[5] I almost didn't find the time to write this paper!

A helpful metaphor is the concept of *activation energy* from chemistry. In an exothermic chemical reaction, energy must be initially added to the system to overcome the barrier and start the reaction. Once that occurs, energy is released, significantly greater than was put into the system.

Parochialism (Splinter Groups and Fora)

Membership in professional organizations and participation in the gatherings they sponsor – real or virtual (we'll get to that later!) – are vital to the health of a community. The cost community struggles to achieve critical mass and economies of scale as it is. Any unnecessary splintering into rival groups and factions weakens the community and makes us less efficient. We're all capitalists here, and a little competition is healthy, but I would rather it be competition between ideas at a consolidated forum than rivalry between fora themselves.

"A house divided against itself cannot stand."

-Abraham Lincoln

The aforementioned ISPA/SCEA merger was a significant step in the right direction, and ICEAA is now celebrating its 10th anniversary. The foregoing process illustrated that such steps are often more onerous than common sense might dictate. For many years, the Space Systems Cost Analysis Group (SSCAG) operated in parallel with the Joint Space Cost Council (JSCC). While the former arguably tended more toward research and consultancy, and the latter toward policy and industry, their coexistence came across as more than a little redundant.

Somewhat less redundant were the long-time parallel Annual DoDCAS in Williamsburg, VA, every February, and the ISPA/SCEA conference in June. As a member of the ICEAA Board of Directors (BoD), I agitated to no avail for a co-branding of DoDCAS as the ICEAA Aerospace and Defense conference, with the Office of the Secretary of Defense (OSD) Cost Assessment and Program Evaluation (CAPE) maintaining control over the content and ICEAA handling the logistics. With DoDCAS in abeyance, there

were plans to add a Defense-focused day on the front end of the annual ICEAA workshop scheduled for May 2020 (in San Antonio!), but they were thwarted then by the pandemic and most recently by limited bandwidth by government leadership in the cost analysis community (again – this harkens back to the tradeoff between investment in research versus execution of day-to-day tasks).

One challenge in rationalizing all these fora is achieving the proper balance of breadth (general-interest cost) and depth (specialization by organization and/or commodity). The Department of Energy (DoE) has started holding its own annual Cost Estimating Community of Practice (CECoP), and OSD CAPE sponsors a Cost Assessment Data Enterprise (CADE) Focus Group to discuss data systems and policy within the Department of Defense (DoD). There is a Joint IT and Software Cost Forum sponsored by the IT-CAST consortium, and various Cost Integrated Product Teams (CIPTs) in which government and industry discuss data and methods related to certain groups of programs outside of milestone reviews. While there are real organizational and data-sharing barriers that may prevent consolidation, better coordination and situational awareness across these fora might be beneficial for the community. Either the ICEAA (https://www.iceaaonline.com/) or CADE (https://cade.osd.mil/) websites would be a natural place for this to happen, but thus far neither has risen to the challenge.

ISPA traditionally had a Continental focus, in conjunction with organizations like the European Space Agency (ESA) and North Atlantic Treaty Organization (NATO). Putting the “I” in ICEAA, there has been considerable success expanding further, especially to the Commonwealth nations of Canada, the U.K., and Australia. There are strong partnerships with Nesma in the Netherlands and the Society for Cost Analysis and Forecasting (SCAF) in the U.K., though there seems to be reluctance to formally “convert” the latter into an ICEAA Chapter.

Of course, the proverbial elephant in the room is the Association for the Advancement of Cost Engineering International (AACEI), whose acronym is conveniently an anagram of ICEAA. While AACEI has more of a civil engineering and construction focus, the two organizations may find they have more in common than not. Going back before the ISPA/SCEA merger, there has been an understandable skittishness by the cost

community about the possibility of being “swallowed up” by a larger and more diverse group and losing our identity. This fear is addressed in the next section.

On a hopeful note, one example of two potential competitors’ joining forces for the betterment of the cost community came in the form of a memorandum of understanding (MOU) signed by the Defense Acquisition University (DAU) President, Mr. James P. “Jim” Woolsey, and the ICEAA President, Mr. Richard B. “Rick” Collins II on February 10th, 2020, just in the nick of time before the pandemic shutdown. The MOU outlined a plan to collaborate on the topic of software cost estimating, sharing resources between DAU’s BCF 250 course that subject and ICEAA nascent Cost Estimating Body of Knowledge for Software (CEBoK-S). This is reminiscent of the cooperation between ICEAA and the Government Accountability Office (GAO) when GAO was developing its Cost Assessment Guide under the leadership of Ms. Karen (Richey) Mislick. It promises to be a win-win, enabling DAU to keep its training for the defense acquisition workforce up to date, and enabling ICEAA to make available to the community an important certification for government and industry alike.

Identity Crisis (In Search of Goldilocks)

The root of this fear is not wanting to lose our professional identity, what makes us quintessentially cost analysts. We know what we mean by “cost analyst,” but nobody else seems to. Introduce yourself as a cost analyst at a cocktail party, and people will think you’re an accountant (or worse!). Cost is by its very nature an interdisciplinary field, and so the delicate balance to be achieved is incorporating approaches from and collaborating with those other disciplines as appropriate without being subsumed by them. The countervailing human desires to belong and to be unique and special are encapsulated with delicious absurdity by King Missile:

"I don't want to blend in and be indistinguishable/
I want to be a part of the different crowd/
And assert my individuality along with the others/
Who are different like me"
-King Missile, "Saturday," Happy Hour [1992]

An existential threat to the cost community, at least within DoD, came with the Back to Basics (BtB) effort of the early 2020s led by DAU. The intent was to refocus what had become a multiplicity of career fields, many only tangentially related to acquisition, and to streamline the Defense Acquisition Workforce Improvement Act (DAWIA) Certification process to reduce "scrap learning" and move specialization into peripheral Credentials. At one point, there was a proposal for as few as two career fields, presumably Program Management (PMT) and Contracting (CON), but in the end an additional four were retained: Engineering (ENG), Test and Evaluation (T&E), Life-Cycle Logistics (LCL), and Business (BUS), which was split into Financial Management (FM) and Cost Estimating (CE). Thus, it can be said that Cost is the seventh of the six surviving Career Fields.[6] It was only through the heroic efforts of community leaders like Dr. Richard P. "Rick" Burke, Deputy Director of Cost Assessment (DDCA) in the Pentagon, and Mr. Thomas M. "Tom" Henry and Ms. Min-Jung "MJ" Gantt, both of the OSD CAPE, that the status of CE was preserved. Figure 2 below illustrates the supporting roles Cost Estimating can play in relation to the other fields.

[6] Tired joke: There are three kinds of cost estimators, those who can count, and those who can't!

