Using the MCPLXS Generator for Technology Transfer

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Introduction

In the present environment of future space systems development and SDI research, demands are being made on cost estimators to predict systems costs years in the future. Techniques for doing this are scarce and still in the development stages themselves.

Cost estimating tools for near-term systems rely on historical databases of analogous systems and some sort of extrapolation method to account for the differences in the historical data and the project being estimated. The extrapolation method can either be one-dimensional, such as simple weight-based CERs, or more complex, such as some of the commercial models like RCA PRICE, FAST, and others.

Whatever methodology used, there is a heavy dependence on the historical database which is composed of the state of present and past technologies. But how can these data be used to model technology that doesn't even exist yet? Some method of transfer between the present state of the art and future technologies that are in various stages of development is needed for the cost modeler. A new set of techniques and tools is needed to handle unique problems.

The environment at Langley Research Center is largely pure research. It has been said that "If it has been done before, it is not being done at Langley". This presents a challenge to the cost modeler at Langley. Not only are futuristic large space systems the subject for feasibility studies, but cost estimating tasks include projecting NASA's 40 year budget and a variety of projects in the post-2000 planning period. Cost analysts must not only be modelers but futurologists as well.

Objectives

The objective of this paper is to acquaint you with some of the approaches we are taking at Langley to incorporate escalations (or de-escalations) of technology when modeling futuristic systems. Since we have a short turnaround between the time we receive enough descriptive information to start estimating the project and when the estimate is needed (the "we-want-it-yesterday syndrome"), creativity is often necessary. There is not much time available for tool development. It is expedient to use existing tools in an adaptive manner to model the situation at hand. Specifically, this paper describes the use of the RCA PRICE MCPLXS Generator [1] to incorporate technology transfer and technology escalation in estimates for advanced space systems such as Shuttle II and NASA advanced technology vehicles.

It is assumed that the reader is familiar with the RCA PRICE family of models as well as the RCA PRICE utility programs such as SCPLX, PARAM, PARASYN, and the MCPLXS Generator.

Background

The methodology described in this paper has evolved over time, and is still being developed and validated. It is based on the concept that the manufacturing complexity (MCPLXS) of a system will change over time. This has idea has been advanced at the system level by Darryl Webb [2], at the subsystem level in PRICE H [3], and at the electronic board level in PRICE M [4]. Time, then, becomes just as important a parameter as weight, volume, amount of new design, and other physical and design parameters. The techniques presented in this paper are an attempt to model the temporal change based upon knowledge of the technology involved. These technology based techniques and the techniques extending Webb's ideas have been used in various forms in Langley estimates such as the Single Stage to Orbit Shuttle II, the Advanced Technology Shuttle, the High Technology Shuttle, the Entry Research Vehicle [5], and the Space Station Structural Assembly Verification Experiment (SAVE2).

Before describing unorthodox uses of the MCPLXS Generator, it should be mentioned that the MCPLXS generator has been used successfully at Langley in the manner in which it was intended (i.e. to generate a complexity for a structural piece when the manufacturing process is known) on many projects. It has proven to be an invaluable tool, especially in estimating composite materials. A model based on the MCPLXS Generator for SAVE2 provided estimates of local fabrication shop hour estimates within ten percent.

Example 1

The MCPLXS Generator was first used in an unconventional manner when estimating the Entry Research Vehicle (ERV) which had a high percentage of advanced technology components and structural material. A concentrated calibration effort on Space Transportation System (STS) Shuttle occurred simultaneously and the results of that calibration were starting to emerge. It was desired to use these calibrations to capture the complexity of the subsystem level assemblies. The problem arose that Shuttle, of course, is a manned-space vehicle (PLTFM = 2.5) and the Entry Research Vehicle (ERV) was unmanned (PLTFM = 2.0). Veteran PRICE users are aware that a change in platform necessitates a corresponding change in MCPLXS as well.

PRICE supplies a utility called PARAM to determine what the corresponding MCPLXS should be. However, anyone that has ever used PARAM knows how time-consuming and cumbersome it is for high platforms. PARAM will not allow a quantitative jump from PLTFM =

2.5 to PLTFM = 2.0, it only allows small incremental changes. To achieve this jump, the user must exit from the program, alter the file using an editor, and restart the program. Since ERV had a 94-box file, it was deemed unacceptable to use PARAM in the time frame in question. An alternate, faster method was was needed in order to utilize the calibrated Shuttle complexities.

