NASA QuickCost 5.0

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Introduction

QuickCost 5.0 is the latest released version of QuickCost, a model that originally began development in the early 2000 timeframe[1]. The four previous versions of QuickCost were applicable to NASA automated scientific satellites (aka. "unmanned spacecraft"). QuickCost is dedicated to the proposition that acceptable estimating accuracy is obtainable working at the top levels of the project WBS (quickly). A corollary to this principle is that more details do not necessarily lead to more accuracy and in fact, since "the devil is in the details" lots of details often provides obfuscation of the basic likely cost of a space mission[2].

QuickCost 5.0 is a major expansion of capability of QuickCost and now provides several parametric cost modules:

- Satellite module (for estimating missions typical of NASA's Science Mission Directorate missions). This module estimates both the spacecraft bus and the instrument/mission equipment complement on board the spacecraft (as well as the ground control facilities, the launch services and the annual mission operations and data analysis cost over the life cycle).
    - In addition to the automated satellite module, QuickCost 5.0 includes a "satellite trades model" which includes additional independent variables then the version above and is intended to be used when performing cost trades which involve more variables).
- Modules and transfer vehicles (such as the Space X Dragon, Orbital Cygnus, new International Space Station modules, new Lunar or Mars transfer vehicles, new variants of the European Automated Transfer Vehicle, new variants of the Japanese H-II Transfer Vehicle variants, etc.— any type of orbital module, crewed or not, with propulsion capabilities or not).

[1] The original version of QuickCost, retroactively named "QuickCost 1.0" was actually part of the PhD dissertation of the author. Beginning with QuickCost 2.0, the model was enhanced under NASA funding while the author was employed by SAIC.

[2] The previous two statements are at odds with the intrinsic held opinions of most managers (and some cost analysts). All project managers believe that their project is "different" and cannot be simply estimated parametrically from the historical record because this negates their belief that they and their team are from Lake Wobegon "where all the children are above average".

- X-Vehicles (any new experimental space flight vehicle similar to past programs such as X-15, X-33, X-34, X-43, DC-X, etc.).

- Liquid rocket engines (such as NASA's plans to develop a new hydrocarbon or liquid hydrogen rocket engine).

Together these modules provide a fairly comprehensive cost estimating capability for many of the more common assignments confronted by NASA[3]. As other needs arise, the QuickCost 5.0 can be expanded to address new requirements (for example, expendable or reusable launch vehicle stages, a dedicated spacecraft instrument module, etc.). The model is resident in a straightforward Excel spreadsheet with different worksheet tabs for the each estimating module and other worksheets

QuickCost is generally meant to be used early in the life cycle of projects when the conceptual definition is immature and only high level cost driving parameters are available. The model operates on costs drivers that should be known (or capable of being estimated) very early in the conceptual phases of definition—for example, for the satellite module, QuickCost operates on spacecraft dry mass, power, design life and a few other parameters to be explained later. The other three modules operate with similarly high level parameters but tailed for each of the model applications (e.g. the liquid rocket engine module works off of thrust, Isp and other engine parameters that are good engine cost drivers. In a similar vein, the modules all estimate at the top of the Work Breakdown Structure (WBS). The satellite module estimates the total bus and instrument cost as one number (and then separately estimates the ground control facilities, the launch services and the annual mission operations and data analysis cost over the life cycle). In the case of the satellite module a pseudo subsystem level cost breakout is provided simply based on historical percentage breakouts for similar missions. Similarly, top level cost estimates are provided for the other three modules (modules and transfer vehicles, X-vehicles and liquid rocket engines) but without the historical subsystem break.

While QuickCost operates and estimates at the top of the WBS and is generally conceived to be a model designed for use early in the life cycle of missions, there is no reason why the model cannot also be used later in the life cycle as a cross check to more detailed models (such as NAFCOM, NICM or as an analogy based approach.

QuickCost Database

The QuickCost model includes the database upon which the model cost estimating relationships (CERs) and schedule estimating relationships (SERs) are based. Each of the estimating modules is supported by its own database which resides on the worksheet tab adjacent to the model. The satellite module has the most extensive database consisting of 131 historical satellite missions (aka "satellite projects") and 109 data fields which provide descriptive information both quantitative and qualitative, about the 131 missions. Many of these 131 fields were at least considered in the regression analyses to derive CERs and SERs. Despite whether or

[3] While NASA projects has been the major focus of QuickCost, the model has been applied with success to at least one Air Force project and should be applicable to Air Force and NRO projects possibly with supplemental data and or calibrations.

not a field of information was ultimately used in the statistical estimating relationships, the field is still useful for understanding the various historical missions.