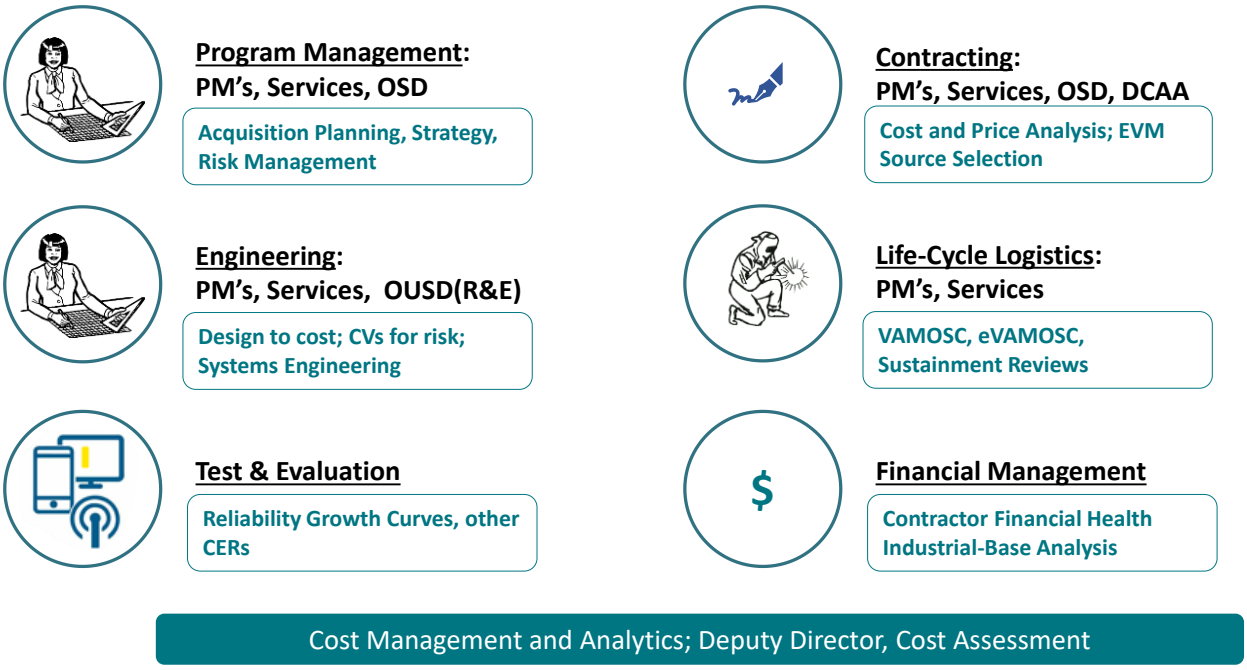

Figure 2: DAWIA Career Fields and Cost Estimating Roles

While the affirmation of the importance and uniqueness of Cost within Acquisition is reassuring, fundamental questions remain about where Cost belongs, and the answer is simultaneously everywhere and nowhere. Cost applies many analytical techniques from Operations Research (OR). In fact, most federal government employees serving in cost analysis positions are classified by the Office of Personnel Management (OPM) as job series 1515, OR Analyst. The Military Operations Research Society (MORS) has an active Cost Working Group, and its Affordability working group has struggled to establish and maintain its identity in a way that's eerily parallel with the cost community itself. The civilian counterpart, the Institute for Operations Research and Management Science (INFORMS), has a Certified Analytic Professional (CAP) certification that nicely parallels ICEAA's Certified Cost Estimator/Analyst (CCEA).

Arguments can be made for several other "home rooms" for Cost Analysis in additional to the general field of OR, with its many and varied supporting organizations:

- Program Management, Project Management Institute (PMI)
- Contract Management, National Contract Management Association (NCMA)
- Budgeting, American Society of Military Comptrollers (ASMC)

- Earned Value Management (EVM), College of Performance Measurement (CPM)
- Systems Engineering (SE), International Council of Systems Engineers (INCOSE)
- Statistics, American Statistical Association (ASA)
- Software Metrics, International Function Point Users Group (IFPUG), Practical Software and Systems Measurement (PSSM), and the Center for Software and Systems Engineering (CSSE).

Articulating our identity goes hand in hand with articulating our value proposition, without which we risk being marginalized. In the end, that value proposition traces back to the Strengths discussed above. These are the traditional, immutable values of Cost, but we must take care not to become too hidebound in the application of those principles lest we become the rabid Christmas tree growers association, ready to do battle with the purveyors of artificial trees at the cynical urgings of Ryan Reynolds's consultant.

"See, what you're really selling/ Is the way things oughta be/
So your pitch becomes compelling/ Selling more than just a tree/
It's a symbol of your values/ It's your ethics and your cause/
You can either be fake like the trees they make/
Or take a stand for Santa Claus"
-"Bringin' Back Christmas," Spirited

Conservatism (Clinging to Old Methods)

Recall that historical actuals provide the fundamental basis of cost estimates: *What did you buy?* and *How much did you pay for it?* It's right there in the name, "historical." Our analysis is rooted in the past. When people complain about data being too old, I remind them that databases for complex expensive commodities like satellites and ships typically go back decades and include *every single program*. Only in so doing can we begin to define the envelope of design possibilities. Of course, we always want to

include the latest programs, systems, technologies, etc. Part of the reason we so attentively study EVM estimates at complete (EACs) is that they may enable the use of in-process data points with a reasonable degree of confidence instead of excluding them from our analysis until they are 100% complete.

In the old world of sparse data, data trumped methods. We could argue and write papers about Cumulative Average (CUMAV) vs. Unit Learning Curve (ULC) Theory, and about ZMPE vs. MUPE – and we did! – but in our hearts we knew that solid, well-normalized historical data did more for creating a defensible estimate than any analytical subtleties. Still, this led to the pernicious attitude of #IJE ("It's Just Estimating"), the conscious or subconscious belief that the imprecise nature of our forecasts should cover all manner of analytical sins. If we're just glorified TV meteorologists, why should be worry about anything after the first significant digit or two? It is to combat this attitude that my original mentor coined Coleman's Law of Avoidable Errors, which is simply "Don't make any!" Put another way, even though some of our mathematical constructs embody uncertainty (i.e., probability distributions), and some are imperfect reflections of reality (the whole "all models are wrong, some are useful" bit), we should still perform manipulations in accordance with mathematical precision and demonstrable best practices.

The potential weakness here is that it is only natural to become too comfortable with old data sets and methods. Even where there is the desire to refresh both data and methods, inadequate resourcing (as described above) may not allow it. Established practices are "tried and true" for a reason, but there is always room for improvement.