A devision was made to use the MCPLXS Generator as a tool to transfer the complexity from one platform to another. In essence, the MCPLXS Generator was used as a PARAM simulator using the methodology described below.

A careful assessment was made of each of the five MCPLXS Generator parameters in relation to the Shuttle Work Breakdown Structure (WBS) item. These parameters were entered into the generator and the resulting MCPLXS value was noted. This value was compared to the value calibrated for the same item by the PRICE ECIRP mode. At this point, holding PLTFM constant, the other four MCPLXS Generator parameters were adjusted until the MCPLXS Generator output matched the ECIRPed value. Since the MCPLXS Generator equations are published by RCA PRICE, this can all be done off-line on a simple spreadsheet program.

Once a match was achieved between the two MCPLXS values, PLTFM was changed in the generator from 2.5 to 2.0. The resulting MCPLXS value was used as the corresponding complexity for a delta in platform specification from manned space to unmanned space.

Several boxes that had been calibrated in this manner were compared with test cases produced using the on-line PARAM. The complexities generated by the two methods were within ten percent. The results provided enough consistency to warrant using this shortcut method in the interest of expedience.

Example 2

Another problem arose using the Shuttle calibrated values on the Entry Research Vehicle estimate. Shuttle is aluminum construction, while some analogous ERV structural pieces were proposed to be titanium. The Shuttle MCPLXS values needed to be modified to account for the material differential for use on ERV.

This was also done in the MCPLXS Generator. The WBS items in question were simulated in the generator to match the calibrated value. This time, machinability index and maturity were changed to appropriate book values for titanium along with the change in platform, and the MCPLXS Generator was used to convert Shuttle manned, aluminum complexities to ERV unmanned, titanium.

As a check, the ratio between book titanium and book aluminum values were calculated. The ratio between the Shuttle calibrated values and the modified ERV titanium values, normalized to account for the platform differential, fell between the range of ratios for book values.

The transfer of the complexities from one specification level to another and to accommodate the change in structural material from aluminum to titanium described in these two examples provided the groundwork for using the MCPLXS Generator in other ways.

Technical Basis

Before discussing the extension of this procedure to modeling technology transfer, it is worthwhile to review the technical basis. This is not offered in the way of a mathematical proof, but rather as a simplistic explanation.

With the exception of maturity, all of the parameters in the complexity generator are in power law form which preserves percentage change. Removing maturity and then dividing the manufacturing complexity of one technology by that of another provides a ratio controlled by the ratios of the parameters. With a little thought concerning maturity this procedure provides a relative form of the MCPLX Generator. One may then think in terms of percentage increase of manufactuing complexity as a function of percentage increase in a parameter. This is very convenient for calibrating to a manufacturing complexity for which some of the parameters are uncertain.

Rather than use the relative form with a calibration coefficient, the normal generator form can be used to perform the final calibration by adjusting the most uncertain generator input parameter to obtain the desired complexity after the "known" parameter values have been chosen. Alternatively, the parameters which will not change based on technology can be used to calibrate after selecting good values for those that will change with technology for your projection. A calibration coefficient could be added if desired.

It is often difficult to obtain precise inputs for the generator, especially when working with a top level system or subsystem. It is comparatively easy to obtain from experts a percentage change in the new technology relative to a known one. Thus by calibrating to a system such as STS, one can obtain reasonably good answers from an engineer's perceptions of technology induced change in the parameters relative to the standard. The MCPLXS Generator input parameters are then the values used in the calibration modified by the percentage change. This approach is valuable also when uncertainty exists as to actual parameter values for the calibration.

In practice, the normal generator form seems best since it permits a combination of precise and relative parameter input which is most representative of the information received.

Questions arise when working at top levels since one is working in a gross sense with parameters which were derived to precisely describe low level machined pieces. For example, does one use the dominant material of a system, say aluminum, and ignore other materials present to obtain the machinability index, or does one use a weighted average of the individual machinability indexes, or does one split out the various materials and PARASYN for the the manufacturing complexity after modeling each with the complexity generator? All three approaches have been used in the example to follow depending on time and information available.

Example 3

When confronted with the requirement to provide an estimate for an Advanced Technology Shuttle (ATS) with a 2005 Initial Operational Capability (IOC), once again it became evident that the present set of modeling tools was insufficient. This estimate required new techniques in order to capture the magnitude of advancements in technology proposed for this vehicle.

