The Legacy of Parametric Estimating

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Abstract

This paper chronicles the people, methods, and achievements over past centuries leading to today's acceptance of proven parametric methods for credibly predicting future costs of the world's most significant tools, weapons, spacecraft, structures, and processes.

Parametric models, for most cost estimators, became their tool of choice during the past five decades. Parametric methods were refined by government, industry, and academia. They were then enabled by realistic cost and technical databases which satisfied government audit standards, and filled the need for quick, credible, and repeatable cost and schedule estimates. This paper explores the evolution and legacy of these models.

To help appreciate parametrics' foundations, this paper incorporates original research by the late Keith Burbridge who chronicled achievements by early parametricians including da Vinci, Brunel, Bayes, and Freiman - namesake for the ICEAA Lifetime Achievement Award. Frank Freiman developed one of the first commercial parametric modeling systems, working from contemporary databases including the Sears Roebuck catalog.

A compelling example of legacy parametrics assembles the elements of engineering, construction, and economics – the challenge of medieval cathedral builders to estimate their construction costs! As for contemporary model developers, their models incorporated distinctive estimating metrics.

This paper summarizes personal achievements plus contributions from cost estimating societies and associated initiatives. The International Society of Parametric Analysis (ISPA) is one of several original societies merging to create the International Cost Estimating and Analysis Association (ICEAA).

Author Bio

Henry Apgar is an MCR cost engineer, with 45 years' experience developing parametric models and statistics-based parametric cost estimates for international government and commercial clients.

Hank is a lifetime ICEAA member and a Certified Cost Estimator/Analyst (CCEA), with a degree in electrical engineering and an MBA. He authored the Cost Estimating Chapter for the Space Mission Engineering Handbook; previously, he was a cost engineer at The Aerospace Corporation.

He is co-founder and past president of ISPA and recipient of the Freiman Lifetime Achievement Award.

Contents

1. Early History

Figure 1- Hank Apgar and Dave Mizer present first Parametrician-of-the Year Award to Keith Burbridge (1982).

Our first ISPA Secretary, **Keith Burbidge**, published a well-received tome in 1984 entitled, "A Touch of History," with 27 original vignettes of famous kings, clergymen, military officers, financiers, scientists, engineers, and others who employed parametric methods to predict future outcomes - mostly cost. Keith noted, "*None enjoyed the advantage of a modern computer, although some created mathematical simulative models of considerable elegance."*

Keith was honored posthumous by being named for the ISPA annual Service Award. He was an early recipient of the Parametrician of the Year Award, as seen in **Figure 1.** His vignettes begin chronologically with the introduction of parametrics during the Golden Age of ancient Greece.

One vignette was about **Leonardo da Vinci** (1452-1519), who developed a sales price cost estimating relationship (CER) for Italian cargo ships based on their size and capacity. City-State Genoa derived its wealth from shipping; the citizens owned and operated shipyards, including tracked ship production assembly lines. They measured the costs at each station where planking, decking, deck-houses, internal fittings, masts, and external rigging were added. Leonardo, engineer and mathematician, designed the process and, in doing, developed the means to establish the sale price of each vessel. These early CERs are exhibited in the Vatican Museum.

Another vignette, which should resonate with attendees to the **2017 ICEAA International Conference in Bristol, UK**, is about **Isambard Kingdom Brunel** (1806-1859), Bristol bridge builder (Clifton Bridge), ship builder (SS Great Britain), railroad builder (track and rolling stock), and applied mathematician. Brunel scorned the 4' 9" standard gauge railroad track, laying instead a wider track of 7' 6" and designed all his rolling stock for the wider gauge. While his practice set up interesting problems of logistics where rival lines intersected with Great Western Railway (GWR), the decision was based on sound engineering and applied mathematics.

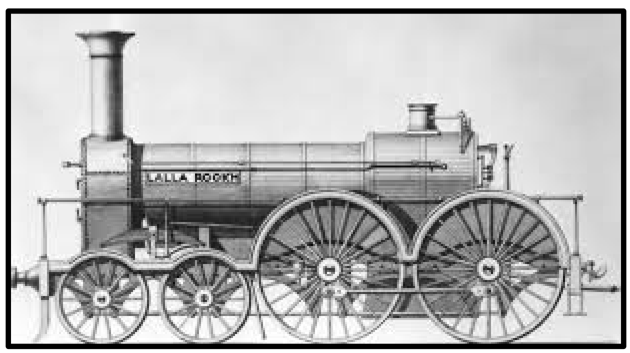

Figure 2 – Early Brunel locomotive for GWR and basis for early railroad CERs.

Brunel, a pioneer parametrician, evolved an elaborate series of CERs dealing with foot-print, locomotive and railroad car weights, tractive power per unit of consumed fuel, and a parameter for rail "striction." His system required more right of way to lay the wider track, and more wood for the wider track ties. Against these cost factors were traded heavier locomotives (as in **Figure 2)** and haulage loads (both passenger and freight), better traction and stability, and less rail wear over time. Brunel ran a cost/benefit analysis based on cost per ton-mile and demonstrated a more cost-effective operation for the GWR. Details come from an exhibit at the British Rail Museum in London.

Brunel's belief that anything manufactured could be expressed in monetary metrics per unit of weight or size. He provided his CERs to **Cyrus W. Field** (1819-1892) who was planning to lay the first submarine cable between Newfoundland and Ireland. After three failures (mostly broken cable) using cable-laying ships provided by the US and UK governments and great monetary loss, Field leased Brunel's great paddle wheel steam ship, the Great Eastern, and the cable was laid ahead of schedule with zero failures. More interesting to our audience, is the fact that the total cost of the project including cable spinning, copper wire, enamel clad iron wire, waterproofing, and installation labor matched Brunel's predicted CER of $0.28 per foot or $0.75 per pound.

