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A Parametric Building Cost Estimating System

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PURPOSE

AACE International has established a committee whose primary goal is to advance the practice of parametric cost estimating. One way to advance its practice is to document examples of parametric applications. This paper provides an example of a unique computerized parametric cost estimating system developed for building construction cost estimating. The case discussed here is intended to illustrate what parametric estimating can do, highlight the variety of parametric approaches that are possible, and provide an example of how an individual estimator can develop a parametric system.

INTRODUCTION

In pursuit of continuous improvement, cost estimators continue searching for more effective means to prepare building conceptual cost estimates for project budgets. Fewer owners are accepting gross square foot estimates as a basis for project funding justifications. They are asking questions about ranges, options, risks, and trade-offs—complex questions that the cost estimator is expected to answer quickly and for little expense. Parametric estimating, which includes a broad class of methods such as capacity factoring, equipment factoring, and cost modeling, has much to offer the owner in this regard.

At Eastman Kodak's 'Kodak Park' site in Rochester, New York, the Capital Estimating Department has developed a cost estimating system for buildings that can answer those types of questions quickly with a tested accuracy range of -5 to +15 percent for total buildings, and -15 to +30 percent for any building system. It differs from available parametric square foot systems by eliminating the need for a detail or assembly level cost database. By combining elements of standard square foot unit estimating with parametric techniques, the system can be used to quickly estimate the cost of most common buildings, yet it only has about 100 cost records in its database and resides on a small spreadsheet.

THE BUDGET PROCESS: WHY MAKE A NEW ESTIMATING SYSTEM?

Budgeting Problems

At Kodak Park, the capital budgeting process is a multi-step affair. There are two steps in the budgeting process where cost estimates are needed:

- The first step takes place a year or more in advance of when funding for a project is needed. In this step, the scope of the project is ill-defined and estimates are in the -30 to +50 percent strategic accuracy range. These estimates are used to put together prioritized long range capital plans. For building work, gross square foot estimates have commonly been used at this stage.
- The second step takes place when actual project funding is allocated and approval to proceed is obtained. Here, the scope of the work is somewhat better defined and estimates are prepared in the -15 to +30 percent conceptual accuracy range. At this stage, estimates have usually been prepared using a combination of square foot and semi-detailed methods.

Problems often occur when inconsistent estimating methods are used between the strategic and conceptual stages. The fuzziness of gross square foot methods combined with loosely documented design assumptions at the strategic stage leaves managers with only weak rationalizations to explain changes between the strategic and conceptual estimates. At the conceptual stage, very little additional design has been done. However, the conceptual -15 to +30 percent estimate becomes the project cost baseline for cost control purposes. A gross square foot estimate does not have sufficient detail for cost control, but neither is there enough design done to support the preparation of a detailed control estimate. An article by D. E. Parker contains a more thorough discussion of project budgeting for buildings [3].

Estimating Needs

The Estimating Department felt that an estimating system was needed that could address these budget and funding estimate problems. The system would have the following traits:

- for consistency, it should produce both strategic and conceptual building estimates using consistent, documented building design parameters as the estimate basis;
- for control, it should produce estimates using a consistent, recognized code of accounts with sufficient level reporting detail for management cost control purposes;
- for efficiency, it should produce both strategic and conceptual estimates in a matter of hours given the appropriate design parameter assumptions;

- for defensibility, it should clearly highlight the building system design parameters and options assumed, and it should show where those parameters exceed the minimum functional requirement for each building system; and
- for added value, it should be useful in performing value engineering (what-if and trade-off studies). It should also be able to estimate a broad spectrum of building types (warehouses, offices, labs, light manufacturing, and heavy industrial buildings) and project types (new buildings, additions, remodeling, and demolition work).