Recent examples of persistence of inferior methods or failure to adapt superior methods include:

- Use of CUMAV instead of ULC, despite systematic approaches to address challenges of ULC with Lot Data
- Use of LOLS or ZMPE for fitting nonlinear CERs to data when more appropriate regression methods are available, as described in the Joint Agency Cost Estimating Relationship (CER) Development Handbook

- Persistent application of the "pseudo-IID thought process" for risk factors
- Limited adoption of progress-based EACs
- Limited adoption of machine learning (ML) techniques after the NATO ship example presented in the "Data Mining" paper[7]
- Limited adoption of Bayesian techniques after the paper on CERs with limited data.[8]

I embody the reality of an old dog needing to learn new tricks. Though it sounds a bit extreme, "Adapt or die" is an apt catchphrase at both an individual and collective level. We need to meet the problems of the moment – head on. Indeed, in a clarion call to action, Maynard Keynes famously reminded us, "In times of tumultuous seas, we should not take solace in knowing that they will eventually be calm, because in the long run we're all dead."[9]

Where do we stand in the world of Big Data and Data Science? Does data still trump methods, or has the situation reversed? Even as data collection becomes more centralized and systematized in many pockets of the community (cf. FlexFiles), Data Denial is a weapon we should still be wary of. The next section will discuss the Opportunities available on both fronts and recommend a concerted push for leveraging both Data Management (DM) and Data Analytics (DA).

[7] "An Application of Data Mining Algorithms for Shipbuilding Cost Estimation," Dr. Bohdan Kaluzhny, SCEA, Orlando, 2012.
[8] "Bayesian Parametrics: Developing a CER with Limited Data and Even Without Data," Dr. Christian B. Smart, ICEAA, Denver, 2014.
[9] General Theory of Employment Interest and Money, John Maynard Keynes, 1936.

Opportunities – More Data, Better Data, More Often

If we pride ourselves on being a data-driven profession, we certainly must learn and discern how best to embrace the new world of data. This is not necessarily a direct transfer from Big Data, nor even Data Science, though we certainly can and should borrow liberally but selectively from both.

Digital Engineering and ERP (Native Data)

Copious data are being collected as part of (Systems) Engineering and Program Management processes, in the normal course of business. There is no reason these data can't be systematically mapped and "exported," with the content and format tailored to fit cost estimating use cases.

On the technical side, systems capture architecture, requirements, and design specifications, and in the most extreme cases create a digital twin of the delivered system. Whether accessed directly via API, exported to a generic format necessitating some data wrangling, or used to populate a specific Data Item Description (DID) such as CADE's Technical Data Report (TDR) and Software Resources Data Report (SRDR), data from these systems directly inform estimate by providing context and potential cost driver variables, both quantitative and categorical. In the original cartoon, we actually migrate from right to left as the program proceeds through development, maturing from original plans to as-built actuals.

On the cost side, Enterprise Resource Planning (ERP) and EVM systems capture hours and dollars at the account level, together with overhead burdens. There are similar means of accessing these data, and the relatively new Cost and Hour Report (aka FlexFile) and IPMDAR both utilize Java Script Object Notation (JSON), which is essentially a zip file of related database table. This approach helps enforce data integrity, ensuring that the various aspects of the data set are consistent with one another.

For all of these data types, the data are native to the developer's systems and therefore both more granular and unadulterated compared to the raw material cost estimators have traditionally had to work with. The usual challenges persist in normalizing data to

be consistent across sources, but these steps can now be clearly documented and automated using the techniques described in the next section. For DoD, the Cost and Software Data Reporting (CSDR) Planning effort is more important than ever, and DoDI 5000.73, "Cost Analysis Guidance and Procedures," and the associated Defense Federal Acquisition Regulation Supplement (DFARS) clauses ensure that the DD Form 2794 CSDR Plan is put on contract. A CSDR Readiness Review shortly after contract award provides government and the contractor the opportunity to tweak the plan as needed and make sure that the contractor's systems are properly configured to capture the desired data. Flow-down of reporting requirements to major subcontractors is also crucial at this juncture.

While we have not made significant inroads, there is some precedent even for collection of government data. This might include data from government research labs (the Army, Navy, and Air Force each have one), government maintenance depots, and even from the four public Naval shipyards. For government software factories, a tool like Enterprise Jira that typically only captures Epic-level data might be extended all the way down to the Features, Stories, and Tasks of the developers actually building the software. While it might be considered more Finance than Cost data, cost estimators are even making wider use of data from government ERP systems.

Data Management and Data Analytics (New Sources and New Methods)

The cost community has long acknowledged the need for cost databases. The mandate for each Military Department's Visibility And Management of Operating and Support Costs (VAMOSC) system dates back to the 1970s, and now the Enterprise VAMOSC (EVAMOSC) effort is working to leverage data from all three VAMOSC systems[10]. DACIMS served as not so much a database but as a repository of CSDRs and later evolved into the CADE system. CSDR-based databases were developed for individual commodities, such as JCARD for aircraft and the Army's various ACDBs. Outside the cost community, the government's embrace of data is exemplified by the

[10] Navy VAMOSC includes O&S data from both Navy and Marine Corps systems.

proliferation of Chief Data Officer positions and organizations. The Pentagon has gone so far as to formalize the erstwhile Joint Artificial Intelligence Center (JAIC) as the Chief Digital and AI Office (CDAO)[11].

With the move toward data platforms such as the Air Force's VAULT, it becomes imperative to deploy cost databases to these platforms so that they can be effectively integrated with other data sources as part of automated, repeatable, and well-documented data flows. These data environments are not unlike the Software Factories that are springing up under DevSecOps. Both aim to put a powerful standardized toolset in the hands of practitioners – data analysts and software developers, respectively – to enable them to increase the quantity and quality of their work. That cost data are generally considered proprietary is a challenge, but not an insurmountable one. Such data platforms incorporate access controls to ensure that only analysts with a signed non-disclosure agreement (NDA) are able view corresponding data.[12]

While an adequate description of the VAULT is outside the scope of this paper, a helpful rubric for the cost analyst is the notional of bronze, silver, and gold data tables. Gold data are what are desired for analysis, but to get there may require transformation (normalization steps such as applying inflation), the application of a metadata layer, and other steps tied to a particular *use case*.

[11] https://www.ai.mil/

[12] As a side note, the effective use of support contractors within the cost community arguably rises to the level of a Hilbert's Problem.

