PARAMETRIC ESTIMATING – PAST, PRESENT, AND FUTURE

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Introduction

Parametric estimating, which involves using design parameters to estimate cost and schedule for hardware, software, and microcircuits, is very popular today with both Government and industrial agencies throughout the world. It has grown extensively since its origins in the 1970s, and is often used as the sole or primary estimating method in many organizations. Despite its popularity, however, parametric estimating presents numerous challenges, and can produce adverse effects if misused.

This paper discusses parametric estimating and it's potential benefits and pitfalls. First, a concise history of parametric estimating is presented. Next, the current status of parametric estimating is summarized, and a projection for the future is given. Finally, some issues for parametric estimating are discussed, along with some suggestions for dealing with these issues.

History of Parametric Estimating

In about 33 AD, Jesus Christ himself said, "Suppose one of you wants to build a tower. Will he not first sit down and estimate the cost to see if he has enough to complete it?" (NIV, Luke 14:28) Undoubtedly, some sort of parametric estimating was used even in Biblical times, such as forecasting cost (and time) based on the size of the tower and materials used. However, parametric estimating as we know it today has its origins in the decade of the 1950s with Rand Corporation studies for the United States (U.S.) Air Force. Furthermore, parametric estimating did not become widely used until the decade of the 1970s. This increase in use was mostly due to Frank Freiman's introduction of the PRICE-H model in 1973, and the PRICE-S model in 1977. Since this time, parametric estimating has become prevalent in both government and Industrial organizations. There has been a proliferation of parametric models, especially in the software cost estimating area. Furthermore, the scope of estimating has expanded from development and production costs to life cycle costs. Additionally, parametric estimating models are now available for other than hardware and software cost and schedule estimation, such as microcircuit estimating and software sizing.

Figure 1 shows a timeline of advancements in parametric estimating from 1973 until the present time (1999). In 1973, the PRICE Hardware model (PRICE-H) was marketed by RCA PRICE Systems as the first widely-available parametric cost estimating model. It estimated the development and production costs of hardware based on design parameters such as weight and manufacturing complexities. It received instant success, and in 1976 RCA PRICE Systems released the PRICE Life Cycle (PRICE-L) model to address the maintenance, or support costs of hardware once it has been developed or produced. In 1977, RCA PRICE Systems released a model for software development costs, the PRICE Software (PRICE-S) model. This model used software design parameters such as software size, application, and complexity to estimate software development cost and schedule. Like PRICE-H, this model achieved considerable success after it was released.