Existing Systems at Kodak

The Capital Estimating Department at Kodak Park has several estimating systems that can be used for estimating building costs. Figure 1 illustrates the systems currently available to the department. EST1 is the primary system, serving both as a general line item type estimating system and as a platform for interfacing with the various specialty estimating modules available (see Hollmann and Dysert [1] for more about the systems at Kodak). With EST1's database being tailored for machine and chemical process projects, it is not well suited for comprehensive building estimates (it does not use the CSI MASTERFORMAT or UNIFORMAT account structures).

The Department also has a statistical spreadsheet model called SQFOOT for doing quick gross square foot estimates by building type, but it contains no detail by building system. The SQFOOT model is based on multi-variable, linear regression analysis of the total cost of numerous Kodak worldwide building projects against the gross square footage and other gross parameters.

What was needed was a hybrid of these line item and parametric systems. We also wanted to avoid the expense and complication of incorporating a large CSI detailed database and account structure in EST1 (process work takes up the lion's share of Kodak Park's capital budget).

SYSTEM CONCEPTUAL DESIGN

Establishing System Requirements

To meet the needs discussed above, the minimal requirements of a budget estimating system were identified by the Estimating Department (in conjunction with Kodak Park's Architectural and Engineering Services Division) as follows:

- scope of projects—the system must estimate costs for new buildings or additions, as well as remodeling and demolition type work;
- account structure—the database and report presentation should follow the broad outlines of the UNIFORMAT account structure. This structure outlines basic building systems for which design parameter/cost relationships can be established. For more information on the uses of UNIFORMAT see Parker [3] and Wilson [5]. Also, contractors using the CSI MASTERFORMAT can fairly easily roll costs up into UNIFORMAT accounts for cost control reporting;
- level of detail—there must be enough cost items and levels of detail in reports to discriminate between sub-systems within the overall UNIFORMAT system categories. Also, labor and material requirements would be estimated separately to allow preliminary resource planning, productivity adjustments, and mark-ups. Take-off type detail reports were not required or justified;