Thomas Bayes (1702-1761) was founder of the Bayesian School of Statistics and had much in common with the parametricians of today. He was preparing a treatise for the Royal Academy on parametric analysis. An earlier manuscript read, in part, "*I am convinced that the Universe functions in obedience to some Divine Model…I am constrained to believe that among men of affairs, whose paths lie in fields of business and commerce, a means is needed whereby the units of monetary systems can be related to the products in the market place. It has occurred to me that mathematics might be applied to the problem of determining a priori, the cost of a fine fowling piece [*A shotgun or scattergun*], a chronometer, or a sextant, especially when more than one of these instruments is to be crafted. …It should be possible to contrive a model by which money, skill, time spent in labor, and the fineness of the article crafted [parameters?] might be related. What is needed is to discern the outcomes desired, then arrange the known variables to accommodate these outcomes. [CERs?]. It may be that the laws of chance will play no small part in this process, and the probabilities attendant upon each set of events are as yet unknown. I envision for future ages; a model of such capabilities as might become standard for employment in every counting house [a computer?] in the nation…"* Unfortunately, the Reverend Thomas Bayes died before completing his manuscript.

2. Economics of Cathedral Building

I was intrigued by the vast number of European cathedrals and the central role that cathedral building played in the life of medieval families, as described in Ken Follet's historical novel, "The Pillars of the Earth."

During the high middle ages, between 1100 and 1250, the Catholic Church built over 1400 Gothic churches in the Paris Basin, alone. According to Denning (see References), this lavish ecclesiastical building campaign absorbed more than 21% of the regional economy. The building program, and the supporting economics, are well documented with enough data to estimate and convert these costs into current US Dollars. Thus, one can compare their building efficiency with more recent US experience.

The significant cost drivers for cathedral building during this period are seen to be:

- **Labor** was abundant, but mostly unskilled peasants who learned on the job. Since the church was the typical financier, some labor was voluntary and not included in the cost database. And, as noted by Kraus (see References), many cathedrals were built with some slave labor. It has been estimated that cathedral building during this period employed 9% of available local adult males with an average building crew size of 309 workers.
- **Material** was a major cost driver, depending on source location; being close to a forest or a quarry made some difference since material transport was a significant cost driver. Think of Stonehenge where large (20 ton) building blocks were shipped overland by hundreds of miles.
- **Design** standards and building complexity evolved slowly, with the French in the lead at this time. Every cathedral was a unique 'new design.' Even adjacent towers of the same cathedral were sometimes different[1]. But, since Gothic churches served as symbols of wealth and power for the Church at that time, the focus was on size and grand design – essentially built for height and light.

[1] Usually, drawings were not used – at best, only a timber model. Medieval units of measure were based on classical geometry, often recorded on metal or stone rods.

- **Management** was skilled and developed a class of professional builders who served as designers, master masons, site managers, trainers, and project integrators. And, they often worked to an annual budget (design-to-cost).
- **Funding**, however, was sporadic, since the Church and the local bishop often ran out of funds - forcing trained labor to be furloughed for months or years at a time. Even the neo-gothic Washington Cathedral took 81 years to complete during the 20th century. As with large military systems, delayed projects cost more. Medieval funding sources also included tithes, land rents, donations, bequests, judicial fees, sale of indulgences, and income from various monastic endeavors including agriculture. During the high middle ages, 1,472 Gothic churches were built in the Paris Basin, according to Denning (see References). It is estimated that more stone was quarried in France during this period than in ancient Egypt during its whole history[2]. The cost of the building site usually was not considered part of the estimate as many were built on the sites of existing Roman monuments.

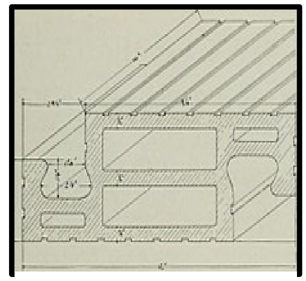

Figure 3 – Building Cost Metric was key estimating parameter.

Most interesting, however, was the development of a **cost metric**, developed in the 1300s by the French, based on the "unit building method" (see **Figure 3**) and which is defined by James (see References) as a small section of the cathedral based on then building techniques as developed by 'quantitative surveyors.' **Chartres Cathedral**, in **Figure 4,** for example, consists of 7,448 such units where one unit would cost $81,500 in 2018 US dollars to build. By this method Chartres Cathedral (begun in 1145 as a flamboyant gothic style cathedral with mismatched spires) would have cost **$607M** to build (in 2018 dollars) with limestone. One can imagine, however, the intricate, and perhaps uncertain, method of collecting 12th century costs in the local (and unstable) currency, then converting to US dollars, and accounting for inflation over 9 centuries.

Figure 4 – Chartres Cathedral; cost $607M in current US dollars to build.

Currencies were not stable during the big cathedral building period, but the French **livre** [pronounced lee-ver] was most stable within Europe and it was common to convert other local currencies (pounds, lira, marks, etc.) into livre. The livre was the currency of the Kingdom of France and its predecessor state of West Francia from 781 to 1794 AD. Coins were issued in gold, silver, or copper. Converting labor and material cost (with inflation) across 9 centuries was another challenge, considering that some of these countries were not what we could consider countries today and even those that were have undergone major government and economic changes. But, the conversions were accomplished and documented strictly. Most references estimate one livre in the year 1200 to be worth about $1,160 in 2018. Much of the conversion rationale was based on the statistical French database maintained by the National Institute of Statistics and Economic Studies (INSEE).

