Systems Engineering and Software Engineering Cost Estimation:

State of the Practice, Current Issues and Moving Forward

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Agenda/Purpose

- Describe and contrast top-down and bottom-up SE and SW cost models.
- Describe problems/challenges to SE and SW cost estimation.
- Solicit audience views.*
- Develop consensus for way forward.*

* Primarily at the workshop tomorrow morning.

Some Definitions

- *Cost Estimating Relationship (CER).* A mathematical expression or other representation (e.g., a graph) that relates the cost (effort) to perform a task (or set of tasks) to one or more cost driving variables.
  - If you can identify an independent variable (driver) that demonstrates a measurable relationship with contract cost or price, you can develop a CER.
  - A CER may be:
    - **Mathematically simple, such as a simple ratio for productivity.**
    - **An equation that relates cost (or effort) to various "drivers," such as ones for size or scope of the effort and factors that drive cost, such as complexity of the task(s) to be performed.**
- Parametric Cost Model (PCM): A mathematical representation that relates a cost/effort value to the values of various parameters. It could be explicit (i.e., where the cost is the dependent variable, isolated on one side of an equation) or implicit (i.e., where the cost is not isolated on one side of an equation).

Thus, PCMs constitute a class of CERs.

Principal Estimating Cost Model Types

- The **two principal types** of estimation models: bottom up and top-down
- **Top-Down or Holistic Models** estimate a job or task as a whole.
  - Top-down view of the job.
  - Deals with top-level or global relationships among size, cost, and schedule.
  - Examples: COCOMO and COSYSMO, SLIM, PRICE S, SEER.
  - Often are parametric models.
  - Activity-based models estimate a process in terms of its constituent activities.
- **Bottom-up Models** estimate a job or a task view from a more detailed point of view.
  - Consider each activity (or perhaps a group of activities) separately
  - Overall cost is the sum of the costs of the constituent activities
  - Based on Work Breakdown Structure (WBS)
- In each case, use analogies and recognize differences between the new project of interest and past projects: use a detailed comparison of the characteristics of the proposed job with other, previously completed jobs.

Some Parametric Model Forms

- Many parametric models provide relationships among two or more of the variables:
  - C (cost or effort; e.g., labor hours)
  - T (schedule or duration; e.g., months)
  - S (size; e.g., KSLOC)
  - Q (quality; e.g., defect removal efficiency)
- These models can be used for estimation and for conducting trade-offs, and to point out opportunities for alternative approaches to enable cost objectives to be realized.
- A very important parametric model form is:

  $C=A*S^{E}*(\Pi K_i)$, where the values for S, size or scope and the cost drivers, K_i (i=1, 2, ...n) are selected for the project. The values for A (the productivity constant) and E are based on organizational experience.
  - This is the form of both the *COCOMO* software cost and the *COSYSMO* systems engineering cost models in which the cost/effort for a set of activities is estimated.
  - Note: This form is basically the same as the activity-based model where typically only one or a small set of activities is included and no cost drivers (e.g., K_i s) are explicitly stated.

Some Parametric Models

- COCOMO
- SLIM
- PRICE Systems
- SEER
- COSYSMO
- COSYSMOR SE Model
  - LMCO has developed “COSYSMO Risk/Reuse,” COSYSMOR, model in which parameter value (cost driver, size driver) uncertainty is quantified so the resultant cost uncertainty (cost risk) can be identified. It also allows for differentiating among new, reused, deleted and modified cost drivers.
- Consider the possibility of a “COCOMOR” model to complement COSYSMOR.

Activity-Based Cost Models

- Activity Based Cost (ABC) Models:
  - Estimate the costs for each activity or group of activities that compose project
    - Ideally, derived from the work break-down structure (WBS)
  - Enable the estimator to separately consider each activity in the process (e.g., software development process)
    - Provides an intellectual framework for considering the effect of changes (relative to past experience) such as: a new tool, a process change, different skill mix, etc.
    - Users need to identify all of the activities that compose the specific process whose cost is to be estimated
    - Relate to WBS and potentially more specific staffing
- Cost elements may be driven by:
  - Size of the product
  - Proportions (percents) of the cost (effort)
    - Examples: quality assurance, builds and controls, program office

Activity Based Cost Models, Contd.