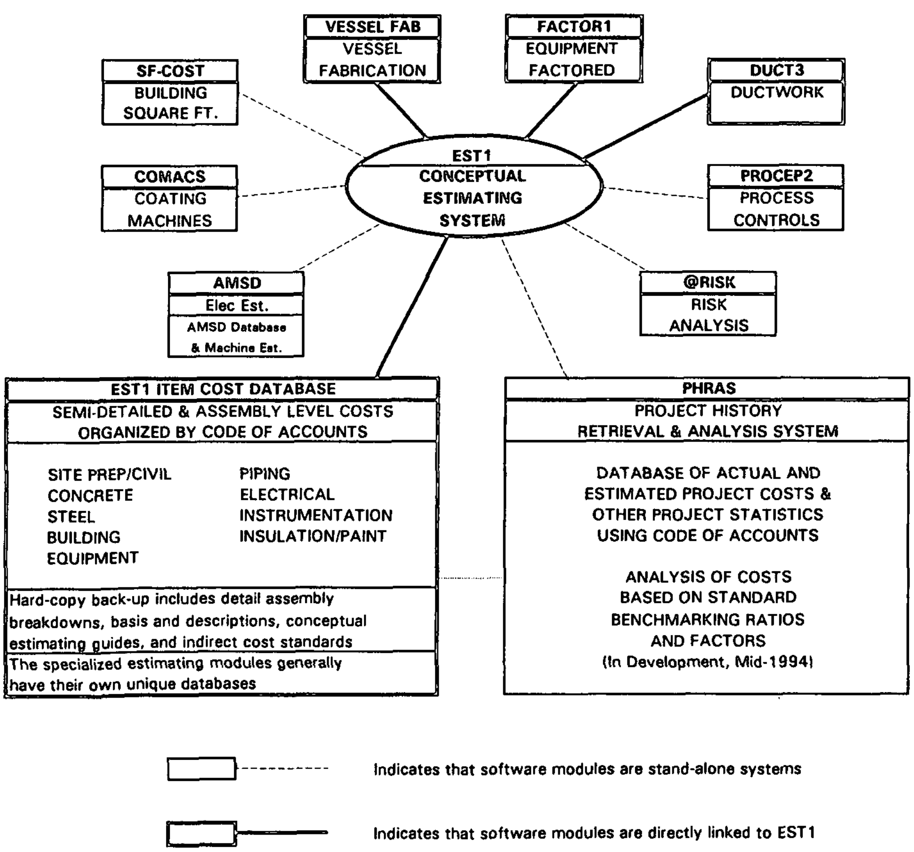

Figure 1—Estimating Systems at Kodak Park

- interface with engineering— estimates would be developed directly from input from engineering about key building design parameters. The system would document each assumption made and directly calculate estimate item costs from these design assumptions. The input design parameters would be clearly understandable and readily quantified with little or no intermediate calculation. Documentation containing guidelines and rules-of-thumb would be provided to help the user quantify the parameters appropriately;
- simplicity/minimal take-off—the only units of measure the estimator would have to enter would be horizontal square feet of area (SF). Thus, the only design needed would be a rough outline layout. This would minimize the amount of input required, simplify the database and system screens, and speed up the estimating process (but require more up-front data development);
- efficiency—an experienced user of the system should be able to create a complete building estimate in four hours or less given basic design assumptions. Estimate input forms, guidelines, and other documentation would be developed to aid rapid, consistent, and complete estimates; and
- accuracy-conceptual estimates— -5 to +15 percent on total buildings and -15 to +30 percent on a building system (most parameter values are known at the conceptual stage); strategic estimates— -15 to +30 percent on total buildings and -30 to +50 percent on a building system (most parameter values are assumed at the strategic stage). The smaller the scope, the lower the accuracy due to less off-setting of errors.)

Functional Concepts

As mentioned, the means to achieve these requirements were envisioned as a hybrid system combining typical building square foot assembly item costs with parametric cost scaling or factoring. For each building system selected as a database standard, a cost assembly would be estimated to provide a base minimum labor work hour and material unit cost for that system. The standard would be based upon the minimum allowable design parameters for that building account. Parametric cost algorithms would be established that would allow the unit work hours and material costs for the item to be factored up as the design parameter assumptions were altered from the base conditions. Quantities are always entered in terms of horizontal square feet of area. Other factors could then be applied for remodeling, demolition and removal work, size/scale, building configuration, and productivity impacts where appropriate.

These requirements and concepts presented a number of data development problems regarding how to present all data in terms of horizontal SF units, how to handle interdependence of design parameters, and how to calculate the multitude of parametric relationships. These problems and the approaches taken are discussed below.

SYSTEM AND DATABASE DETAILED DESIGN

System Development Estimate

With the system requirements and functional concepts defined, a cost estimate and schedule for data and system development were made based on experience with similar work. Table 1 shows the actual work hour and progress report. The work was completed for about 14 percent fewer hours than estimated, with the savings used to pay for expanding a test spreadsheet into a functional, semi-automated, spreadsheet based estimating system. As can be seen, the labor expended on data development activities was substantial. This effort was justified by the fact that no alternative approach was found that met the requirements established.

Table 1—System Development Estimate and Progress Report

Activities	Completion Date Planned	Completion Date Actual	Budget Hours
Final Proposal	11/22/91	12/13/91	58
Prepare Assembly Estimates	1/23/92	1/30/92	212
Develop Param/Option Factors	1/23/92	1/30/92	120
Develop Demo Factors	2/6/92	2/6/92	80
Develop Site and Other Factors	2/20/92	2/13/92	80
Develop System Specification	2/28/92	2/21/92	56
Test Data	3/6/92	3/12/92	40
Prepare Documentation	3/31/92	4/21/92	120
System Review with Engineering	3/17/92	4/24/92	24
Total Budget			790
Total Expended			653
Over/Under Budget			(137)
Note: Savings were expended on converting the test spreadsheet into a working estimating system			

Alternatives Evaluated

Alternative estimating systems that have parametric capabilities were evaluated, but the systems and methods were rejected for this application. In general, the available systems use parametric algorithms to define or modify the quantities of detail items contained in pre-built building system assembly estimates (parametrically defined quantity models). An associated general line item, unit cost estimating system is usually part of the system to allow the user to build up the assembly estimates. The systems often come with a large database of pre-built assembly estimates and parametric algorithms in some level of detail.