Financial documents do exist during this building period from England, France, Germany and Italy describing the budgets (cost of work planned) and actuals (cost of work completed) as well as the

[2] The Paris catacombs, dug primarily to produce cathedral limestone, are more than 200 miles in length.

cost changes whenever the design changed (contract mods). Not quite an example of modern earned value management (EVM) - but the intent was the same. Also consider:

- How realistic is the estimate for Chartres of **$607M** (converted to 2018 dollars)? By comparison, the 83,000 square feet Washington Cathedral (1907-1990) cost $65M in TY$. This included a $34M underground garage and two full sets of bells (carillons). Converting this then-year (TY) cost to fixed-year (FY) 2018 cost would be **$665M**, or a cost today per square foot to approximately $8,010/sq ft.
- Compare this cost with the typical American residence of $150/sq ft, the World Trade Center of $1,100/sq ft, and the new Apple Park of $1,750/sq ft. Of course, a cathedral includes much more volume than a residence of office building of the same square footage.

3. Maturing of the Parametrics Culture

3.1 Evolution of Professional Societies

Professional cost estimating societies have played a significant role in maturing the culture of parametric cost estimators. Following WWII, there was renewed focus on credible predictions of future program costs for costing budgets and programs. Gene Fisher, a disciple of David Novick at RAND, developed the concept that cost analysis models and their CERs should be open-ended with respect to key cost-generating variables to accommodate ranges of parameter values to measure what effect that would have on cost estimates; thus, the concept of cost sensitivity would be investigated, leading to better understanding of cost uncertainty.

The earliest US professional cost society devoted to aerospace and military systems was chartered in 1960, when Roy Ashe of Convair recognized that existing cost estimating societies focused on civil engineering and construction projects and so he led creation of the **Industrial Estimating Society of San Diego** (IESSD) to focus more on aerospace projects (see **Figure 5**). There were 160 local estimators at their inaugural meeting. Six years later (in 1966), they merged with the **National Estimating Society** (NES) to focus on cost engineering issues beyond aerospace. Then, the **Space**

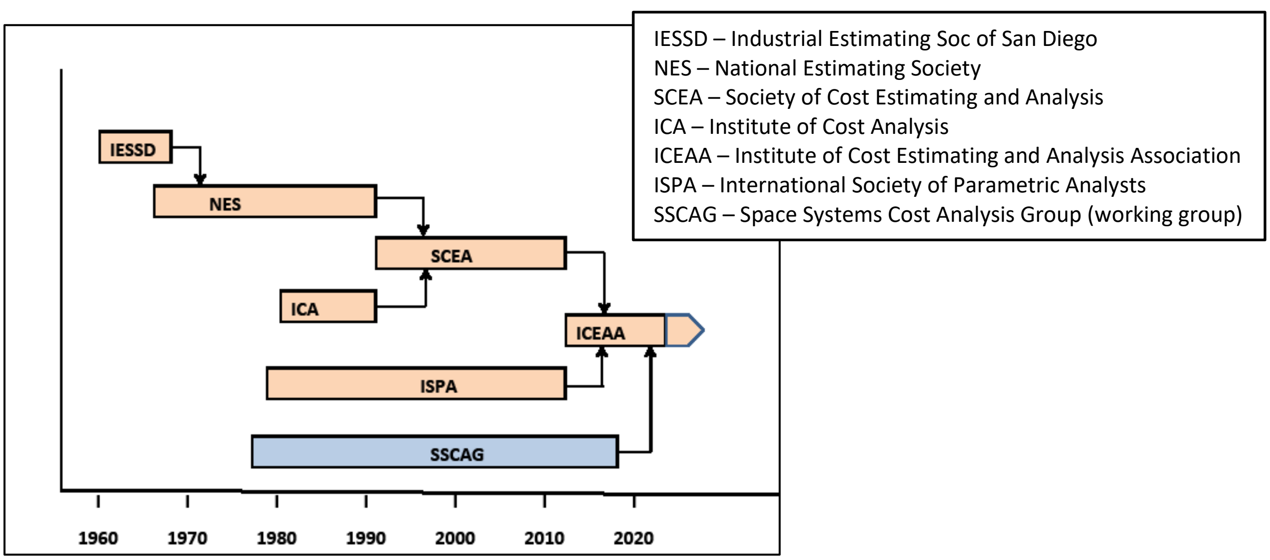

Figure 5 – Consolidation of estimating societies in America reflects the changing environment and methods employed by cost estimators – particularly parametric.

Systems Cost Analysis Group[3] (SSCAG) was chartered jointly by USAF, NASA, and contactor organizations in 1977 to further interests by parametric estimators supporting the growing military and civil space industries. SSCAG soon enrolled as many international organizations as US organizations.

Then, in 1978, 300 international cost engineers, with primary interests in parametric estimating methods, convened in Washington DC to charter the **International Society of Parametric Analysts** (ISPA). ISPA was founded to promote the development, application, and acceptance of parametric cost estimating methods throughout government and industry. Prior to IPSA's charter, parametric estimating methods and cost modeling techniques were limited to engineering trade studies, cross-checks on program and proposal estimates, and proposal bid decisions. This motivated group of cost engineers in the US and in Europe joined forces to share experiences and to jointly proclaim the virtues and advantages of the parametric approach for business decisions and for program management.

Their initial goal was to convince the US Government to allow parametric cost estimating models to be used for DoD cost proposals. SSCAG and ISPA formed a close bond since there was strong participation between the two memberships; they frequently sponsored joint international meetings.

To supplement NES which attracted mostly industry members, the US Department of Defense (DoD) in 1981, with support from government support contractors and federally funded research and development centers (FFRDCs), established the **Institute of Cost Analysis** (ICA). Their goal was to provide universal training in parametrics and other estimating methods at annual conferences and local workshops.