- Ultimately, every project must have an ABC cost estimate, and cover all of the activities to provide a product or service, based on the WBS.
- This kind of model was first used at what is now MS2 - Manassas, beginning about 1980.
- Some more recently LMCO developed ABC based models/tools include:
  - GABE, TSS, major upgrades to an existent air traffic management system.
  - PAMM, Aero, avionics systems upgrades.
  - System-specific, Space Systems
- Other applications of ABC include:
  - NASA –developed air traffic control decision-support tools
  - Health-care
  - Manufacturing
  - Construction
- Commercially available tool: SCAPlanner^{SM} , SCA Technologies LLC

Concerning the Application of Cost Estimation Models

- Best to calibrate the model(s) that you employ using data from ***your*** organization or project.
- It's also very important to compare and benchmark your experiential data with data from other programs, and "industry" data if you find some and can trust it (In other words, you must know where it came from, what it means, the conditions under which it was obtained, etc.)
- You can obtain the values of the parameters by regression techniques AND by Delphi technique/expert judgment/experience of persons in an organization with appropriate experience and ability to project to new situations.

Pros and Cons – Comparison of the Two Approaches

Top Down (Parametric Models)

- Pros
  - Represents the factors that drive cost
  - Enables comparison of different estimates for the same task/product.
  - Good for developing initial estimates and sensitivity/impact relatively quickly.
- Cons
  - Difficult to tune to one's process/set of activities.
  - Varying cost driver effects on activities not readily represented (e.g., effect of better tools on one specific activity)
- Future Outlook (for COSYSMOR)
  - Enable user to change mixture of cost allocations amongst activities, by phase.

Bottom-up (Activity Based Cost Models)

- Pros
  - Can ensure that all activities (i.e., on the WBS) are estimated.
  - Can reflect varying effects to modify unit costs from baseline/past project experience.
- Cons
  - Sometime difficult to compare basis of estimate (driving factors not specifically articulated).
  - Does not enable a quick/easy comparison with past project experience.
  - Not good for developing initial estimates or quick sensitivity/impact analysis.
- Future Outlook
  - Some of the overhead of doing an initial estimate where many details are often not known appear to be automatable.

Factors Leading to Poor Estimates

- Lack of definition of the process/activities to be estimated.
- Lack of historical data on which to base estimates.
- Focus on getting “the right answer” (“what the boss wants”) instead of the best answer.
  - There should be an “independent” estimate
- Poor definition of the user needs, mission, or technical solution.
- Lack of estimating experience.
- Too much reliance on unthinking use of models and/or estimator naiveté.
- Lack of a systematic estimation process, sound techniques, or models suited to the program’s needs.
- Failure to include essential program activities and products within the scope of the estimates.
- Unrealistic expectations and assumptions.
- Failure to recognize and address the uncertainty inherent in estimates, due to models not completely representative, poor baseline data, parameter value uncertainty, etc.
- Reliance on one model or method.

STRONGLY Recommend: Use both top-down and bottom-up estimates.

Some Challenges

- Known industry challenges
  - Accurate data with enough granularity to provide a sound basis of past experience on which to base estimates
  - Integration of the SE, SW, and HW models
    - Consistency of activities covered and terminology employed.
  - Assessment of uncertainties and risks
    - Need to characterize cost uncertainty, yet not build in “too much” tolerance.
- What challenges do you see in addition?
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Recommendations for Path Forward

- Some possibilities
  - Put together a Lockheed Martin and other (e.g., “industry”) data base of cost/driver information and program profile data
    - Note: This is being done and has been done to some extent on the COSYSMO(R) project and for software defects.
  - Develop a “COCOMOR” SW Model/Tool
  - Integrate with COSYSMOR SE model with a “COCOMOR” SW model to provide a more nearly seamless estimation capability across SE and SW.

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