Space Cost Engineering Conference

PROGRAMME & ABSTRACT BOOK

11 – 12 February 2019
ESTEC, Noordwijk, The Netherlands

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INTRODUCTION

The Cost Engineering profession in the space domain is constantly evolving, needing to keep up with new tools and methods as well as the rapidly evolving space market, space systems and services that are the subject of our cost estimates.
This conference and its future editions aim to facilitate the exchange of best practices, methods, trends and lessons learned within the cost engineering community, giving opportunity to participants to demonstrate and share their work through papers and presentations on:

- Cost modelling
- Cost analysis
- Affordability analysis
- Design-to-Cost
- Earned Value Management
- Technical and Cost Data Acquisition and Storing
- Cost evolution trends
- Impact of and lessons learned from New Space approaches
- Cost reduction vs risk taking
- Cost engineering in feasibility studies, concept studies and running projects
- The evolution of the cost engineer profile
- … and related subjects.

The current conference will furthermore host the first meeting of the new **COMET** group on cost engineering. The term COMET refers to ‘Communities of Experts’, which are open innovation networks managed by CNES and in which ESA is a playing a significant role. More details can be found at: www.comet-cnes.fr

The cost engineering group will initially be part of the System COMET.

PROGRAMME

Monday 11 February

12:30 *Registration*

14:00 Opening Speech
Van Pelt, M.
ESA ESTEC

16:00 *Coffee Break*

16:15 Visit to the ESTEC Concurrent Design Facility

Tuesday 12 February

GENERAL INFORMATION

Presentation & Full Papers
The presentations and (some) full papers are available on the USB key inside the conference bag.

Wireless Internet
All pre-registered participants have received their log-in details by email, sent by the ESA ServDesk.
To connect to the WIFI, select the profile 'esa conference'. There will be information at the back of your name badge specifying your log in details.

Coffee and Lunches
Coffee is served during the dedicated breaks in the Newton Foyer. Lunch is served in the ESTEC restaurant at the participants' own expense.

Dinner
The dinner for registered participants will take place at ESTEC in Noordwijk. The dinner will start at 18h30 on Monday 11 February 2019.

ESTEC Shuttle Services
Participants are recommended to make use of the ESTEC Shuttle services for travel between Noordwijk and ESTEC, and between Schiphol Airport and ESTEC. More information is available at the main ESTEC reception.

ABSTRACTS

The Art and Science of Cost Modelling

Hamaker J[1], Smart C[2], Sanchez S[3], Sick E[4]
[1]Galorath Federal, [2]Galorath Federal, [3]Galorath Federal, [4]Galorath Federal

The development of cost models involves a heavy reliance on mathematical techniques, particularly the correct application of statistics. However, the process of developing a cost model is not a cut-and-dried mechanical process. There is a significant amount of judgment required. There are many effective ways to develop a cost model, but no single best way. The best models are a judicious admixture of both art and science. We discuss the estimating process and discuss a variety of considerations that need to be handled along the way. The process starts with data collection. We need more than just cost data, we also need schedule, technical, and other programmatic inputs to develop a model. Once data are collected, they need to be normalized and checked for errors. If key parameters are missing for a potential data point, the decision must be made whether to exclude that data point, or to impute the missing value or values. Once the data are collected and normalized, variables and model forms must be investigated. The attempt to try out different equation forms and variable combinations is fraught with the strong potential for overfitting, the most important scientific problem that you have probably never heard of. The problem with overfitting is that it makes the model look great on your data set, but those models tend not to do provide accurate predictions when used in practice. To avoid overfitting the choice of variables and model forms can be established by prior experience. The use of the power equation form Y =Ax^b has proven effective in modelling spacecraft costs for several decades. Experience with cost modelling can also be used for variable selection. However, we still need to look and the data and focus on the variables that are statistically significant. There is a tendency to want to include as many statistically significant variables as possible, because it makes our goodness-of-fit statistics look better, but this leads to overfitting. One way to avoid overfitting is to employ cross-validation. We discuss cross-validation in detail. We provide practical examples of cross-validation in practice and recommendations for its use in modelling.