Then, in 1990, NES and ICA merged to form the **Society of Cost Estimating and Analysis** (SCEA). Reasons for the merger included the quest for economy of scale by holding a single annual conference with similar training programs and a single management office. ISPA declined to join the merger initially, citing their ongoing focus on wider use of parametric estimating techniques but joined later, after first achieving their goal of universal acceptance of parametric methods with the US Government in 1999.

In 2012, SCEA and ISPA merged to form the **International Cost Estimating and Analysis Association** (ICEAA), for some of the same reasons that NES and ICA had merged 22 years earlier. In 2017, SSCAG joined ICEAA as a special interest group (SIG) focused on space system estimating.

3.2 Parametric Achievements by Decade

The past decades have seen major developments and applications for parametric cost estimating tools and techniques, as summarized in **Table 1** and followed by a detailed narrative by decade.

Table 1 – Evolution of parametric achievements by decade.

Decade	Emphasis	Innovations	Artifacts
1930s-1960s Statistical Estimating	Statistical cost estimating.	RAND Cost Analysis Dept.; industrial engineers.	Learning curve equations, aircraft production CERs, deductive models.
1970s: Emphasis on Parametrics	Cross-checks on engineering estimates; introduction of commercial models; support decision makers.	Mainframe models; 300 baud timeshare terminals; TI-59 calculators.	Inductive models; PRICE model; DTC; CAIV.

[3] SSCAG was, strictly, not a professional society but a government/industry working group of organizations (rather than of people).

1980s: Golden Age	Parametrics for government proposals; large databases; software CERs; ISPA chapters; uncertainty.	2400 baud PCs; MS degrees in Cost Analysis; model comparison studies.	SEER models; COCOMO model; expert system models; special purpose models.
1990s: Applications	PCEI Reinvention Laboratory; independent cost estimate; business case analysis.	Everybody needs a tool; Europe joins initiatives; cost forecasting.	Parametric Cost Estimating Handbook; government cost analysis agencies.
2000s: Quality	Affordability; credibility; Monte Carlo risk; software sizing (cost drivers).	DoD/NASA guidance;	Estimating handbooks; data books; NASA CARD; NASA CADRe; quality metrics
2010s: Information	Cloud computing; focus on data rather than models.	Mathematicians; scientists; risk analysis.	Wait and see.

Statistical Estimating – the 1930s through 1960s

Post WWII, NASA and USAF studied multiple scenarios concerning how the country should proceed into the age of jet aircraft, missiles, and rockets. The military saw a need for a stable, highly skilled, cadre of operations researchers (OR). In 1950, the RAND Corporation established its Cost Analysis Department under David Novick for the purpose of analyzing weapons system costs using operations research (OR) methods developed during the war. One of their first challenges was to identify the elements of cost, later to become the standard work breakdown structure (WBS). Once cost elements became common, and cost drivers could be identified, the RAND analysts focused on developing cost estimating relationships (CERs); the term parametric cost estimating became common by 1952. Novick developed the concept of "cost considerations in systems analysis." Subsequently, RAND found it necessary to differentiate between one-time outlays - non-recurring expenses for investments and recurring expenses for procurement and operations. David Novick retired in 1971.


Figure 6 - Frank Freiman receives Honorary Director Certificate from Bryant Barnes, first ISPA President, at close of Charter Meeting in Washington DC (1979).

Emphasis on Parametrics – the 1970's

During this decade, government and academia lead the push to adopt a parametric approach to cost estimating. RCA PRICE Systems unified international parametricians with their PRICE Model Users Group. In April of 1979, some 300 international parametricians from eight countries met in Washington DC to test the feasibility of an independent professional society - the International Society of Parametric Analysts (ISPA), dedicated to the principles of developing and applying parametric methods to the process of predicting future costs. Although cost prediction was of our greatest interest, some members were also interested in predicting performance, size, reliability, and other metrics important to our high-tech community. **Frank Freiman**, then-Director of RCA PRICE Systems, actively supported the formation of ISPA and later was honored by ISPA as its Honorary Director, as shown in **Figure 6**.

Those early parametricians were mostly cost engineers and program estimators, with a strong representation from the ranks of statisticians, scientists, and program managers. The representation was about equal between government and industry and 15% represented academia. Their unifying concern among US representatives was the Lack of acceptance by the US Department of Defense (DoD) for parametrically-generated cost proposals in spite of government and contractor engineers routinely using parametric estimating tools for preliminary estimates, for engineering trade studies, and for estimate cross-checks. Conference Registration fee was $50. Annual dues were set at $10 ($5 for students).

Prior to the ISPA Charter Meeting, RCA PRICE had released its first family of commercial cost estimating models, identified as PRICE-H (1973), PRICE-L (1976), and PRICE-S (1977). Frank was honored posthumous by becoming the namesake for the ISPA (and now ICEAA) Lifetime Achievement Award.

The most-noted initiative of those first years was the application of parametric models for primary estimates, not just for cross-checks or for engineering trades. Typical presentations at follow-on conferences were case studies on how parametric methods had produced estimates more useful than from other methods, in less time, and with less-detailed information. The application of statistically-derived algorithms relating cost parameters (dependent variables) to non-cost parameters (independent variables) was already in widespread use as for engineering cost estimates at NASA and at most aerospace organizations.

Golden Age – the 1980s

In 1981, the first of 52 ISPA Journals assumed responsibility for developing a new standard and vision for parametrics. Many of these papers attracted large international audiences when presented at subsequent ISPA and SCEA conferences (see **Figure 7**).

Figure 7 - ISPA and SCEA members learn from the masters at the international conferences.