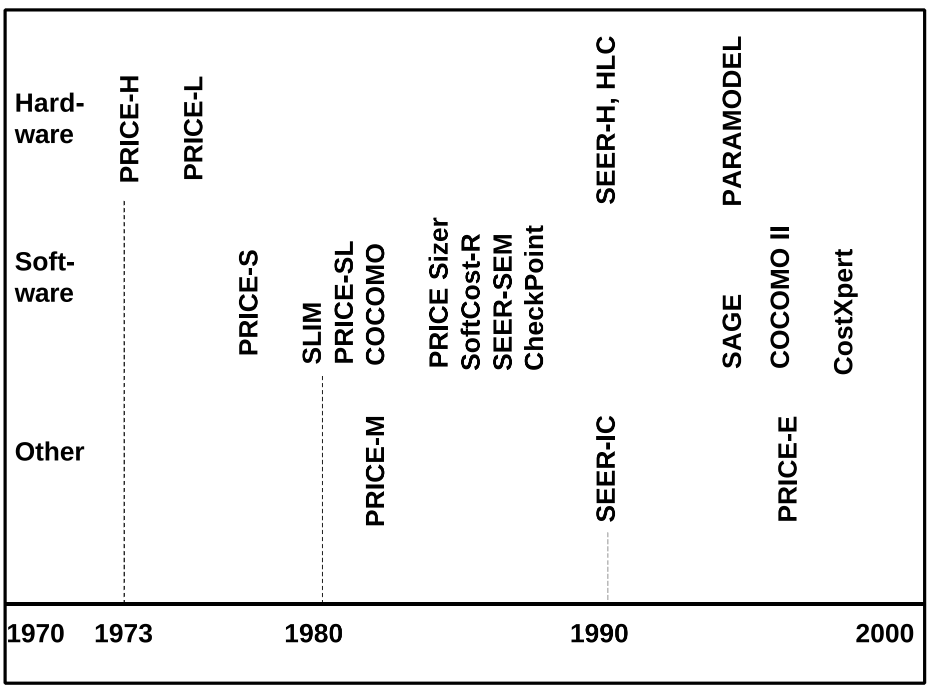

Figure 1: Parametric Models Timeline

Since PRICE-S was quite profitable, other agencies developed parametric software models shortly afterward. QSM Corporation, founded by renowned software estimator Lawrence Putnam, marketed their Software Life Cycle Model (SLIM) in 1979. Dr. Barry Boehm also developed a model, the Constructive Cost Model (COCOMO) during the late 1970s. Instead of marketing COCOMO, however, Dr. Boehm published it in his now-famous book, “Software Engineering Economics”, in 1981 (Boehm, 1981). Meanwhile, in 1980, RCA PRICE Systems released a model to estimate software maintenance, or support costs. This mode, the PRICE Software Life Cycle model (PRICE-SL), was provided to users as part of the PRICE-S model.

With the emergence of microcircuits in the 1980s, PRICE Systems released a model to estimate these costs, the PRICE Microcircuit (PRICE-M) model, in 1982. Meanwhile, a plethora of new software cost and size estimating models were developed and marketed in the mid 1980s. PRICE Systems released a sizing model, PRICE Sizer, to estimate the size of software in lines of code. A new software cost model, SoftCost-R, was developed and marketed by Reifer Consultants in 1986. During the same year, Software Productivity Research released a model named SPQR/20, based on the work of renowned software analyst Capers Jones. This model was enhanced considerably and released as CheckPoint in 1988. The CheckPoint model differs from most other software models in that the preferred size input is function points instead of lines of code.   In 1987, Galorath Associates released the SEER-SEM model for software cost estimation and the SEER-SSM model for software size estimation .

Although several software models were released during the 1980s, there were few hardware or microcircuit models other than the PRICE-H, PRICE-L, and PRICE-M models. This changed in 1990 when Galorath Associates released several models for hardware and microcircuit cost analysis. These were the SEER Hardware (SEER-H) model, the SEER Hardware Life Cycle Cost model (SEER-HLC), and the SEER Integrated Circuit (SEER-IC) model to estimate microcircuit costs. Later in the 1990s, Mainstay Corporation released ParaModel, a parametric hardware model that also performs software cost estimation.

The 1990s witnessed several new software estimating models and techniques in addition to the software estimating portion of ParaModel. Dr. Randall Jensen's company, Software Engineering, Inc., released the SAGE model in 1996. This model emphasizes management factors as key software cost and schedule determinants. Dr. Barry Boehm and a group of research associates at the University of Southern California have developed COCOMO II, an upgrade of the 1981 COCOMO. Marotz, Inc. released CostXpert in 1998; this model has similarities to COCOMO II and has six software sizing options. New techniques have been developed in the area of software size estimation, including function points variants and, more recently, object points.

PARAMETRIC ESTIMATING TODAY

Today, parametric models are widely used throughout the world, and often are used as the primary or, in some cases, the sole basis for estimating. They are especially useful early in a program where detailed information is not yet available. New models and techniques are being developed, existing models such as the PRICE models are frequently being enhanced, and some groups are dedicated to ongoing research in selected areas. For example, the International Function Points Users Group (IFPUG) continually researches function points.