The use of modern regression techniques is important in determining the cost model coefficients. We need to avoid developing biased models that tend to underestimate cost. We discuss several different regression techniques and their use in practice, including the minimum unbiased percent error and minimum percent error methods. We also discuss a recent paper by one of the authors [1] on the use of maximum likelihood techniques for regression analysis, including a method for developing unbiased estimates in the presence of lognormally distributed residuals.
Technology readiness is a key driver for program cost. A program that begins development with a technology readiness level that is low will almost certainly experience cost growth. We discuss how to model the cost of developing technologies prior to the start of program development.
Once a model is developed, validation is important. Cross-validation and out-of-sample testing can be used for this purpose. If enough data are available, it is advisable to hold out some of the data for validation to ensure the model is not overfit. Models are used by human beings, so the modelling process needs to be tailored with the result in mind that it needs to be useful. We discuss several criteria for model usefulness, including: relevant inputs; ease of use; and others. The issue of overfitting can lead a model developer to produce models with only a few inputs. This is the principle of parsimony and is an important part of the scientific side of model development. On the other hand, too inclusion of too few variables leads to a model that is not relevant or useful for the end user. A healthy balance of these two is important – the use of variable combination can be helpful. As Einstein once said, “models should be as simple as possible, but no simpler.” The authors discuss the application of the art and science of cost estimating to a recent project that they worked on together.

References

[1] Smart, C., “Cutting the Gordian Knot: Maximum Likelihood Regression of Log Normal Error,” Proceedings of the International Cost Estimating and Analysis Association’s Annual Conference, June, 2017.

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Critical National infrastructure (CNI): The cost of vulnerability

Shermon D[1], Tagima M[1]
[1]*QinetiQ Ltd*

When the Investment Division of the Organisation for Economic Co-operation and Development (OECD) issued a paper regarding the role of investment policies relating to national security of critical infrastructure protection in 2008[1] it was largely an academic exercise. However, it found that:

- Many nations had strategies to protect critical infrastructure;
- Risk management approach was broadly utilised;
- Risks could be natural, for example floods earthquakes or severe space weather such as solar flares, or man-made, for example sabotage or sophisticated attack from new and novel threats such as High Altitude Electrometric Pulse (HEMP), EMP and Cyber;
- OECD members had some investment measures to address these risks;
- The role assigned to investment measures varies with some considering this provides added value, while the others investment policy is used to address only a narrow (national security) range of these risks and only as a measure of last resort.

CNI includes low cost elements, for example, highways and roads through to high value assets, such as launch pads, satellite tracking stations and space infrastructure.

This paper will explore this complex decision space through the identification of the emerging threats to CNI, the countermeasure and protection strategies and finally the cost associated with CNI vulnerability.

The techniques and cost analysis approach will be applicable to other domains beyond the space industry

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Using Bayes' Theorem to Develop Cost Estimating Relationships – Extending the Gaussian Model

Smart C[1]
[1]*Galorath Federal*

Bayes' Theorem is a mathematical way to combine prior experience with new data. This prior experience can be objective or subjective. The use of Bayesian methods in cost estimating has been advocated by multiple authors [1], [2]. The author provided a paper in 2014 [2] that motivates and explains this approach in detail for the Gaussian linear model. The use of Bayesian methods is still limited in cost estimating, with applications to date focused on the Gaussian framework (e.g., [3]).
The use of Bayes' Theorem is extremely important in leveraging limited information, which is often the case in cost estimating for government programs, since the programs are often cutting-edge, and if not one-of-a-kind, often one of a handful with that exact application. In the case of limited sample data, there are two key assumptions in the standard Gaussian linear model that are dubious. One is that the variance of the estimating equation is known and is equal to the estimating equation variance based on the sample data. A second is that the residuals of the estimating equation derived from the sample data follow a Gaussian distribution. Neither of these is valid for small samples. (See [4] for a discussion of issues with the Gaussian assumption for small data sets.)
This paper is an extension of a previous paper that dealt with the application of Bayes' Theorem to cost estimating. That paper showed how both objective and subjective prior experience could be combined with new data to improve predictive accuracy. We provide an overview of these results and explain the Gaussian model framework in a straightforward and intuitive manner. We then relax the assumption of known variance, and derive an analytical method for conducting Bayesian analysis for this case. We next relax the assumption of Gaussian residuals, and model them with a Student's t distribution instead, as is typically done for small samples in statistics. With both assumptions changed there is no analytical solution possible. We discuss Markov Chain Monte Carlo simulation, and show how it can be used to provide a cost estimating relationship when both questionable assumptions are changed.