The PRICE hardware model was chosen as the primary modeling tool for the estimate. Again, this being a Shuttle analogous system, it was desirable to use the Shuttle calibrations mentioned earlier to capture the complexity of the space manufacturing process and thus provide a sound basis for the estimate. The problem was to adapt the calibrated MCPLXS values for the 1972 Shuttle technology to the level of advancements proposed for the Advanced Technology Shuttle. This vehicle is characterized by advanced avionics, highly advanced composite matrix structures, new propulsion and an advanced thermal protection system.

Many alternate techniques were considered for decalibrating from STS to ATS technologies. Time available restricted the choices to extensions of Webb's temporal projections and the MCPLXS Generator. To obtain reasonable complexity allocations to lower levels from a top level temporal projection requires consistency with subsystem technology projections. The SCPLX utility allocates complexity on an equal percentage basis and thus was not consistent with technology projections when STS calibrations were used as the seed parameters. A generalized SCPLX based on SCPLX, relative complexity modification, and PARASYN was used to obtain complexity allocations. But allocations came from the top level and did not constitute an estimate from the 14 Box level as was desired. The MCPLXS Generator could decalibrate from the 14 Box level directly, so it was used.

The first step was to relate the WBS for the ATS to the WBS format of the Shuttle calibrations. This was accomplished with a mapping technique using the PRICE SCPLX and PARASYN utility programs. This realigned lower level components into the proper WBS categories. The estimate was performed at major subsystem level (14 WBS items) though calibrated values at a more detailed level were used for the mapping.

Another adjustment required was the incorporation of electronic components into structure. The Shuttle calibrations had been performed treating components as Mode 1 (electro-mechanical) where appropriate. It was realized that, since the MCPLXS Generator is a structural complexity generator, even those components with electronics would have to be treated as all-structural items. The added expense and complexity attributed to the electronics had to be incorporated into the structural complexity.

The estimate was being performed under rigid time constraints. It was not feasible to recalibrate STS treating the components as all-structural items and then redo the massive mapping process. It was determined that if the cost of the item remained the same at the top level, then the electronics would be "wrapped" into the structural complexity. A new set of STS complexities were generated by starting with the calibrated MCPLXS values and iteratively running the boxes forward as Mode 2's until the resultant development and production costs matched the costs generated by the original Mode 1's. Thus, the MCPLXE values were incorporated into the MCPLXS values with proper capture of the design change activity.

Inclusion of electronic components turned out to be one of the major problems with this methodology and warrants further investigation.

Once electronics was incorporated into the structure, each WBS item was modeled in the MCPLXS Generator to replicate the new set of Shuttle calibrated complexities. This was an iterative process. There are five input parameters to the MCPLXS Generator: Machinability Index (MI), Platform (PLTFM), Precision (PRECI), Maturity (MATUR), and Number of Pieces (NP). Some of the parameters, such as platform and maturity, were easier to assess than others. It was impossible within the time frame to count precisely the number of pieces or the exact composite precision of a wing, but a concentrated effort was expended to select reasonable values for these parameters. After much deliberation and iteration, 14 vectors of MCPLXS Generator inputs, one for each WBS item, had been determined.

The key to this process is to start with a reasonable set of input parameters and change them in a relative manner with information about the future vehicle. The goal is to quantify the degree of relative movement in parameter space.

This was achieved by careful examination of each of the parameters in each of the fourteen boxes to determine the relative quantitative change warranted by new vehicle technology. In some cases, such as platform, there were no changes. Changes were not implemented casually. There was a concentrated effort to assess these changes in as realistic manner as possible and to use as much backup and research material as was available.

For example, the fuselage of the present Shuttle is aluminum structure with spars and struts. Although piece count and precision were unavailable, this box was modeled by selecting "book" values for platform, maturity and machinability index. Then NP and PRECI were adjusted until a "believable" mix was achieved. For the ATS vehicle, it was assumed that a highly advanced composite matrix material would be used for structura instead of aluminum. Changing material automatically implied a change in MI, MATUR, and NP. Engineers were consulted to determine if changing over from aluminum to composite matrix would constitute a quantifiable change in PRECI. Published reports were available that addressed the issue of the decrease in part count resulting from a change from metals to composites. Recommended values for MATUR were used after consultation with design engineers and RCA PRICE staff.