Other generally-available cost prediction tools (mostly software) followed, including Larry Putnam's QSM SLiM (1979); Barry Boehm's COCOMO (1981); PRICE-M (1982); Don Reifer's SoftCost-R (1986); Caper Jones' SPQR/20 (1986) and later rereleased as CheckPoint (1988); Dan Galorath's SEER-SEM (1987) and SEER-H (1990); and Randy Jensen's Sage (1996). This was, indeed, an exciting time to build a professional society dedicated to the development and application of parametric cost estimating models which could be developed by inductive reasoning, where the modeler (as quoted by Frank Freiman) believes, "It should work this way."

Subsequent parametric journal articles in the 1980s focused more on software models than hardware models - trying to catch up for the previous decade when industry focused on hardware estimates and software was simply a percentage of the hardware estimate. For example, three of the six articles in the December 1984 journal proposed methods and applications for software estimating. In the September 1984 issue, three of the four articles described software estimating, and the September 1986 issue featured four of the five articles on software estimating techniques.

David Parker, British Diplomat, while assigned to the UK embassy in Washington DC, described in the December 1985 Journal the emergence of parametric estimating in the UK defense industry. He proclaimed that parametric estimating was introduced to UK companies who were bidding on US defense contracts, including AMRAAM. This led to incorporation of the concept of the UK Design for Through Life Costs (DTLC). Parker pointed out that parametrics applications in the UK were pioneered by industry, rather than by the government, which was the reverse from the case in the US. The European Space Agency (ESA) followed later with an article (September 1985) by Achim Franzke, Chief of the ESA Cost Analysis Division, and Joe Lex, who described their ESA parametric Cost Model (ECOM).

During the 1980s, ISPA pursued a deliberate path of international relations, implementing the plan for an international conference every four years, as seen in **Figure 8**. International acceptance was due also to wider offerings of parametric-type training and invitation to a wide range of business cultures. ISPA chapters were formed in the UK, Germany, France, and Korea. Several European nations adopted parametric initiatives of their own, modeled on the US Parametric Cost Estimating Initiative (PCEI) as described later in this paper.

Within our first decade, ISPA members began expressing (in Journal articles) our own identity. In the June 1986 Journal, Bernie Grabois pondered how parametricians should be organized and to which department the parametricians should be assigned. His 1985 survey of 286 ISPA members attending the 1985 conference concluded that Engineering was the preferred location with Finance a distant second. Bernie cited a 1979 conference presentation by Noel Hargrove on integrating parametrics into the management decision process with the goals of: (1) permanent staff, (2) with modeling their sole assignment, (3) with a technical orientation, (4) with access to top decision makers, and (5) with the opportunity to interface with designers, pricers, and managers.

Figure 8 - We found time to network at international meetings (Frascati, Italy in 2004).

In March of 1986, Paul Garvey introduced the concept of measuring uncertainty in a software development effort estimate, where he recommended the triangular density function and provided a table of suggested confidence levels. This led to a plethora of innovative risk articles by Bob Black, Jim Wilder, Paul Garvey, Steve Book, and others.

Near the end of this decade, the January 1989 Journal published an editorial "The Next Decade," by Keith Burbidge, Journal Editor, in which he summarized the closing decade this way: *"ISPA celebrated its 10th anniversary during 1988, and those members attending the Summer session in Brighton (UK) could not fail to be impressed with the rapid pace of technological change within our chosen profession. In the space of ten short years, our working tools have changed markedly, from 'dumb' terminals operating at 300 baud, to the ubiquitous PC and 2400 baud. When ISPA began, one hardware estimating parametric model was the only game in town. Today, a wide variety of models is the norm. Estimators have changed, too. The green eyeshade, the #2 pencils, the adding machine – all essential to the stereotyped estimator - have vanished. The new 'genus estimatoris' is as much at home with risk analysis, computers, and databases as with learning curves and the cost of money. Societies are people united by common aspirations, motivations, and excellence. Thus, as people changed, so did ISPA, from a small group of like-minded economists, engineers, estimators, and operations research personnel, to a major society in which could be found representatives from almost every technical discipline."*

<u>Applications – the 1990s</u>

Our August 1991 journal reprinted the 1991 Conference keynote address by Larry Uhlfelder, then Assistant Director for Policy and Plans, Defense Contract Audit Agency (DCAA), who explained DCAA's policy regarding audits of parametric cost estimates. Larry referred to a previous article in the Spring 1982 Journal by Chuck Starrett, then the DCAA Director, who identified the five major **auditing criteria** to be verified before submitting a parametric estimate to the government, and still valid today, to be:

1. Logical relationships,
2. Verifiable data,

3. Significant statistical relationships,
4. Reasonably accurate predictions, and
5. Proper systems monitoring.

The May 1995 journal published the 1993 ISPA Conference Keynote Address by Bill Reed, then DCAA Director. After referring (again) to the watershed presentation in our 1982 Journal, entitled, "Parametric Cost Estimating – An Audit Perspective," by the Director of DCAA, Bill reiterated DCAA's support to parametric estimating for contractor proposals but went on to identify where many such proposals were failing the original auditing criteria. The contractor **parametric estimating failures** were perceived to be:

- Estimates not based on actuals or updated data,
- Estimates over time varied significantly,
- Estimators and accountants not communicating with each other,
- Lack of written policies and procedures, and
- Estimates made by persons not responsible for performing the work.

Back in 1981, the DoD established their acquisition initiative, **Design to Cost** (DTC). The initiative would focus on reducing expected unit production cost during the development phase of major acquisitions. Unfortunately, DTC did not entirely succeed because:

- Estimators focused on production cost, rather than life cycle cost.
- The "User" (source of the performance requirements specification) was not involved later in the design trade process.
- There were no mission affordability goals; performance goals were still the driver.
- Cost targets and cost estimates were still absolute measures, rather than being defined by probabilistic bands, thereby making success an unattractive all-or-nothing prospect.