Markov Chain Monte Carlo simulation is a specific version, like that used in the Manhattan Project during World War II, in which each sample is dependent on the previous sample.
We provide a single practical example that we use throughout the paper and show how the equation changes as the assumptions are relaxed. We also provide code in the R statistical programming language that implements Markov Chain Monte Carlo simulation for the example.

References

[1] Foussier, P., *From Product Description to Cost: A Practical Approach, Volume 2: Building a Specific Model*, Springer-Verlag, London, 2006.
[2] Smart, C., "Bayesian Parametrics: How to Develop a CER with Limited Data and Even Without Data," proceedings of the International Cost Estimating and Analysis Association annual conference, Denver, Colorado, June, 2014.
[3] Qi, K., A. Hira, E. Venson, and B. Boehm, "Calibrating Use Case Points Using Bayesian Analysis," proceedings of the International Cost Estimating and Analysis Association annual conference, Phoenix, Arizona, June, 2018.
[4] Druker, E.R., R.L. Coleman, and P.J. Braxton, "Don't Let the Financial Crisis Happen to You: Why Estimates Using Power CERs are Likely to Experience Cost Growth," proceedings of the International Society of Parametric Analyst and Society of Cost Estimating and Analysis joint annual conference, St. Louis, Missouri, June, 2009.

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SPICE - A method for parametric cost estimation

Reinbold G[1]
[1]*Esa*

SPICE (Standard Parametric Information for Cost Engineering) was developed at ESA in 2009, and through lessons learned continuously improved and updated. It is a generic method applicable for cost estimation of hardware products and their integration to complete systems. The level of detail is normally the equipment level. SPICE is applicable from early study phases till phase C/D projects. At ESA it has been successfully used for various space

borne systems, including satellites, probes, landers, human space, robotics, launchers, engines and others.
SPICE is rather a method than a tool. The mathematical formulas are kept simple in order to make cost estimates transparent and understandable. They are easily to implement in EXCEL. In principle the method is not new, because it is based on widely known cost engineering rules. SPICE could be a kind of standard for discussions on costs, where the focus would be on the explanation of factors relative to T1 (see figure below).
The presentation will address the following:

- Historical data, data structuring and normalisation
- History of SPICE, its relationship to PRICE-H, NAFCOM and ECOS
- Explanation of the SPICE method
    - Estimation of T1 (Theoretical first unit)
    - Estimation of equipment follow-on / batch production
    - Estimation of equipment development
    - Estimation of system and subsystem level costs
- Lessons learned with the method
- The benefit of the method, which provides simple and transparent factors for discussion of costs.

Figures

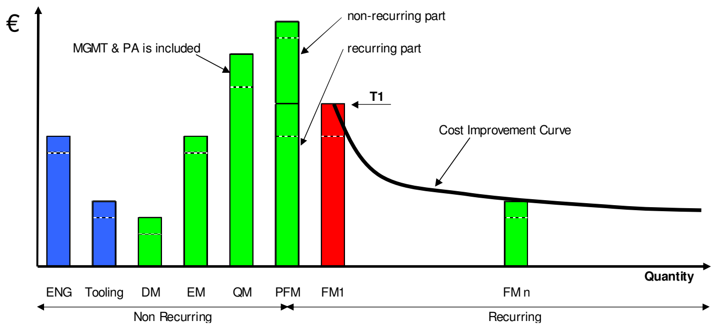

Figure 1: Cost Elements of a HW Product / Equipment

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Cost estimating of orbital space projects in phase 0