One movement that has been researching and promoting parametric estimating, at least in the United States, is the Parametric Cost Estimating Initiative (PCEI). The PCEI has been a collaborative effort between the U.S. Government and 13 U.S. industrial organizations to evaluate the use of parametric estimating on contractor proposals. The participating organizations used a variety of parametric models and company-developed cost estimating relationships (CERs) to negotiate contracts with their customers. (The majority of the organizations used PRICE-H, PRICE-S, or both as their commercial cost model.) In many cases, the effort and time for to prepare, evaluate, and negotiate a proposal were reduced by 50% to 80% when parametric models and CERs were used as the primary estimating methodology (PCEI, 1999, Appendix F). The PCEI organizations also found that the accuracy of parametric models could be substantially improved when historical data was used to calibrate the models. The findings of the PCEI are described in the final product of this effort, the Parametric Estimating Handbook, published in the spring of 1999 (PCEI, 1999)[1].

Government policy is also promoting the use of parametric models. There is a continuing emphasis on cost as an independent variable (CAIV) and affordability in U.S. Department of Defense and other programs. For example, a recent memo by the U.S. Air Forces' Deputy for Acquisition and Management, Darlene Druyun, encouraged the expanded use of parametric models for these programs (Druyun, 1997). A very recent memorandum signed by Eleanor Spector, the Director of U.S. Defense Procurement, also encouraged the use of parametric models and endorsed the Parametric Estimating Handbook (Spector, 1999). Because of the availability of numerous parametric estimating models and methods, the positive findings of the PCEI, and the emphasis on cost for most programs, parametric estimating is enjoying prominence today.

THE FUTURE OF PARAMETRIC ESTIMATING

The future of parametric estimation looks very promising. New models and techniques are constantly being developed, and current models such as the PRICE models are continually being enhanced. Emphasis on CAIV for defense and other programs will undoubtedly continue. The features of parametric models also abet more frequent use; parametric models are relatively fast and easy to use, are useful early in a program, and require minimal input data if default values are used or if they are calibrated to historical programs. Furthermore, parametric models are being applied to environments and programs where cost has not been actively considered in the past, but is now and will be in the future.

The Air Force Research Laboratory – An Example

An example of such an environment is the U.S. Air Force Research Laboratory (AFRL), which is headquartered at Wright-Patterson Air Force Base in Dayton, Ohio.

[1] The PCEI handbook is available on the International Society of Parametric Analysts (ISPA) World Wide Web site, http://www.ispa-cost.org.

During the 1980s and early 1990s, affordability was not an issue for AFRL programs; the emphasis was on new technology with the focus strictly on performance. However, the Department of Defense's current emphasis on CAIV and affordability is changing AFRL's focus such that affordability is now being actively considered for Laboratory programs.

AFRL emphasis on affordability began in 1997 with the selection of seven "pilot programs" in which CAIV would be actively considered. During the same year, a training program was started with James Gregory Associates to educate AFRL personnel in the use of affordability principles, methods, and tools in the Integrated Product and Process Development (IPPD) method and other analysis techniques[2]. At the Affordability Transition Conference held in Orlando, Florida in April, 1999, the results to date of the seven pilot programs were presented. All programs have been successful at considering affordability, and parametric models, including PRICE-H, were used in several cases.

In March, 1999, AFRL established the Corporate Affordability Council to oversee the implementation of affordability in AFRL programs. The Council is chaired by the (acting) Executive Director, and has one Corporate Affordability Officer (CAO) from each of the ten AFRL Technical Directorates. The Council and the CAOs are responsible for planning for training, assisting Directorates in considering affordability for their programs, selecting new affordability programs annually, and guiding the needed cultural changes throughout AFRL for affordability concerns. Each CAO is the affordability focal point for his or her Directorate. The formation of the Council shows AFRL's commitment to affordability. In June, 1999, the Council selected fourteen more AFRL programs for affordability considerations.

Affordability will assume a greater role in AFRL in the future. At least five new programs will be selected each year for affordability, and, by 2002, it is planned that all major AFRL programs will consider affordability. Consequently, the use of parametric models will increase in AFRL. For example, current plans are to use PRICE-S in the Information Directorate's programs, which are almost all software-intensive. Indubitably, parametric estimating will have expanded use in other laboratory environments and for other applications in the future.