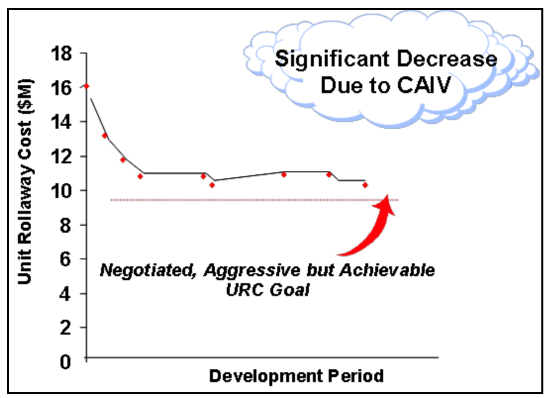

Figure 9 - Unit Rollaway Cost was reduced 30% on the Crusader Program through application of CAIV.

So, faced with a 60% reduction in the DoD acquisition budget from 1985 to 1994, a new cost-reduction initiative, **Cost As an Independent Variable** (CAIV), was introduced in 1995. The consideration of cost as the independent variable launched a crusade for parametric modelers and estimators and they embraced the fundamental tenets of CAIV, through early affordability studies of CAIV flagship programs: Joint Strike Fighter (JSF), Air Force Evolved Expendable Launch Vehicle (EELV), Army Crusader vehicle (see **Figure 9**), and Navy Aim-9X Sidewinder Missile.

The new CAIV tenets were seen to be:

- Focus on life cycle cost,
- User is stakeholder,
- Realistic but aggressive goals, and
- Risk dimension of targets and estimates.

And, so we see a maturing of our discipline over the previous decade, with less emphasis on model selection and estimating methods, but with more emphasis on applications of parametric estimates and focus on estimate credibility.

For the special millennium issue of Parametric World newsletter (Dec 1999); leading Parametricians were invited to answer the question: “What do you regard as the most significant parametric accomplishments of this century?” The responses (in order) were:

1. Commercial parametric models, e.g. PRICE, SEER,
2. Parametric Cost Estimating Initiative (PCEI) to gain DoD proposal acceptance of parametrics, and
3. Evolution of professional societies as a catalyst for knowledge sharing.

Then, Eleanor Spector, Director of US Defense Procurement, in the Office of the Under Secretary of Defense (OSD) Policy Memorandum, in August 1999, released DoD’s **Parametric Estimating Policy** which endorsed (and encouraged!) the use of parametric estimating methods for contractor cost proposals. This step, two decades after the formation of ISPA, satisfied the primary reason for our establishment.

<u>Quality – the 2000’s</u>

The Summer 2006 Journal of Parametrics featured an invited article by Rich Hartley from his position as Deputy Assistant Secretary of the Air Force and Chair of the Air Force Cost Analysis Improvement Group (AFCAIG), entitled “What are Quality Cost Estimates?” in which he identifies the following areas to ‘watch out for’ when preparing government and contractor cost estimates:

- Lack of transparency associated with data sources or estimating methods used - failure to establish a clear track from actuals to estimates that can be reproduced by a knowledgeable reviewer.
- Use of, for cost estimating or cross-check purposes, piecemeal (partial) data or data that otherwise cannot be traced to auditable total program cost data.
- Use of select data and estimating models from multiple sources - raises suspicion of “cherry-picking” to get pre-desired results.
- Unrealistic risk-analysis metrics, i.e., not defining risk inputs, not tracing them to historical experience, and not relating risks to estimate confidence probability, as shown in **Figure 10**.
- Excessively detailed briefings to decision makers or inclusion in such briefings of information extraneous to the decision to be made.
- Failure to integrate schedule and time-phasing with the cost estimate.
- Lack of, or improper, calibration.
- Omitting cost elements (i.e., systems-of-systems level, systems engineering, and program management).

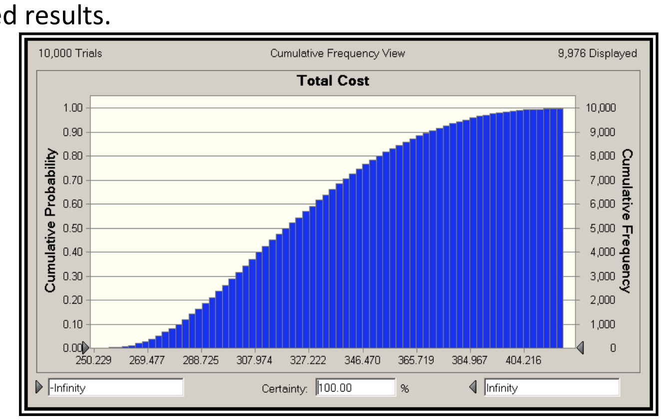

Figure 10 – Cost risk must be based on historical experience and related to estimate confidence.

Then, in the Spring 2007 issue, Joe Hamaker, Director of the Hq NASA Cost Analysis Division, provided his response to the first “What are Quality Cost Estimates?” article but adding his own most important attributes of quality in cost estimating to be:

- Sufficient reserve to cover the “up morphs” that most projects undergo.
- Independent cost estimates performed by non-advocates.

- Top-level sanity checks.
- A management culture that desires good estimating.

These two quality-focused articles by government executives were quickly followed, in the Fall 2008 issue of the Journal of Cost Analysis and Parametrics (successor to the ISPA Journal), by a contractor perspective written by Richard Janda, Vice President of Program Assessment and Evaluation, Lockheed Martin. Richard believes the following characteristics assure a quality cost estimate:

- Is the estimate based on objective data?
- Is the analysis honest?
- Are the data and analysis relevant?
- Is the basis of the cost estimate logical?
- Is the estimate accurate?
- Is the estimate holistic? Integrated? Complete?
- How well is the estimate communicated?