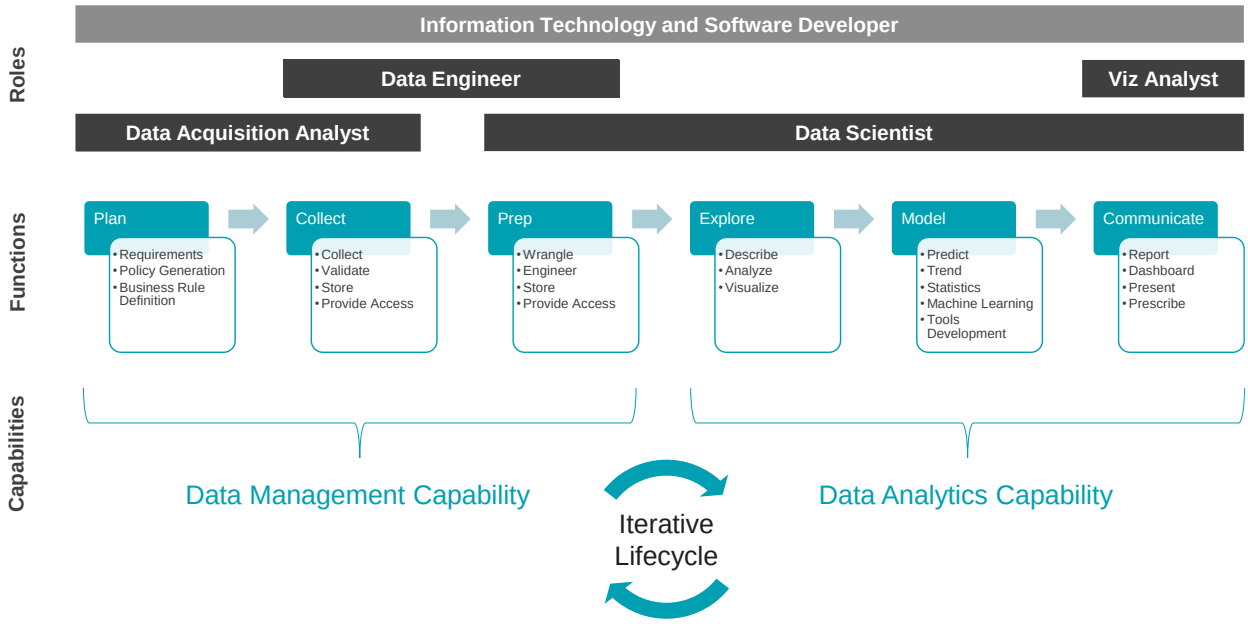

Figure 3: Data Lifecycle (Technomics)

We return to the cost estimating question of data vs. methods. Clearly, this should not be an either/or, and platforms like the VAULT and schemas like the Data Lifecycle shown in Figure 3 above emphasize that they should be viewed as part of a continuum. The cost community has an acute need to improve both data, aligned with the Data Management (DM) capability, and methods, aligned with the Data Analytics (DA) capability.

There are current efforts underway, led by Mr. Dave Brown of Ball Aerospace and the ICEAA Board of Directors, to overhaul CEBoK Module 6 Basic Data Analysis Principles and bring it more in line with modern data analytics and data visualization principles and tools. This is more on the DA end of the continuum. A similar effort on the DM end would be welcome, updating Module 4 Data Collection and Normalization to incorporate cost database best practices and the application of the data pipeline's Extract, Transform, and Load (ETL) steps to cost estimating use cases.

Some cost estimators will choose expand their skills in the direction of DM/DA. Others will embrace a new role as Domain Experts to define and execute those cost estimating use cases. This role is sorely needed. While there is a continual stream of Data Science graduates, but we've found that while many are whizzes at writing Python or R

code, they haven't yet learned to think like analysts,[13] much less cost analysts. Data environments like the VAULT provide a place where these two roles can not only peacefully coexist but collaborate.

DM/DA working in conjunction will enable us to expand our data *and* our methods in equal measure. Whether the new methods will prove to be more effective for estimating purposes remains to be seen, but we won't know until we try!

Feedback Loops (Acquisition Pathways and DevSecOps)

The acknowledgment that traditional Major Defense Acquisition Programs (MDAPs) often take far too long and suffer from cost overruns and performance shortfalls led to the creation of the Adaptive Acquisition Framework (AAF)[14], summarized in Figure 4. While Major Capability Acquisition (MCA) is still the default for the largest and most complex programs, many alternative pathways are now available. With the complication of whole new sets of rules to learn comes the silver lining of more frequent opportunities to collect cost and technical data on a wider variety of programs.

This is particularly the case within the Software Acquisition Pathway, where Agile Software Development and DevSecOps entail a continual stream of data. A typical Agile cadence is four three-week sprints wrapped into a quarter program increment (PI), feeding a continual series of releases into the operational baseline. The "containerization" of software and advances in automated testing mean that new capability releases can be deployed more frequently and quickly, as mission needs dictate. With each PI and release come data on Stories, Issues, and Features, all building to Program Epics (PE) and Solution Epics (SE). For a more robust discussion on the opportunities and challenges presented by Agile software data, see the cited papers.[15]

[13] Keynote, Krystyna Kolesar, ICEAA Pittsburgh, 2022.
[14] DAU has an excellent website (https://aaf.dau.edu/) dedicated to exploring the different pathways
[15] Braxton, ICEAA, 2022; JITSWCF, 2022.