PARAMETRIC ESTIMATING ISSUES

Although the future of parametric estimating looks auspicious, it could be ominous, at least in some organizations, if the models are not used properly and if certain issues are not appropriately addressed. Presented now is a summary of four of the key issues in parametric estimating. It is not intended to be an exhaustive list of

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[2] The course schedule and contents of the James Gregory IPPD courses, and the proceedings of the April 1999 Affordability Conference, are available on the James Gregory World Wide Web site, http://www.jamesgregory.com.

issues, nor a comprehensive discussion of the issues; however, it should help the analyst understand some areas of potential concern.

User Considerations

The current and future success of parametric estimating depends, to a great degree, on proper use of the models and tools available. The user of a model must thoroughly understand the model's capabilities and limitations. For example, the user should understand that parametric models do not provide "pinpoint " accuracy. In reporting the results, a user should specify a statistical range of estimates rather than single values. At best, a single value, sometimes called a point estimate, represents only a 50% probability of successful completion of a program. A user can enhance the credibility of a parametric estimate by using another estimating technique, such as analogy estimating, at least as a cross-check.

Users must be thoroughly trained in the models or methods they are using, and have the necessary experience. A user of the PRICE-H model, for example, should participate in the one-week training class offered by PRICE Systems. Furthermore, the user should have several month's experience in using the model or method in his or her organization, preferably under the observation of another experienced user. The model user must work closely with other organizational personnel in performing an estimate. The writers of the Parametric Estimating Handbook recommend establishing an implementation team consisting of a management council and a technical Integrated Product Team (PCEI, 1999, Appendix F).

Users can further enhance their expertise by participating in professional society activities, such as ISPA activities. They can also enhance their knowledge by participating in conferences such as the annual PRICE European Symposium.

Calibration and Validation

Calibration and validation of the models to a user's environment is the *sine qua non* for effective use and, especially, assessing and improving model accuracy. Calibration is adjusting selected model parameters to the user's organization or environment. Most parametric models provide methods for calibration and encourage the use of these methods. For example, the PRICE-H model has two parameters, manufacturing complexity of electronics (MCPLXE) and manufacturing complexity of structure (MCPLXS), which can and, when possible, should be calibrated using relevant data from historical programs (PRICE, 1996, Chapter 16). The PRICE-S model has a single parameter, a productivity factor (PROFAC), which can and, when possible, should be calibrated using relevant data from historical programs (PRICE, 1997, pp. 80-82). Other PRICE models and other parametric models such as SEER-SEM and SLIM also have calibration methods which should be used when possible.

As stated in the PCEI Handbook, "Calibration is the most significant contributor to model accuracy" (PCEI, 1999, p. 10-15). A 1981 study of calibration of software cost models showed that calibration can improve accuracy by a factor of five (Thibodeau, 1981). Studies such those performed at the Air Force Institute of Technology (AFIT) in the late 1990s have further demonstrated that accuracy is usually enhanced by calibration (Ferens and Christensen, 1998). Statistics such as the mean magnitude of relative error (MMRE) and the percentage of estimates that are within a certain MRE, sometimes denoted as PRED (k) where k is the MRE in question, can help a user determine the accuracy of a model for the database from which it is calibrated (Conte, 1986).

A significant limitation of using calibration statistics alone is that they do not show the expected accuracy of a model for programs outside the database. Since new programs are not included in the calibration database, a model should also be validated. Validation involves comparing a (calibrated) model's results with programs not used in calibration, sometimes called a "holdout sample"[3]. The resulting validation statistics such as MMRE and PRED (k) will be more meaningful predictors of the accuracy for new programs. Unfortunately, validation is usually less accurate than calibration. For example, in an AFIT study by Ourada for a variant of COCOMO, the model was calibrated with fourteen data points of a twenty-eight data point subset of a software database. The results were that PRED (.30) for fourteen data points used in calibration was 0.57, but was only 0.28 for the other fourteen data points (Ourada and Ferens, 1992).