Then, in June 2009, Stephen Bagby, Deputy Assistant Secretary of the Army for Cost and Economics and the Director of the Army Cost and Economic Analysis Center (CEAC) entered the debate on estimating quality to describe the Army process to ensure the probable costs of its programs are adequately reflected in the budget.

Information – the 2010's

Finally, in the Winter/Spring 2010 issue, Herve Joumier, Head of Cost Engineering at the European Cost Agency (ESA) describes estimating quality from the perspective of the cost engineering situation in Europe and its impact on the current state of the world economy. Of significance is the extrapolation of risk analysis to include schedule as well as cost risk, as shown in **Figure 11.** Each point of the chart shows cost and finish time or duration of the project for each iteration, within established cost and schedule targets (green points). This chart makes it possible to visualize the chance that both cost and schedule objectives will be met. Yellow points show deterministic results.

NASA expands JCL process which develops joint **cost and schedule** confidence level (considering risk) to quantitatively assess the likelihood that the project can be completed within the predicted budget (y-axis) and on time (x-axis). Advantages of this approach are:

- Supports risk-adverse and risk-tolerant decision makers.
- Supports portfolio cost policy implementation analysis (Joe Hamaker, 2006)
- Supports planning budgets between specific ranges, such as 50% - 70% confidence.

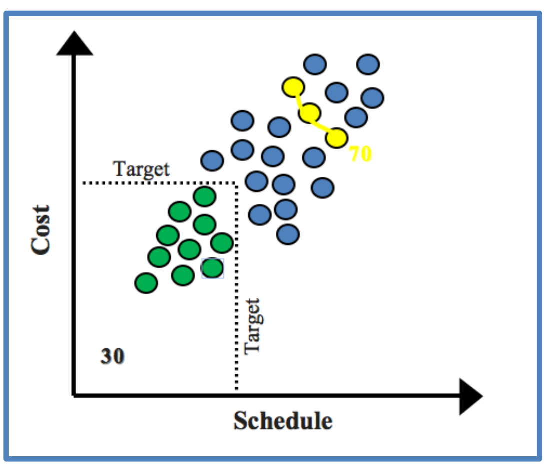

Figure 11 - Joint Confidence Level (JCL) considers both cost and schedule risk.

Ricardo Valerdi, frequent ISPA Journal contributor and current co-editor of its successor, the Journal of Cost Analysis and Parametrics (JCAP), attributes the growth of parametrics to the synergy between industry, government, and academia. He cites the continuing need by industry to better understand the total cost of ownership and to anticipate the opportunity to acquire cost databases from the many large programs being funded during the 1980s and 1990s. Industry began sharing their best practices through professional societies, such as ISPA and SCEA, which provided a neutral forum for knowledge sharing. The societies became an enabler for sharing knowledge and for integrating best practices in their training and certification programs.

In his Keynote Address to a joint ISPA/SCEA Southern California Workshop in March 2011, Dan Galorath expressed the opinion that future parametric cost estimating models would be **data-centric**, rather than CER-centric. Dan feels that the key to good estimating is access to objective, complete, relevant, and verified information. Focus on the database rather than the CER.

A recent illustration of this focus may be found in the NASA Cost Analysis Data Requirement (CADRe) initiative for building cost databases. The CADRe documents the programmatic, technical, and life cycle cost information for Category I and Category II Flight Systems and Ground Support Projects. It is the NASA version of the Department of Defense Cost Analysis Requirements Description (CARD).

4. The Parametric Cost Estimating Initiative (PCEI)

The Parametric Cost Estimating Initiative (PCEI) began in January 1994 with an exploratory meeting initiated by Hq Defense Contract Audit Agency (DCAA) and with participation by Defense Contract Management (DCMA) plus 13 industrial organizations serving as Reinvention Laboratory Teams (as shown in **Figure 12**) who agreed to participate in a laboratory-type experiment to determine the feasibility for using parametrics to improve the DoD procurement process. The first step was a series of meetings that explored the barriers to utilizing parametric estimating methods for proposals due to regulatory and cultural barriers.