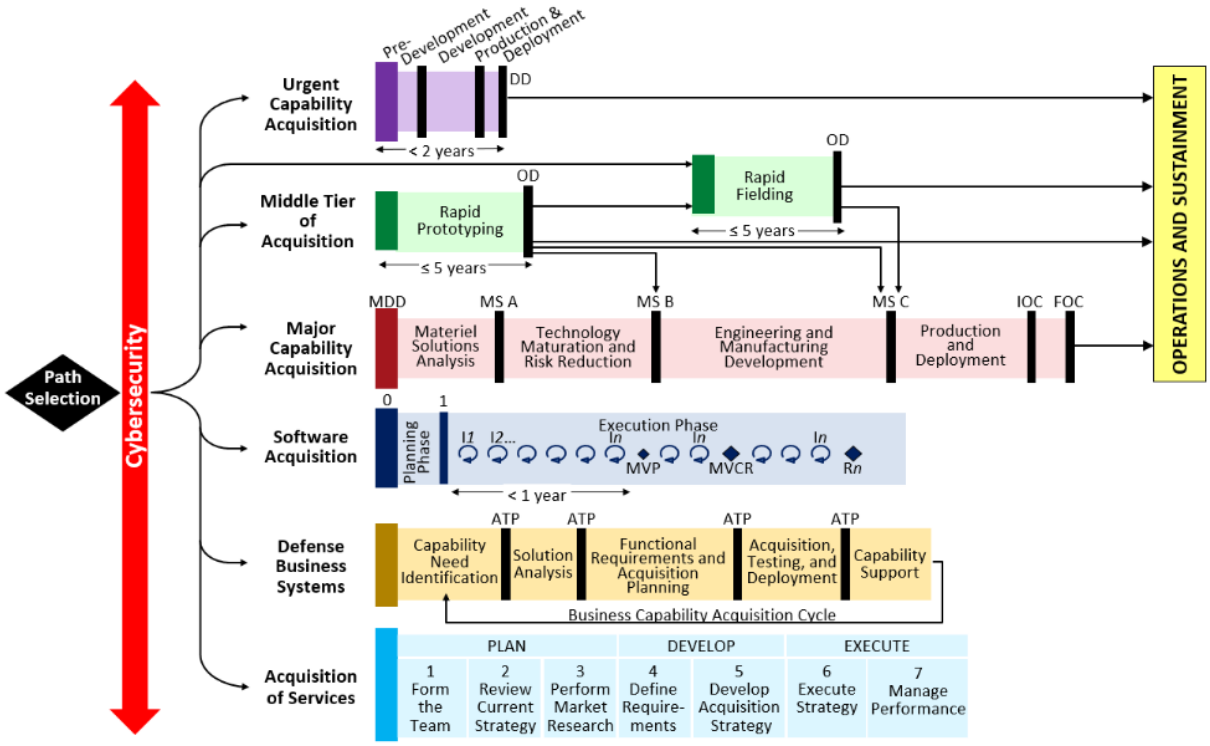

Figure 4: Adaptive Acquisition Framework (AAF)

More frequent data collection can lead to better methods. This phenomenon is two-fold. First, more *frequent* data is *more* data, which means more potential driver variables, more degrees of freedom, etc. Secondly, analysts can iterate models more frequently. Cost analysts can enjoy the same success with Agile and other AAF data as they have with EVM data.

"Go big, or go home!"

As a community, we need to feed not fear the increased demand for cost estimating. If we don't seize the opportunity and staff up the cost function, stakeholders will learn to

live without it. This has sadly happened not once but twice over the course of my career to our beloved Naval Center for Cost Analysis (NCCA).[16]

Proving the cost estimating value proposition calls for a two-pronged approach. On the cost side, we need to take our own medicine and collect data on the effort required for investment in cost data and methods, as well as the effort required for recurring cost products such as Program Office Estimates (POEs), Component Cost Positions (CCPs), Independent Cost Estimates (ICEs), and Independent Cost Assessments (ICAs), non-advocate (NACAs) and otherwise. On the performance side, we need to impress stakeholders with the versatility, efficiency, and effectiveness of our products, building on our Strengths above. If we fail to do both of these, the proverbial cobbler's children will have no shoes.

[16] A Program Decision Memorandum (PDM) is in play to reconstitute NCCA's role in performing independent cost estimates within the Department of the Navy.

Threats – Telework, #NoEstimates, and Brain Drain

"Working" from Home (Mentoring and Collaboration in the New Normal)

There can be no disputing that the Covid-19 global pandemic upended our lives, for better or for worse. Over the past three years, we've worked toward defining what the so-called "new normal" should be, and it continues to evolve. An immediate and persistent casualty was the sharp downturn in genuine in-person interaction. (There also appears to be a generational component, but it may be so inextricably related as to be indistinguishable.)

I knew we were in a brave new world of remote ops the day I had, without trying, four meetings each with a different web conference software platform (Microsoft Teams, Adobe Connect, Cisco WebEx, and ZoomGov)! On another occasion, I arranged a conference room for a review with a decent-sized project team and arrived to find myself sitting alone with the Project Lead, since it was Wednesday and all the analysts were working from home on their Flex Day.

"There is no 'there' there."

-Gertrude Stein[17]

Technomics CEO Al Leung said it best when he asserted that the net result of ubiquitous web conferencing is that "Participation is up, but engagement is down." We have observed this first-hand in conducting multiple virtual training offerings for several different clients, including the ICEAA Washington Capital Area Chapter (WCAC).

Conversely, as it was safer (on and off) to gather again, we were pleasantly reminded of the rewards of direct interaction. Analysts at the Naval Surface Warfare Center Port Hueneme Division (NSWCPHD) heatedly discussed how to assess basis of estimate

[17] https://www.wsj.com/articles/why-gertrude-steins-no-there-there-is-everywhere-1517589198

(BOE) documentation. Teams of students in Technomics Training Institute (TTI) Foundations of Cost Analysis (FCA) classes put the 12 steps of the GAO Cost Assessment process in order by shuffling index cards on the table in front of them. Cross-Service representatives explored the FlexFile+ set of CDRLs in the CADE 301 pilot, immediately benefitting from the experience, expertise, and perspective of colleagues from different organizations.

Perhaps the most pleasant reunion at all was the ICEAA 2022 workshop in Pittsburgh. Its importance in "getting the band back together" cannot be overstated. The leadership of the Technomics team supporting the Defense Cost and Resource Center (DCARC), who spend an inordinate amount of time in planning meetings with representatives from across DoD, remarked that it was the first time in two years – or ever! – that they had the opportunity to meet many of their frequent collaborators. In particular, panelists like Ms. Ranae P. Woods of the Air Force Cost Analysis Agency (AFCAA) inspired a generation of young female analysts in what has in the past been a male-dominated field.

Direct interaction has several benefits, including but not limited to:

- **Building relationships**: Traveling together, working late nights on a proposal or client deliverable, and participating in teambuilding activities for a new project all build camaraderie and establish a level of comfort and trust that makes future remote ops all the more effective. You've been in the trenches together, and everyone has skin in the game.
- **Sneakernet**: I learned from mentors that "The number one weapon of the cost analyst is the telephone." Meaning that an analyst should not passively wait for a CARD or a CCDR to answer all their questions but rather should proactively pursue insight from SMEs, additional data, etc. (Of course, these days no one's at their landline phone number if they even have one!) As much as we try to streamline workflows and enable data access, nothing will substitute for swinging by a colleague's desk and picking their brain about something or throwing out a quick "help needed."

- **Communication**: Cite your favorite study about what percentage of communication is visual, non-verbal, and/or oral. Email is inescapable, but we've all learned by now that it doesn't convey tone particularly well. The more sensitive or nuanced a matter, the more important that it be discussed in person.
- **Brainstorming**: Show me a virtual whiteboard that ever worked as well as a real one! There's something about the tactile experience of giving abstract ideas a concrete presence, even if in "cartoon" form.

Much like data vs. methods, DM vs. DA, or Data Science vs. Domain Expertise, this is not an either/or. We need to optimize the use of all lines of communication, both in-person and virtual. This enables us to maintain the benefits of in-person when it occurs, and evolve virtual mechanisms to reap similar benefits. Web conferences with cameras on can still convey tone of voice and facial expressions. Group chats can yield quick answers as much as a cubicle drive-by and facilitate analytical discussions on par with most meetings. Workflow tools can help maintain configuration control without the continual need to double-check with a collaborator.