The other cost estimating modules similarly include their respective databases on the tab adjacent to the cost estimating module.

Estimating Modules

Satellite Estimating Module

Satellite Estimating Module Inputs

The satellite module estimates the life cycle cost of unscrewed scientific satellites (i.e typical NASSA Science Mission Directorate Missions). The inputs required are "where, when, how long, how complex, how big, how much power and how new", specifically:

- Mission destination (earth orbital or planetary).
- Authority to Proceed (ATP) date (e.g. 2012 would be entered as "2012").
- Design life in months.
- Instrument complexity in percentile terms and representing a weighted average of the entire instrument suite. For example if the instruments are of median complexity, 50% is entered. Instruments that are judged to be around the 75th percentile of complexity would be entered as 75%.
- Dry mass of the satellite in kilograms including bus and instruments.
- QuickCost 5.0 only estimates the cost of solar array generated power (see "Future Work" below). The input is maximum power generated in watts at the beginning of life in low earth orbit equivalent. The CER has been normalized to accept power in terms of what the arrays would deliver in low earth orbit solar flux. The solar flux at Mars is roughly twice that of earth and the solar flux of Mercury is about 4.5 times that of earth.
    - If power is not known, use the relationship below to estimate power as a function of mass (don't forget to convert to watts with e^x)
        - In terms of total spacecraft mass (Ln KG) and…
        - Destination
        - Earth orbital = 0
        - Planetary = 1
        - Use LnPower = 1.03 + 0.818 LnTotDryMass + 0.639 Destination
- Satellite bus new design factor in percentile terms. Consider the following guidelines:

- 20% of totally off-the-shelf
- 60% average
- 100% all new
- 130% (or more) for all new and pushing state-of-the-art

- Instrument suite new design factor in percentile terms with the same scale as bus (but instruments typically have less heritage (high higher new design factors)
- Year dollars desired for output (QuickCost 5.0 estimates in any constant year dollars desired—conversion to "real year/then year dollars" must be performed by the user outside the module proper.
- Confidence level desired for output form 50% to 99%, with 70% being the default.

Satellite Estimating Module Outputs

- The satellite module estimates the median expected cost in millions of dollars and the median expected development span (from ATP to launch) in months.
- The module then estimates the cost upward adjustment in cost and schedule from the median to whatever confidence level the user has input. This upward adjustment is interpreted as the reserve/contingency in cost and schedule to achieve the specified confidence level. The default is 70% confidence level but anything from 50% to 99% can be estimated. This calculation is based only on the statistical standard error and resulting prediction interval of the QuickCost 5.0 CER and SER (i.e. it does not include an allowance for uncertainly in the inputs). However, it is common in cost estimating for the statistical noise in the model to dominate the uncertainly and QuickCosts 5.0 assumes that confidence level calculation encompasses risk in the inputs (this may be arguable).
- QuickCost 5.0 calculates an approximate value for the PRICE Model manufacturing Complexity Factor (MCMPLX) (®Price Systems). This output is for the convenience of PRICE users who are familiar with the typical range of MCMPLX values for, in this case, NASA science satellites. It thus serves as a sort of sanity check or calibration factor for PRICE users. Note that since the MCMPLX calculated is for the entire integrated bus and instrument laden satellite, the value of the MCMPLX will be higher than is typical for individual satellite components or subsystem since the MCMPLX reflects the rolled up and fully integrated cost from all lower level WBS elements).
- The calculated peak size of the government project office is based on a very rough hueristic which predicts the peak number of heads that would typically be in the government project office. Note that since QuickCost 5.0 estimates in terms of NASA full cost, the cost already includes the cost of these personnel and this value is displayed simply as a possibly useful metric. The headcount does not include the functional line/laboratory labor which is also already reflected in the estimated full cost value above. Most QuicCost users find this headcount to be higher than expected.

- Ground systems cost is estimated by QuickCost 5.0 and includes the operations ground control facility (terminals, software, facility mods, etc.) assuming the normal amount of adaption and retrofitting of a previously used facility (calculated at 6% DDT&E + TFU). This is consistent with the CADRe database which also reflects the "average" mission which normally makes extensive use of existing satellite control facilities. If the mission being estimated is making use of either more or less than the "normal" mission, the user might consider adjusting the estimate accordingly.