These type systems have the advantages of real parametric capability and speed, and they have the ability to produce detailed reports. However, the cost of these systems and associated databases for multi-users was difficult to justify given our installed base of tools. Also, take-off type detail output can give the illusion of accuracy that may not always be supported by the accuracy of the root parametric algorithms. Some excellent examples of systems using this approach include the U.S. Army Corps of Engineers' package called CEG [2], the TRACES system by Delta Research, the SUCCESS system by Softcost, Inc., and COMPOSER GOLD by BSD. QUESTIMATE by Icarus Corp. uses a similar approach for process applications.

All of these systems depend upon having a large, detailed line item and/or assembly cost database to draw upon. This is a feature that a some may find valuable, but it is not necessary and, as an industrial/process owner, we wished to avoid it. We desired to go straight from the design parameters to a cost estimate, eliminating the need for intermediate data and a redundant general estimating system.

System Operation

With our system, there is only one database item for each building system of a particular type; for instance, account 313 called "Steel Structure—Single Story" covers all steel framed structures no matter what dimension, type, or construction method. The user would retrieve this item from the database and enter the desired quantity of the item in SF of horizontal floor area. Next, the estimator provides basic design parameter values as requested by the system (such as imposed roof loading in lb/sf). We limited the number of parameters to four; however, one or two are usually enough to provide -15 to +30 percent cost discrimination. The estimator then identifies any design options desired. Options are discrete "yes/no" type variations as opposed to parameters that are continuously variable (that is, a wall can have only finish A, B, or C, but it can have any number of feet for height). The maximum number of options is seven, but usually no more than one or two are needed. For each design parameter and option entry made by the user, the system modifies the base work hour and material values to match the design entries. The modifications are made using generic predefined equations using fixed factors (or cost parameters) that are included in the database for that item.

The equation built into the system to modify the base work hours and material unit values for continuously variable design parameters takes the following form (while work hour (m-hr) per square foot is used for this example, similar factors apply for material):

$$\text{M-hr/sf} = \text{Base M-hr/sf} \times \text{Multiplier} \qquad \text{Equation (1)}$$

where: Multiplier = $[(P/B - 1) \times f + 1] \times c$
f = the predefined scaling factor specific to the parameter
B = the base "minimum" standard design parameter value
P = the input design parameter value
c = is an optional "curve" function that adjusts the answer for non-linearity when applicable
(For discrete options, the multiplier is simply a predefined factor.)

The equations were a simple matter to build into a spreadsheet based system. Figure 2 provides an illustration of the actual spreadsheet screen (in Excel) used to estimate a building item. It also illustrates all the various multipliers used by the system to derive the bottom line item cost. It should be noted that the multipliers are applied cumulatively in succession.

Data Development

Parametric estimating data development usually imposes a trade-off upon the developer, in order to obtain the great speed and utility of parametric systems, a significant investment in time and effort must be made in up-front data and algorithm development work. The development may require statistical analysis of historical costs, assembly or calculation of cost models, or other analytical work in order to obtain the cost relationships and factors that characterize parametric methods. It also requires a basic understanding of algebraic math and statistics, as well as a functional understanding of the physical systems being analyzed. However, if the resources are available and the estimating workload is substantial, the ongoing benefits of system efficiency and flexibility make the attempt worthwhile.