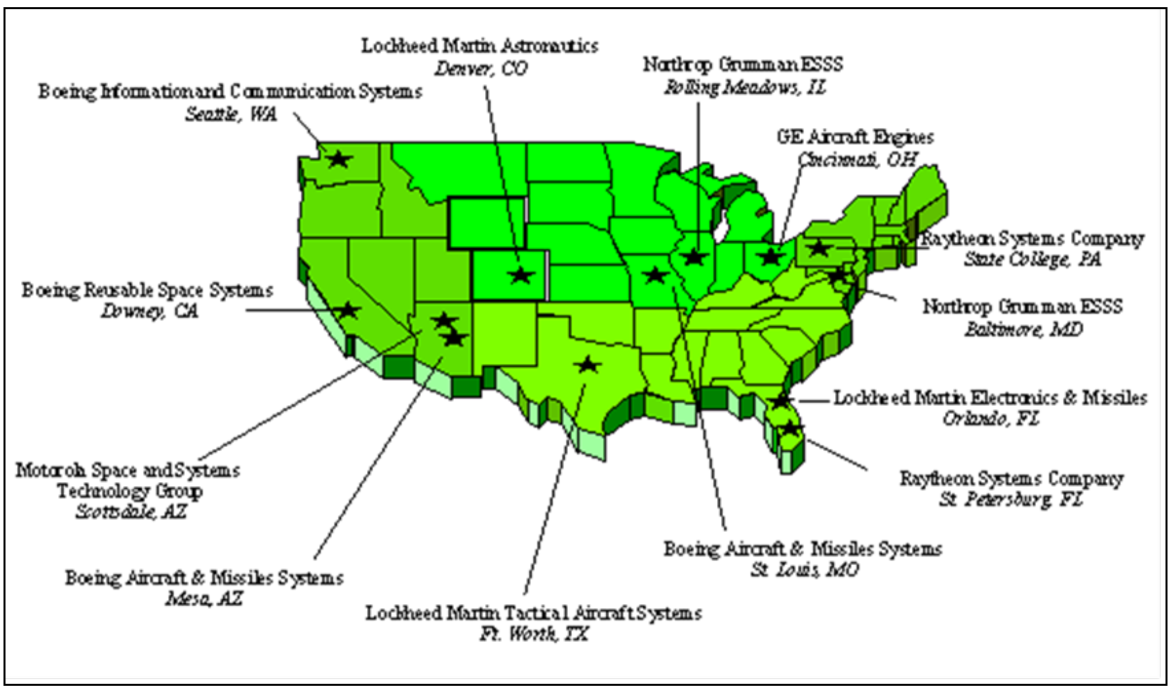

Figure 12 – Parametric Reinvention Laboratory Teams were located across the United States (1994).

The objectives for the Reinvention Laboratory were deemed to be:

- Identify opportunities for using parametric techniques.
- Test parametric techniques on actual proposals previously submitted to DoD and NASA.
- Publish a PCEI Newsletter during the reinvention phase to share best practices and lessons learned, with case studies.
- Recommend parametric-friendly changes for the Federal Acquisition Regulations (FAR).
- Recommend parametric friendly "Instructions to Offerers" in RFPs.
- Publish a Parametric Estimating Handbook.

Success by the PCEI led directly to preparation of the **ISPA Parametric Estimating Handbook** (PEH), shown in **Figure 13**, by a dedicated group of volunteers, first published in 1999 by ISPA and later by SCEA. The PEH became the standard reference for the ISPA Certified Parametrics Practitioner (CPP) exam and was later incorporated into the new ICEAA certification curricula.

The first edition describes early parametric usage this way: *"The origins of parametric cost estimating date back to World War II. The war precipitated a demand for military aircraft in numbers and models that far exceeded anything the aircraft industry had manufactured before. While there had been some rudimentary work from time to time to develop parametric techniques for predicting cost, there was no widespread use of any cost estimating technique beyond a laborious buildup of labor-hours and materials. A type of statistical estimating had been suggested in 1936 by T. P. Wright in the Journal of Aeronautical Science. Wright provided equations which could be used to predict the cost of airplanes over long production runs, a theory which came to be called the 'learning curve.' By the time the demand for airplanes had exploded in the early years of World War II, industrial engineers were using Wright's learning curve to predict the unit cost of airplanes."*

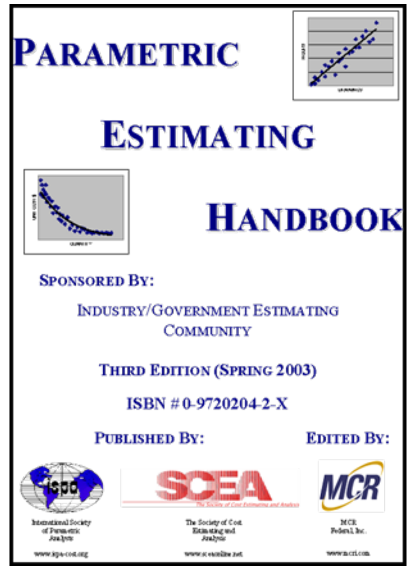

Figure 13 – Parametric Estimating Handbook - PCEI product (1999).

PCEI Laboratory results demonstrated that, when properly implemented, parametric estimates may comply with US Government procurement laws and regulations including the Truth in Negotiations Act (TINA), the Federal Acquisition Regulation (FAR), and Cost Accounting Standards (CAS). Case studies and examples were developed based on the teams' best practices and lessons learned, and they are incorporated in the Handbook, sponsored by HQ DCAA and maintained by ISPA, SCEA, and SSCAG, with:

- Parametric principles, calibration and validation requirements, and guidelines for evaluation of parametric Bases of Estimate (BoE).
- Lessons learned and best practices from Reinvention Laboratory sites.

5. Now What?

The culmination of parametric evolution focuses on integrating multiple methods of predicting cost, e.g., parametric, detailed, analogy, Delphi, to develop a credible cost estimate. Also, the most effective cost Government and industry estimating organizations focus on multiple disciplines, including engineering, economics, program management, schedule analysis, and earned value management, in addition to estimating. The professional cost estimator might be motivated by the initiatives and global visions of our 'early history vignettes.'

How has the professional cost estimator changed over the past decades?

1. There is less need now to develop one's own parametric model. There are available general-purpose parametric models that just need to be calibrated with a few good data points to emulate the user's organization's designs and processes. Some commercial models exploit contemporary databases which adjust for technology maturity.
2. There is a trend away from multiple specialized estimating groups within the same organization with sometimes overlapping responsibilities for supporting bid decisions, engineering trade studies, cross-checks on estimates, cost targeting (CAIV) studies, full-scope estimates for government bids with bases of estimate (BOEs), and program budgets.

3. Similarly, there is less of a distinction between the known estimating methods (parametric, detailed, analogy, Delphi). The skilled estimator incorporates multiple methods as appropriate.
4. Risk and uncertainty are common elements of the parametric estimate.
5. Parametric databases have become the corporate memory.

Now, perhaps, the distinctiveness of parametric estimating may begin to fade considering these evolutionary forces.

<end>

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Acronyms Used More Than Once

CAIV	Cost As an Independent Variable
CER	Cost Estimating Relationship
DCAA	Defense Contracts Audit Agency
DCMA	Defense Contracts Management Agency
DoD	Department of Defense
DTC	Design to Cost
FFRDC	Federal Funded Research and Development Center
NASA	National Aeronautics and Space Administration
PCEI	Parametric Cost Estimating Initiative
USAF	United States Air Force