Historical Data Collection

An ongoing problem area in parametric estimation is the collection of quality, relevant historical data. Historical data is necessary for model or CER development, and for calibration and validation of models and CERs. For model or CER development, it is stated in the PCEI Handbook, "the value of a CER depends on the soundness of the database from which the CER is developed…" (PCEI, 1999, P. 3-4). Therefore, model developers must make efforts to collect or acquire quality data.

For most commercial models such as the PRICE models, the database is resident in the model and, in many cases, is not available to the user. Therefore, quality data for model development is not an issue when commercial models are used. However, as discussed previously, the user of these models should still collect or obtain data to calibrate and validate these models for his or her environment. Within-database calibration statistics such as MMRE and PRED (k) often are better indicators of the quality of the database than of the accuracy of the model being calibrated. High MMRE values and low PRED (k) values can be indicators of low-quality data. Therefore, like model developers, commercial model users should also make efforts to collect or acquire quality data.

[3] For small data sets, a resampling technique may be used for validation in lieu of setting aside data as a holdout sample. This technique is described in (University of Maryland, 1997) and summarized in (Ferens and Christensen, 1998).

Building a quality database is an important, but difficult and time-consuming task (PCEI, 1999, p. 3-4). It is necessary to collect not only cost data, but also non-cost data (PCEI, 1999, P. 2-1). These non-cost data include technical factors such as hardware weight and software size, and organizational factors such as personnel skill levels and experience. Furthermore, the data must be normalized for differences among projects such as inflation rates, developmental phases, labor categories, etc. According to Humphrey, effective data collection requires a data collection plan, adequate resources, and a commitment by both managerial and technical personnel (Humphrey, 1990).

Software Parametric Estimation

Software parametric cost (and schedule) estimation is an area of special concern. It is becoming increasingly important because of the rapid growth of software and the increasing dependence of systems on properly functioning software. (A current example is the infamous "Y2K" situation.) However, the history of software projects is replete with substantial cost and schedule overruns.

Currently, there are numerous software cost models available, including PRICE-S, SEER-SEM, SLIM, COCOMO, and KnowledgePLAN (formerly CheckPoint). There are also various models and techniques for estimating software size, a key input for all software cost models. Despite the proliferation of models, however, software estimating is still an enigma in many respects. There are substantial disagreements among software experts as to what factors influence software costs and schedules, and what mathematical relationships exist between the factors and the cost and schedules. These differences are reflected in the models; an AFIT study concluded that models could not be "normalized" or be made equivalent because of the substantial differences among them (Coggins and Russell, 1993). While these differences may provide an interesting collage of theoretical ideas, they often confound the analyst.

Another challenge to software estimation is that the models have not been demonstrated to be accurate, at least for a diversity of programs. A conclusion of an AFIT study conducted in the late 1990s is that development effort was not accurate to within 25% more than ½ of the time, or PRED (.25) < 0.50 (Ferens and Christensen, 1998). According to Conte, Dunsmore, and Shen, a model must have at least PRED (.25) > 0.75 to be credible (Conte, 1986). This conclusion is consistent with results of earlier studies such as the Ourada study mentioned previously. One important mandate from these studies is this*: Never sign, or award, a fixed-price contract for software development!* A cost-plus award fee contract is much more suitable (Ferens and Hunter, 1996).

The area of software support, or maintenance cost estimation is even more problematic. A small study in 1984 concluded that accuracy of software support cost models can not be demonstrated at all. Unfortunately, no subsequent studies have disproved this conclusion. Furthermore, an AFIT study performed in 1998 showed that support cost models differed substantially in definitions of support (or maintenance), staffing profiles, support cost drivers, and other facets (Ferens, 1999). Software support cost models, therefore, should be used only for relative comparisons and not for cost or person-month estimates.