- Launch services cost is estimated using a CER which uses wet mass as the independent variable with a dummy variable controlling for earth orbital versus planetary. In the QuickCost satellite module the CER automatically increases the spacecraft dry mass to wet mass by 1.3 for earth orbital and 1.6 for planetary missions and adds an additional 10% for a payload adapter/ASE (and converts CER to 2004$).

- Annual mission operations and data analysis (MO&DA) includes the Phase E operations phase cost and is estimated as an annual amount on the satellite module main sheet (and then allocated as a yearly cost over the design life specified for the mission above). MO&DA is calculated as a simple CER of 5% of the previously calculated DDT&E + TFU.

- Life cycle cost is the accumulated total of the above cost (with annual MO&DA converted to life cycle MO&DA using the number of years of operations inferred by the design life).

- Below the main input/output section of the satellite module, there is a display of the time phased cost in constant year dollars.

- Also below the main input/output section there is a display of the cost in the standard NASA WBS format. This WBS breakout is calculated based on the average WBS breakout of earth orbital or planetary missions from the CADRe database. As noted in the Future Work section below, the accuracy of the method decreases as the new design factor of the satellite being estimated departs from the median (around 60% new). Also the method is not now sensitive to the relative complexity of spacecraft subsystems.

Satellite Trades Estimating Module

QuickCost 5.0 provides a second version of the satellite estimating module—one which has more detailed inputs. This allows the user to gauge the sensitivity of cost to additional satellite characteristics. The trades module is less parsimonious[4] in terms of independent variables than the satellite module but does not necessarily provide a "better" estimate. This module is provided more to support trade studies that might need to have insight into the cost

[4] Parsimony is a generally accepted attribute of regression analysis and holds that a model should not use more than the minimum number of variables required to achieve statistically acceptable results. To use more variables than necessary leaves the model open to criticisms such as overfitting.

effect of additional variables not included in the main satellite estimating module. Specifically, the satellite trades module adds the following input variables:

- Bus and instrument dry mass separately accounted (as opposed to total dry mass)
- Structural material (mostly aluminum, minor composites, significant composites, or exotic materials)
- Number of deployables (a count)
- Deployable complexity (none, simple, complex)
- Propellant mass (kg)
- Thermal control type (active, passive) where an active rating requires pumped fluids (consistent with NAFCOM rating scheme)
- Array material (silicon, gallium arsenide)
- Percent active instruments (active instruments include radars, lidars, altimeters, radio science)
- Spacecraft volume (cubic meters—assume cylindrical and use (length x pr^2)
- Data rate percentile

Other Estimating Modules

The inputs and outputs of the other QuickCost 5.0 modules are very similar to those of the satellite module but are adapted to the cost drivers of each module. For example the modules and transfer vehicles module includes a human rated input (yes or no), an input designating whether or not the module has transfer capability (i.e. propulsive capability beyond RCS) and whether or not the module was developed in a non-market economy (a variable to explain Russian hardware lower cost in the database but to be used for other non-market economy providers). The X-Vehicle module[5] adds mach number and fuselage dimensional data as independent variables. The rocket engine estimating module uses thrust to weight ratio, chamber pressure (psia), and specific impulse (seconds) and engine cycle description as independent variables.

Future Work

[5] Both the The X-Vehicle and liquid rocket engine databases and estimating modules use English versus metric measurement units to be consistent with the main practice in the U.S. launch system engineering community.

A number of QuickCost enhancements can be made depending upon future funding. These include but are not limited to:

- Periodic refreshes of the database as new projects complete and CADRes become available. These refreshes would include a refresh of the regression analyses to generate new CERs and SERs,

- An improvement of the cost and schedule risk methodology to include uncertainty in the cost estimating inputs and to include joint cost and schedule risk.

- Enhancements to the algorithms which break down cost into lower level WBS elements. In QuickCost 5.0 this capability is only operational in the satellite module and the accuracy of the method decreases as the new design factor of the satellite being estimated departs from the median (around 60% new). Also the method is not now sensitive to the relative complexity of spacecraft subsystems.

- The development of additional QuickCost modules (e.g. a launch vehicle and upper stage module, a dedicated spacecraft instruments module and other estimating capabilities).

- Dummy variables for out of the ordinary characteristics such as RTG powered spacecraft, ion propulsion, multiple elements (such orbiter/landers), etc.

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