The development of data for this system required substantial amounts of calculation. The major steps taken during development were:

- determination of the building systems for which cost/design parametric relationships would be developed;
- creation of standard cost assembly estimates for each of the 100+ building systems for which relationships would be developed. Again, these base assemblies reflect the minimum cost set of design parameters expected on most jobs. A combination of R. S. Means [4] and Kodak data was used in the estimates for Kodak type assemblies;
- selection of the design parameters and options that would have the most impact on cost variability for each building system (cost drivers);
- for each parameter in a given system, recalculating the cost of the assemblies twice—once using the minimum value of that parameter, and once using the maximum (a "mid-point" value is assigned to all the parameters not being examined at the moment);
- given the min/max assembly cost points from the previous step, calculate the factors needed in Equation 1 to express how costs vary with each design parameter;
- check the results for each item against known project costs or other accepted standards and make adjustments where needed; and
- establish range limits for each input parameter within which the cost relationship applies with good accuracy.

ENTER ACCOUNT #:	841	HVAC, Air Handling Units
ENTER LINE ITEM NO.#:	15	<CONTROL-R WILL RETRIEVE ITEMS
ENTER AN ITEM TITLE:	Process Facility - South Wing, HVAC	
ENTER ITEM SQ. FT.:	50000	
ENTER ITEM TYPE:	1	(1 = NEW, 2 = REMODEL, 3 = DEMO.)

DATABASE VALUES:		REMODEL FACTORS:		DEMO FACTORS:		P/A
MHRS/SF:	0.0342	MHRS:	1.00	MHRS:	1.00	
MATL/SF:	1.53	MAT'L:	1.00	MAT'L:	1.00	0

SIZE MHR FACTOR>	0.91	P/A FACTORS> MHRS:	1.00	MAT'L:	1.00

DESIGN PARAMETERS:	MAX.:	MIN.:	ENTER PARAM.	FACTORS M-HR	MAT'L
BTUH/SF Required	50	25	40	1.08	1.30
			x	1.00	1.00
			x	1.00	1.00
			x	1.00	1.00
SUBTOTAL DESIGN PARAMETERS:				1.08	1.30

DESIGN OPTIONS AVAILABLE:	SUB-OPT.#	M-HRS	MAT'L
Variable Air Volume, Base=None	0	1	1
Unit Location, Base=Fan Room	0	1	1
Zones, Base=Single Zone	2	1.03	1.19
Selection Made: Multi-zone, for DX cooling			
Unit Type, Base=HW & CHW coils	1	0.61	1.12
Selection Made: DX Cooling & Gas Heat			
Economizer, Base=None	1	1.003	1.1
Selection Made: Economizer Included			
Humidification, Base=None	1	1.12	1.29
Selection Made: Humidification Included			
Qual/Complex, Base=Light Commercial	2	1.1	1.25
Selection Made: Heavy Industrial			
SUBTOTAL DESIGN OPTIONS:		0.78	2.36

ITEM COST ADJUSTMENTS AND COST REPORT:

CALCULATED MULTIPLIERS:	M-HRS	MAT'L
GENERAL ADJUSTMENTS:	1.00	1.08
SIZE ADJUSTMENTS:	0.91	1.00
CONFIGURATION ADJUSTMENTS:	1.00	1.00
REPAIR AND REMODEL ADJUSTMENTS:	1.00	1.00
DEMOLITION ADJUSTMENTS:	1.00	1.00
PARAMETER ADJUSTMENTS:	1.08	1.30
OPTION ADJUSTMENTS:	0.78	2.36
USER ADJUSTMENTS (enter as desired):	1.00	1.00
TOTAL ITEM ADJUSTMENTS:	0.77	3.31