The resulting MCPLXS generated was higher than the STS MCPLXS as expected. The reduced number of pieces caused the MCPLXS to decrease, but was coupled with changes in machinability index that caused a considerable increase. This reflects the real world situation. Composite materials are reducing part count, but are also increasing complexity in terms of tooling, brittleness, handling difficulties, and increased process times.

The same sort of careful analysis was done on all 14 boxes. Experts in their respective fields were consulted for advice.

Consistency and reasonableness was the goal. In this way, we were able to generate a credible set of complexity values that reflected the projected changes in technologies. Once parameters were generated, the estimate was run in PRICE using 14 Mode 2 boxes and an integration box. All other PRICE inputs were selected by interviewing project engineers.

The Langley costing methodology dictates performing three independent cost estimates on each item [6]. This was also the case on the ATS estimate. The process described above was actually done three times for each WBS item, and three sets of MCPLXS values were generated. This method takes into account the uncertainties in setting the parameters. A range of reasonable values is used rather than a single point value. Once the three estimates were performed, the outputs were input to a risk program that produced a range estimate in the form of a cost distribution.

The MCPLXS Generator procedure has not been proven, and it would be difficult to do so without a crystal ball. However, the results of the estimate were consistent when compared to other estimates for vehicles at various stages of technological development.

One confidence check that turned out quite significant. A top level one box model and a second level three box plus integration and test (I & T) model had been used to estimate ATS. These were performed by extending Webb's documentation of MCPLXS trends over time [1] into an estimating tool. For these estimates, the top level calibrated STS complexities were projected from STS initial operating capability (IOC) to the ATS IOC by choosing projection rates analogous to aircraft. The projection rates for a best case, a perceived case, and a worst case were chosen by analogy through careful consultation with Langley vehicle designers. After the 14 box ATS estimate was completed, the complexities were parasyned together with I & T costs to obtain a top level complexity for the ATS. The complexities for the three box plus I & T estimate were also parasyned to top level. For each of the best case, the perceived case, and the worst case, the manufacturing complexities of all three estimates fell within a five percent band.

Issues and Concerns

While applying the MCPLXS Generator to technology transfer several issues and concerns emerged.

- First , the cost estimating community suffers from a shortage of good tools for model development and cost estimating for future systems. There is a critical need for research in this area.
- Second, it must be stressed that in order to use a model like PRICE or the MCPLXS Generator, particularly in an adaptive manner, the models must be thoroughly examined by the estimator. The relationships and foundations upon which these models are based must by clearly understood before the estimator can manipulate the model to achieve relevant results. Parameter values must be selected with caution and with keen awareness of the real world situation.
- Electronics modeling is another concern. Electronics was artificially treated as structure in the ATS estimate. There is evidence that electronics behaves differently over time than structural material and it should be handled separately. It would be more realistic to be able to segregate the electronics, structure, and perhaps even other classes of items when using this method. More research into the behavior of non-structural items and analogous MCPLXE Generators is needed.
- Cost estimating is a time-consuming endeavor. Even the simple physical tasks of keeping track of the files being used to run the models can overwhelming. There is a need for preprocessing and postprocessing tools that could apply parameter modifications semi-automatically with traceability throughout multiple WBS levels and across multiple WBS's. The use of a tool such as the MCPLXS Generator in conjunction with PARASYN and SCPLX in an integrated form is just a small initial step towards achieving this goal.
- Finally, it is particularly important to be aware of technology trends and to have a method of decalibrating from historical calibrations to account for technology advancement. This is the technology transfer sought throughout this paper. For example, the

estimated ATS manufacturing complexities are significantly greater than STS calibrated manufacturing complexities. This leads to a significantly greater cost per pound. Hence, significantly reduced weight must be a by-product of the technology in order to just maintain comparable system cost. For ATS the weight reduction assumptions seem to be in line with the technology. The major question is when the technology will be available. Divergence of assumed and actual technology availability dates have a major impact on engineering complexity and consequently development cost. Although temporal projection indicates the manufactuing complexity is appropriate for ATS IOC, until weight reduction trends are confirmed, temporal technology divergence remains a major risk area in the ATS estimate.

Conclusion

Three different applications of the MCPLXS Generator have been discussed. The first two, using the MCPLXS Generator as a quick-and-dirty PARAM simulator in technology transfer from manned to unmanned space specification and as a tool to account for a structural material differential, led the way for the technology improvement application of the ATS estimate. These applications are far from being mature processes. This is just an initial step that opens the door for greater research in tool development for cost estimating systems for the distant future.

References

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