"Some idiot just called me up on the phone. What!?
Don't they know how to text? OMG"
-"Weird Al" Yankovic, "First World Problems"

As alluded to above, the pandemic may have accelerated and exacerbated generational divides. I recently attended a highly technical conference, and it struck me that scarcely a presentation went by without memes/GIFs, emojis, or both. (Let us resolve never to talk trash about the ancient Egyptians and their silly hieroglyphics again!) Perhaps amongst the more frivolous new tricks this old dog is learning, I can appreciate that these devices can be succinct and even nuanced, albeit open to misinterpretation. Cost estimators think in analogies, and perhaps it is appropriate that they communicate in them as well. As discussed above, mathematics demands precision, as does coding, for that matter. Imprecision and ambiguity may be appropriate in some communiqués but not others.

The entire discussion of this particular Threat is not on the face of it specific to the cost community, but given the aforementioned Weaknesses, our tenuous position may leave us more susceptible to perturbations than a larger or more well-established group. Thankfully, the Great Resignation and Quiet Quitting appear to have had minimal impact on the cost community thus far, but they merit monitoring.

Agile and the Death of EVM (What is Value?)

It thankfully appears to be a minority, but there is a faction of the Agile Software movement that advocates #NoEstimates (it's even a hashtag on Twitter!). This is perhaps the most marked example of the view that attempting to forecast cost and schedule is futile at best and counterproductive at worst. This sentiment is clearly an existential threat to the cost community. Mr. Glen Alleman has been one of our staunchest defenders in this arena, and his chief antidote to this poison is the rule of thumb that estimating is required whenever you are spending *someone else's money*, such as the U.S. Taxpayer's (or any other stakeholder's, for that matter).

At its essence, cost estimating relates *requirements* to *resources*, depicted in the right-hand side of the Cost cartoon. The former are the denominator: *what are you planning? what are you buying?* The latter are the numerator: *what will it cost?* and *how long will it take?* The units of that denominator may vary between true mission requirements (capabilities), performance requirements (how fast, how high), and technical specifications (space, weight, and power), which are at the very least proxies for the scope of the work – the "stuff" being procured. Any approach that ceases to measure or care about the "stuff" being delivered is antithetical to cost estimating.

Put another way, cost estimating is crucial to enabling the PM to smartly manage the so-called Iron Triangle of cost, schedule, and performance. The more mainstream approach to Agile inverts the Waterfall paradigm of fixing performance, which determines cost and schedule, and instead fixes cost and schedule (the "Time Box"), which determines performance. Cost estimating is fine with this inversion, and has in fact supported it in previous eras under the guise of Cost As an Independent Variable (CAIV), Design To Cost (DTC), or Target Costing. In both paradigms, the quantities of interest are related, not decoupled.

In the extreme (extremist?) version of Agile, fixing the time box and not caring what is actually delivered by each sprint of PI is the Productivity version of moral relativism. The contractor is sending the message, "Trust us, we're being efficient." The detrimental impacts of this approach could be mitigated by a very active Mission Owner and Customer Advocate, who make absolutely certain that the backlog of new capabilities and existing issues (discrepancy reports) is being properly prioritized. It is somewhat comforting to know that the developers are at least working on the *right* stuff, but we still have no idea how efficiently they're working off that backlog.

Under the erstwhile Better Buying Power championed by the late Dr. Ashton B. "Ash" Carter, a Should Cost analysis systematically examining areas for improvement stood in contrast to the Will Cost analysis more typical of independent estimating. (We cynical cost and risk analysts may have been known to refer to Should Cost as "Won't Cost"!) While Agile Scrum Masters should be able to manage their own teams with a minimum of meddling or micromanagement from program leadership, that doesn't obviate the need for top-level productivity metrics. Cost estimators are fairly agnostic as to the units of what is being delivered: Source Lines of Code (SLOC); some variation of Function Points (FP); or Agile measures such as Story Points, Features, or Epics. Ultimately, the proof of the Effort Estimating Relationship (EER) is in the statistics. A wry observer remarked that we worry about Story Points being a relativistic measure of software size, but don't think to ask the same question about SLOC!

There are multiple approaches to contracting for Agile software development, including Time and Material (T&M), Fixed Price Level of Effort (FP LOE), and Fixed Price per Story Point (or Function Point or Sprint). Such discussions are beyond the scope of this paper. We simply want to make the point here that how Agile is managed or contracted for is distinct from how it is planned and budgeted for on the Government (customer) side. Certainly, Cost has a role to play in all three, but the last most of all.

The Next Generation (Where Have all the Farmers Gone?)

Any organization has to deal with attrition, and the cost community has certainly had its share of superstars who have stayed and those who have left for related (or unrelated)

fields.[18] As analysts who consistently practiced and taught both the *art* and *science* of cost estimating have departed, either via career change or retirement, this has impacted the next generation in at least a couple of ways:

- Younger analysts may lack the artistry in crafting estimates and the confidence to defend results that may be contentious.
- Younger analysts may go overboard in their quest for efficiency, leading them down the primrose path to quick and easy answers, without putting in the requisite thinking – "skull sweat," as Dr. Brian J. Flynn calls it! – or research.[19]

Both of these can lead to overreliance on the presumed experts, the program office and its lead development contractor or integrator, but this may be in the realm of Expert Opinion, as discussed earlier.

"Where is my Marlboro man?
Where is his shiny gun?
Where is my lonely ranger?
Where have all the cowboys gone?"
-Paula Cole, "Where Have All the Cowboys Gone"

Diversity and *opportunity* are both crucial to retaining top talent in the field. There is no one kind of cost analyst. As noted above, one of the strengths of cost analysis is that it is a multi-disciplinary field. We've all seen some version of the diagram showing traditional disciplines that feed into cost. My personal favorite is the one DAU developed for its BCE 3000 course. It groups disciplines into two complementary "wings," the Math Wing and the Engineering Wing. (A stark omission is Data Science, or even Statistics, which presumably would be on the math side.)

[18] It is left as an exercise to the student to conduct a "where are they now" analysis of previous Junior Analyst of the Year and Technical Achivement [sic] award winners.
[19] Brian Flynn borrows the phrase from "Ender's Game," Orson Scott Card.