Del Castillo M[1]
[1]*Cnes Toulouse*

Estimating the costs of projects during early phases like mission analysis phase (also called "phase 0") is a decision support for the implementation. It also contributes to the first conceptual choices of orbital system designs. In later phases, it helps to control the total cost. In CNES Toulouse, as in other space companies, the problem lies in the fact that the fields are very wide (telecommunications, land / environment / climate, science, security / defense, ...), the scope differs from one project to another (complete system, satellite, platform, payload, instrument, equipment, ground segment, ...), the responsibility level is different (contractor authority, project management, support, ...), cost ranges and development durations are very variable, and the cooperation countries are different ... Moreover, the advent of New Space widens the gaps with previous projects, and requires more flexible methods, more interactive, more disruptive, and therefore an increased responsiveness of cost estimators.

During phase 0, the cost estimators work in close collaboration with the technical team from PASO office (Plateau d'Architecture des Systèmes Orbitaux) and with expert engineers in the technical departments. However, they report to another department (the Purchasing and Legal Affairs Department) and thus preserve their independence. They are involved very early in the technical meetings and the concurrent engineering sessions taking place in the CNES Concurrent Design Facility (also called "CIC", Centre d'Ingénierie Concurrente). In parallel with their cost estimation activity, they contribute to the identification of risks jointly with the technical teams, so as to readjust the perimeter of the mission if necessary, and thus minimize costs.

In phase 0, the estimators use the method of analogy with historical projects whenever possible. However, for innovative projects, when few observed and reliable cost data are available, the cost estimate is made in collaboration with the technical experts of concerned fields (SCAO, mechanics, thermal, optical, RF, ground segment ...). The other methods (parametric, even analytic) come in addition. For one year, a prototype of a Cost Database is under development: CARINA (CApitalisation et Recherche d'Informations Normalisées sur les projets spAtiaux). The goal is to develop a tool easy to use and to maintain, and directly correlated to PASO technical studies elements (product breakdown, mass and power budgets). The presentation will illustrate with an example the method used at CNES for a phase 0 orbital system cost estimating.

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Using energy-based performance metrics to design a universal 'tariff map' for space transportation cost, from sub-orbit to interstellar space

Eilingsfeld F[1], Millin N[1]

[1]*Price Systems Limited*

Background

The original question that prompted this paper was: "How do you compare the specific transportation cost of suborbital rockets with the launch cost of traditional space transportation systems?" Obviously, the traditional metric of cost per kg to Low Earth Orbit (LEO) does not apply to suborbital vehicles.

There is a solution, however, in the form of energy-based metrics.

Down here on Earth, transportation metrics like Megajoule (MJ) per ton×km (for cargo) and MJ per passenger×km (for passengers) have been established for decades. They are universally applied, be it for road, water, rail or air transportation. There is no compelling reason against using similar, universal metrics to the space domain as well. Ultimately, it would make space transportation easily comparable to terrestrial modes of transportation.

Methods

Space transportation can be modelled as a process, representing a utility that merely supplies energy for the transportation of payloads into space and within the space domain. It is assumed that optimization of space transportation systems will always involve a trade-off between (1) the

dimension of desired physical reach into space and (2) the dimension of transportation economics.
The (1) physical performance of space transportation shall be measured by total energy of the payload (in kWh) upon injection into whatever destination trajectory its mission foresees; (2) economic performance shall be measured as cost per unit of energy delivered to the payload in $/kWh.
Employing these two dimensions, and pursuing the paradigm of terrestrial public transport, something like a 'tariff zone map' can be drawn for space transportation. It will show specific energy cost depending on total energy delivered, which in turn is a function of mission destination (LEO, cislunar space, Moon, Mars, asteroids, beyond). That way, every space transportation system, be it past, present, or future, leaves its own distinct footprint when its physical and cost performance data is plotted on the proposed map. It helps to visualize performance trends and allows easy analysis of affordability. It makes visible the invisible, namely how the specific cost of space transportation determines the future physical and economic expansion of humankind into the solar system and beyond. This can help rational discussion of future project options and roadmaps for human expansion into space.