	M-HRS	LABOR $	MAT'L $	TOTAL $
PER SF	0.0263	1.13	5.06	6.19
TOTAL	1315	56500	253000	309500

Figure 2—View of SF-Cost System Spreadsheet

The above approach gives consideration to the dependence of design parameter/cost relationships. Dependence can be illustrated best with an example: suppose in an independent calculation it was determined that the cost for single story structural steel framework increases 10 percent for every 10 percent increase in roof loading (in lb/sf). Another calculation shows that framework costs increase 10 percent for every 10 percent increase in average column spacing (span in lf). One might assume that if the roof loading and span each increase by 10 percent, then cost should increase by 21 percent (1.1 x 1.1). However, in reality, we may find that varying these two parameters simultaneously yields cost increases of, for instance, 30 percent. This may be due to the span/cost relationship being nearly linear for light roof loading, but not for heavy roof loading. In other words, the span/cost relationship is not independent of the roof loading (note that these relationships are examples for illustration only).

The approach used above was a simple way to accommodate dependence and to keep the system accuracy within -15 to +30 percent on any one item. When developing factors, instead of keeping all other parameters at a minimum while changing the subject parameter, the other parameter values were set at a midpoint value (average of their min/max values). While not removing all effects of dependence, this approach decreased the impacts to within acceptable tolerances by avoiding the relationship distortions that often occur when all design parameters are pushed to one extreme or another.

System Testing

A simple spreadsheet was set up using Equation 1, allowing the parameters and factors for each building system to be individually entered and tested at the -15 to +30 percent conceptual (known parameters) accuracy level. Later, by putting all the factors in spreadsheet "look-up" tables and by building look-up functions into the equation, the test spreadsheet was expanded into a working estimating system called SF-COST. The spreadsheet also has macros to save and retrieve each item estimated, tabulate costs by the UNIFORMAT code of accounts, and print reports.

To test the system and database as a strategic tool (assumed parameters), cost histories and rudimentary design data for five past building projects of various types were obtained for use as benchmarks. The costs for the benchmark cases were broken down to the basic UNIFORMAT level. Gross square footages and descriptions for each of the buildings were obtained, but the building system parameters and descriptions were assumed just like an estimator would have to assume for a "strategic" estimate.

The actual bottom line costs of the five buildings varied from the five test estimates by a range of -4 percent to +16 percent, which approximately equaled our goal for conceptual total building estimates (a constant labor productivity factor for Kodak Park relative to the R.S. Means basis was applied). At the UNIFORMAT system level, the range increased to -32 percent to +44 percent, which met our strategic requirements.

THE SYSTEM IN USE

System development was completed in mid-1992. In the two years since completion, the system has not been used as much as planned due to capital budget reductions. However, the system has been used on several major building estimates and dozens of small jobs with good results. After a few hours of training, the estimators have been able to pick up quickly on its use. The system has occasionally found use as a "line item generator" for our general EST1 system. For instance, if estimators doing a conceptual process job needs a quick, all-in number for area lighting, they can jump into SF-COST and get an answer for entry into EST1.

Our plans to develop a stand-alone, executable software version of SF-COST are on hold, pending signs of increased internal demand. We have since become interested in the possibility of modifying our general EST1 system to allow any of an item's unit quantity, m-hr, and material values to be optionally modified or defined by a parametric algorithm. We could then use the minimal database approach of SF-COST directly through EST1, and expand its application to process and other estimates as well. This would expand on the approaches used by commercially available systems that are limited to parametric definition of unit quantities only.

CONCLUSION

At Kodak, we have developed and make daily use of many successful parametric estimating systems utilizing cost modeling, equipment factoring, and other techniques. SF-COST is an important addition to our suite of parametric tools (although not the most heavily used). Our experience has demonstrated that given time and incentive, parametric estimating systems can be developed by individuals, in-house using basic skills in estimating, spreadsheet, mathematics, and statistics. Advice involving the expanding discipline of parametric estimating is available through the AACE Parametric Estimating Committee. Also, many excellent parametric systems are commercially available. Parametric estimating developers and users are all encouraged to participate in the Parametric Estimating Committee and to share their experiences through the AACE's various forums.

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