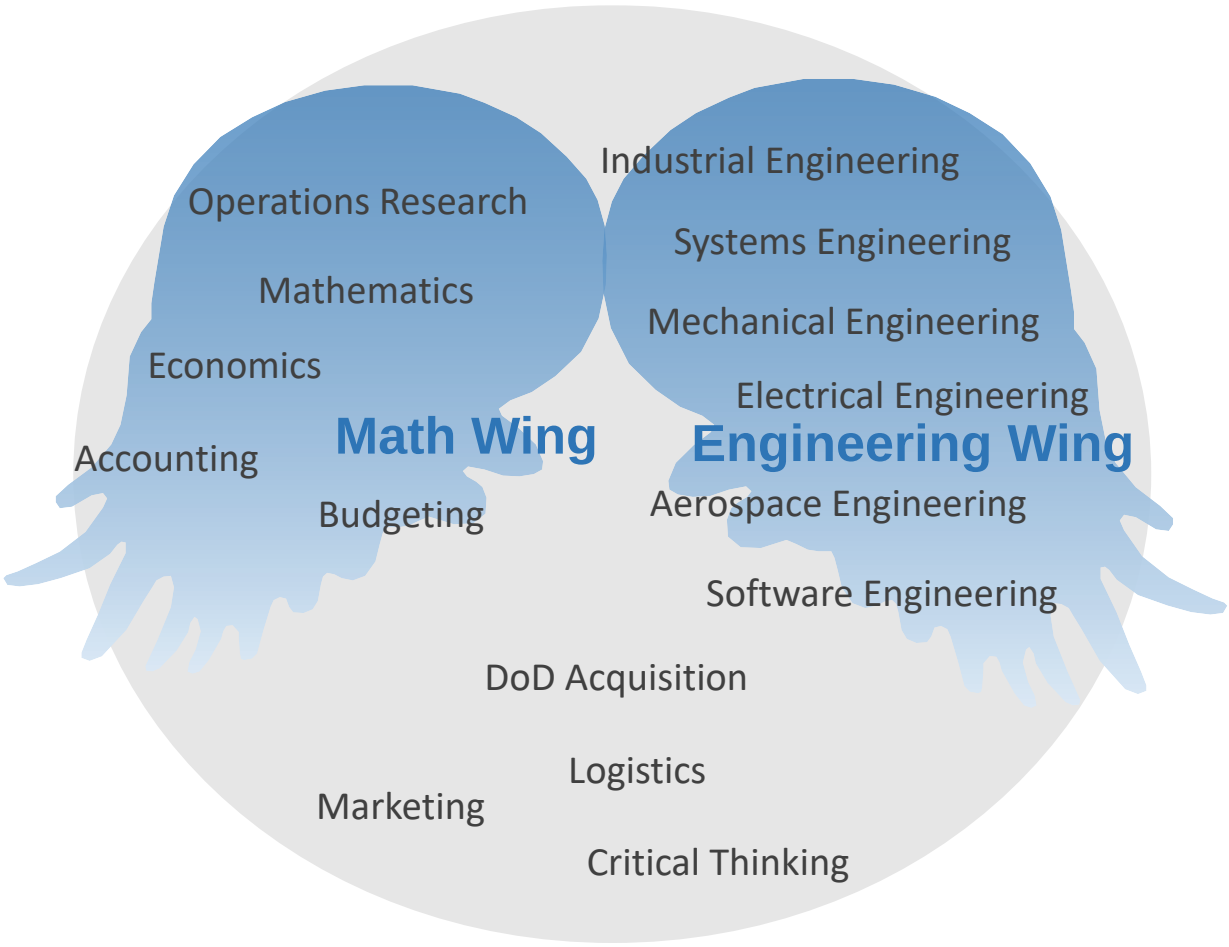

Figure 5: Cost Estimating Disciplines (Math Wing and Engineering Wing)

This addresses diversity in the backgrounds of individuals *before* coming to Cost, but equally important are the diversity of skills they develop and roles they play *after* coming to Cost. If you want to narrowly specialize, Cost is probably not for you (nor consultancy, for that matter). But there are multiple different roles or avenues to appeal to the next generation of analyst, and it is crucial that cost organizations staff up enough to have the critical mass and the economies of scale to diversify. This will also enable them to provide opportunities for growth for their staff, which creates a positive feedback loop. As previously discussed, some combination of DM, DA, and Domain Expertise comprises a robust skillset for a cost analyst.

Another perennial debate is whether it is better to have a homeroom for Cost or to matrix cost analysts out to acquisition organizations and programs. Ideally, a balance can be struck. The pros of the central organization include cultivating a strong identity,

independent mindset, and professional tradecraft, and being free to critique, but the cons include the danger of being out of the loop with program goings-on or generally out of touch ("ivory tower"). Conversely, matrixed support has the perils of "Lost Patrol Syndrome" or "going native" and becoming too much of a program advocate. Advantages include being better "plugged in" to the program and developing a stronger understanding of the system(s) being acquired. Ideally, we want estimators to have the objectivity of Outsiders but the knowledge of Insiders – embeds, not moles.

Whatever our organizational structural, a key skill of estimators is the ability to work deftly and constructively *across* organizations. When it comes to DM/DA, we must discern how to leverage data professionals whether we "own" them or not. This may include interfacing with the aforementioned CDO organizations.

"Il faut cultiver notre jardin."

-Jean-Marie Arouet Le Jeune, aka Voltaire, "Candide"

I aspire to be a polymath, and my previous profession, teaching, is a prototypical one requiring a wide array of skills. Another such is farmers, who must be biologists, mechanics, accountants, and so much more. I like to think of cost estimators as farmers: cultivating the data, growing the algorithms, and bringing the analysis to market! At the end of the day, we can take great pride in tending our garden.

Epilogue – Rise of the Machines

Fast on the heels of "Big Data" were fellow buzzwords "AI" and "ML." While no doubt the subject of many current and future papers, we say a few words about the pair here.

"Eventually, computers and robots will run things. Humans will manage those machines, but that doesn't require courage or strength, or any characteristics like those. In fact, men are outliving their usefulness."
-Photographer-writer Robert Kincaid in The Bridges of Madison County, *Robert James Waller*[20]

Machine Learning (New Algorithms, Same Stuff)

The real immediate boon to cost estimating, after adequately implementing DM/DA as described above, is in machine learning, or ML, which is a subset of the broad field of predictive analytics. New and varied models can be developed on larger, more detailed, and more diverse data sets. It is the role of the analyst to assess and apply these models judiciously, just as with a traditional regression-based CER.

Machine learning, importantly, and as demonstrated in an internal Technomics IR&D effort, considers all data in a sample, such as 130 technical and performance characteristics of amphibious vessels, rather than only two or three independent variables ("X's") as in traditional regression analysis. Building the databases and preparing the data for analysis is just as important as the analysis itself. It's 80% of the effort, just like in traditional cost analysis. The better the data, in terms of accuracy and degree of granularity, the better will be the ML output. Anybody can run a canned ML routine these days. Maybe even an intelligent dog. But only a skilled, highly-trained, persistent and dedicated cost analyst can collect and normalize the raw data.

[20] This book was published 1992, well before the Dot Com Bubble, and set in 1965, showing that existential dread about the possibility of being replaced by machines significantly predates the current era.

As the Nobel Laureate Lawrence Klein once remarked: “It’s sometimes necessary to roll up your sleeves and do a bit of distasteful work in order for strong results to be achieved.”