One explanation for the lack of accuracy is probably related to data collection. Many agencies have not collected quality, relevant software data from past programs. Furthermore, data collection is complicated in that some of the key cost drivers are personnel factors such as capability and experience (Boehm, 1981). These factors are often difficult to assess or report accurately. For software support, data is often virtually non-existent. For example, for a U.S. database of more than 3,000 programs, more than 600 programs have development effort and schedule reported, but only 13 have support, or maintenance effort reported! Software developers and supporters would do well to establish a program for data collection as discussed previously.

SUMMARY AND CONCLUSIONS

Parametric estimating has evolved substantially since its origins in the 1970s. Today, there are numerous parametric models and methods available for divers applications. There is widespread usage in both governmental and industrial organizations throughout the world. With emphasis on CAIV and affordability, the number of models and their usage is expected to increase in the coming years.

There is a challenge, however, in that parametric models and methods must be properly used to be effective. A user must understand the models he and she is using and be trained and experienced with them. Users must also perform calibration and validation of models and collect quality, relevant historical data. Users must also understand the current limitations of software parametric estimating models and act accordingly. If models and methods are used improperly, parametric estimating will be of little or no value.

REFERENCES

Boehm, Barry W. 1981. *Software Engineering Economics.* Englewood Cliffs, NJ, Prentice-Hall.

Coggins, George A., and Roy C. Russell. 1993. *Software Cost Estimating Models: A Comparative Study of What the Models Estimate*. Unpublished masters thesis. Dayton, OH: Air Force Institute of Technology.

Conte, S.D., H.E. Dunsmore, and V. Y. Shen V.Y. 1986. *Software Engineering Metrics and Models.* Menlo Park, CA: Benjamin-Cummings.

Druyun, Darleen A. 30 January 1997. “Expanding the Use of Parametrics To Reduce Acquisition Cycle Time and Costs.”, U.S. Air Force Policy Memorandum, Washington, D.C.

Ferens, Daniel V., Kevin L. Brummert, and Philip R. Mischler, Jr. 1999. “A Comparative Study of Model Content and Parameter Sensitivity of Software Support Cost Models.” *Proceedings of the 1999 Joint ISPA-SCEA Conference.* San Antonio, TX.

Ferens, Daniel V., and David S. Christensen. November, 1998. “Calibrating Software Cost Models to Department of Defense Databases – A Review of Ten Studies.” *Journal of Parametrics,* Volume XVIII, Number 2, pp. 55-74.

Ferens, Daniel V., and Major Mark T. Hunter. 1996. “Use of Cost Plus Award Fee Contracts for Software Development Efforts.” *Journal of Cost Analysis*, Spring, 1996, pp. 119-148.

Humphrey, Watts S. 1990. *Managing the Software Process*, New York, Addison-Wesley Publishing Company.

New International Version of the Holy Bible. 1978. Grand Rapids, MI, Zondervan.

Ourada, Gerald L. and Daniel V. Ferens. 1992. "Software Cost Estimating Models: A Calibration, Evaluation, and Comparison." *Cost Estimating and Analysis: Balancing Technology and Declining Budgets.* New York, Springer-Verlag, 1992, pp. 83-101.

Parametric Cost Estimating Initiative. June, 1999. *Parametric Estimating Handbook, Second Edition*.

PRICE-H Version 3.1 Reference Manual. 1996. Mount Laurel, NJ, PRICE Systems.

PRICE-S Version 3.0 Reference Manual. 1997. Mount Laurel, NJ, PRICE Systems.

Spector, Eleanor R. 23 August 1999. “Parametric Estimating”, Office of the Under Secretary of Defense Policy Memorandum, Washington, D.C

Thibodeau, Robert. 1981. *An Evaluation of Software Cost Estimating Models*. Huntsville, AL, General Research Corporation.

University of Maryland. 1997. "The Resampling Project." College Park, MD. Ferens, Daniel V., and David S. Christensen. Fall 1997. “Software Cost Model Calibration, An Air Force Case Study.” *Journal of Cost Analysis.*