Artificial Intelligence (The Chatbot Ate My Homework)

One of my personal heroes is the folk hero John Henry, who dueled a steam engine at driving railroad spikes.

“John Henry was a steel-drivin’ man/…

And he died with a hammer in his hand, Lawd, Lawd”

-“John Henry,” American folk song

While I aspire to a long and prosperous career in cost estimating, I might not go so far as to wish to die with a “[spreadsheet] in [my] hand!”

When it comes to AI, or any sort of automation, my watchword is “Let the machine do what the machine does well, and let the human do what the human does well.” This is often easier said than done. There is the romantic notion that once machines automate all the drudgery, all the humans will have left to do is higher-order thinking, what we cost estimators like to call “analysis.” This is always the sales pitch for systems like CADE. The irony and the paradox may be that what we’re automating, while computationally intensive, is actual the interesting analysis, and we humans are left with the drudgery. Whether the machines become the source of our liberation or the source of our enslavement is yet to be seen. The subtitle of this section notwithstanding, if the latter comes to pass, it may be more likely with a whimper (cf. *The Matrix*) than with a bang (cf. *Terminator*).

Lest you fret about losing your job to a computer immediately, a wise commentator pointed out that there’s a continued need for humans to train the machines.[21] Language

[21] *Ten Arguments for Deleting Your Social Media Accounts Right Now*, Jaron Lanier, Bodley Head, 2018.

translation algorithms need humans who understand slang and nuanced meaning to train them. Image detection algorithms need humans who can tell a fighter aircraft from a bomber to train them. Natural Language Processing (NLP) algorithms for software sizing need Certified Function Point Specialists (CFPS), or equivalent, who understand simple vs. complex requirements to train them. And cost and risk algorithms need program SMEs who can provide accurate assessment scores to train them.

Two specific concerns leap to mind when it comes to automation. The first is that as soon as you lay down the rules of the game, humans will start gaming the system! Long sought for Digital Engineering and other design-centric efforts (cf. Jed Richards's Army work) has been a "cost model in the loop" that could magically provide the cost of any design excursion and run as part of a grand optimization. (This is dangerously close to the Cost Estimator's Book of Answers we started with….) Because of the stochastic nature of most cost models, we are hesitant to use them blindly for optimization purposes, though this did not prevent the incorporation of VAMOSC-based CERs into the systems dynamics-based Operating and Support Cost Analysis Model (OSCAM), a suite of models that the Navy cost community employs for platform and related mission systems cost analysis. One example prone to gaming is the NLP method for software sizing presented by Mr. David H. "Dave" Brown from Technomics at this very conference. If those doing software architecture and design are aware that this method is being used, they may purposely write wordier Lean Business Cases (LBC) if they're trying to pad their program budgets, or more succinct ones if they're trying to squeeze into existing ones and appear more affordable.

"Any sufficiently advanced technology is indistinguishable from magic."

-Arthur C. Clarke

The second concern is the Black Box problem, which is not at all new to cost estimating, thanks to off-the-shelf models like PRICE and SEER. I think I know the inputs to and the outputs from a model, but I can't really articulate the algorithms or computations going on inside the model, either because I *don't have direct insight*, as with commercial

models, or because I *don't understand them*. This becomes an epistemological problem: *How do I know?* This is not just a *theoretical* problem for unrepentant from-first-principles mathematics majors like me. It is a *practical* problem for all analysts presenting their results to decision-makers and trying to convince them to pursue a course of action based on those results. This becomes a credibility issue for the community as a whole.

This is even thornier when ML models are almost by design intended to function without deep human interaction, as might occur in more traditional predictive analytics such as ordinary least squares (although as the Nobel Laureate Milton Friedman points out, there's often a fine line between the scientist and the crackpot in econometric modeling). This sort of difficulty first arose in mathematics in the proof of the Four-Color Theorem in the 1970s, where the exhaustive exploration of cases was feasible with modern computing power but not independently verifiable by humans in a practical amount of time (before the heat death of our sun, say). Our confidence in the results relies on our ability to vet the algorithms carrying out the computations.

When the machine does something for you is exactly when you most need to understand the methodology. When you do it by hand, the focus is on the outcome, and you might just do it by rote and not truly understand. Examples might include the multiplication and long division algorithms you learned in grade school. As the focus shifts to process, it is more important to understand what is going on and when you might use one methodology over another, for example. We still rely on the logic of mathematical proofs to have confidence in certain approaches, such as the normal equations as the closed-form solution to an ordinary least squares (OLS) regression under the standard assumptions. But as we have access to a wider array of "brute force" algorithms, we need to be acutely aware of *overfitting* and other analytical perils. This is the same reason we took such care with p-values in CEBoK Module 8 Regression Analysts: we didn't want analysts walking around using a CER with an independent variable that isn't really a cost driver.

The Ethical Analyst

My tombstone will read "Too lazy to Google."[22] While that is sometimes true, more often than not I refrain from Googling, at least initially, because I want to figure it out myself. I'm an avid cruciverbalist, and one nice thing about the standard American crossword is that every empty square is included in both an Across and a Down entry, so that there are two distinct clues for words or phrases containing that letter. The only time the solver is unable to fill in a letter is when they have a gap in their knowledge for *both* clues, the dreaded "natick."[23]

That said, there is too much to know these days, and there is no shame in Googling. It's just a more convenient way of doing good old-fashioned research. But there's a fine line between efficiency and cheating. Where we used to look up reference material on Google, or check for standard approaches on StackOverflow, we can now just start typing in ChatGPT, and it will complete our code for us!

I have long thought that ICEAA and the cost community need a formal code of ethics.[24] The initial focus hearkens back to the Speaking Truth to Power strength, to serve as the independent arbiter, to "speak for the data," and not be swayed by program advocates. With the prevalence of AI/ML, that code of ethics needs to extend to the intellectual honesty of our analysis and how we conduct that analysis. As consultants, we are told to apply best practices. As engineers, we are told not to reinvent the proverbial wheel. As coders, we use and even build reusable libraries. Standing on the shoulders of giants is good, but we need to continue to learn and to be forthright about our own contributions. More than anything, we need to understand the powerful analytical tools we wield as best we can so that we will "Do no harm."

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[22] Also, "One last email."
[23] https://en.wiktionary.org/wiki/natick
[24] The RStudio organization (now posit) has a strong statement on data ethics that we might consider adopting.

"I've done my best to live the right way/
Get up every morning, go to work each day/
But your eyes go blind, and your blood runs cold/
Sometimes I feel so weak, I just want to explode…"
-Bruce Springsteen, "The Promised Land"
*(*Darkness on the Edge of Town*, 1978)*

Acknowledgments

This paper was greatly improved by the assiduous reviews of the aforementioned Rick Collins and Brian Flynn. I am inspired by their dedication to mission and proud to call them colleagues.