Results

While surface transportation on planet Earth barely ever costs more than 1 $/kWh (all costs given are 2010 economic base year), air travel costs significantly more, around 2 $/kWh. In comparison, space transportation costs are literally out of this world. The Space Shuttle, for instance, averaged 7000 $/kWh over its 31-year service life with 134 flights. The forthcoming Space Launch System (SLS) is highly unlikely to improve upon the Shuttle's economic performance. At the same time, the commercial launch market offers pricing between 360 $/kWh and 6600 $/kWh.
Surprisingly enough, suborbital space tourism – originally advertised as "low-cost space travel" – has roughly the same high specific costs of the Space Shuttle: SpaceShipTwo will cost at least between 6700 $/kWh and 8300 $/kWh, depending on ticket price ($200k vs. $250k)!

Conclusion

Using the energy-based performance metric of $/kWh for space transportation allows to do away with the previous metric of $ per kg to Low Earth Orbit (LEO). Today, Apollo-era cost levels are unaffordable, yet there are only very few signs of any cost breakthroughs required for meaningful human exploration beyond LEO, preferably below 500 $/kWh for the Solar System and 5 $/kWh for interstellar space. These endeavours will need new technologies.

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Low cost space mission trends and approaches in early design phases

Cifani, G[1]

[1]*ESA ESTEC*

"Buying a low-cost spacecraft is comparable to buying a family car. We look at our approximate budget, evaluate what is available on the market, and select a car which is some compromise between what we want and what we can afford." [1]

During the last decade much more often "low cost mission" have been implemented or studied by national and international agencies, seeing a wide range of mission objectives, from In-Orbit-Demonstration to interplanetary exploration. These led to an increase in the cadence of missions. Mission cadence is a major enabler of technological innovation and the driver for the training and testing of the next generation of managers, engineers, and scientists.

This paper describes recent trends and approaches related to the definition of low cost projects. In particular, it address aspects such us: requirements definition, achievable performances, standard products utilization, reusability, and related impacts on procurement, engineering and product assurance processes. Moreover, the exploitation of future technological trends (e.g. advanced manufacturing) and commercial products such as CubeSat standard are treated.

Ultimately, this paper aims to provide to the reader a compressive picture on trends and approaches for low cost mission definition.

References

[1] James R. Wertz, Simon Dawson. What's the Price of Low Cost?, Microcosm, Inc. Torrance.

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Innovative Cost Engineering Analyses for Future RLV

Sippel M[1], Trivailo O[2]
[1]DLR, [2]DLR

In the early phase of development, a parametric cost estimation approach is most promising. The TransCost model [1] of cost engineering for space transportation systems has usually been used as the baseline tool. At least concerning the development cost fraction, the TransCost model seems to be well suited as it includes targeted reference data also on different reusable launch vehicle (RLV)-projects from the past. [2]
Beyond that, an innovative Amalgamation Approach (AA) has been developed at DLR for future RLV and applied to the SpaceLiner cost estimation as a typical example [3]. Many of the significant cost estimations, in particular for large scale complex projects like those undertaken within the space sector, rely on one main cost estimation source, model, tool or CEM. A minimum of three cost estimate results are required and contrasted amongst each other. In this way, multiple points can be used by the estimator as reference, with strategic analyses then employed to justify selection of a most representative cost estimate or range. Three models and tools were selected to implement within the AA_{MAC} framework in [3]. These were the parametric TransCost, and two other commercially available models used widely in the aerospace sector.

Example of development cost estimation

Four SpaceLiner components encounter both non-recurring development costs, as well as consequent production costs. These are:

- SpaceLiner Booster (SLB)

- SpaceLiner Passenger Stage (SLP)
- SpaceLiner Main Engine (SLME)
- Passenger cabin and rescue capsule (SLC)

Figure 1 shows the shares of the major components and the results deviations of the tools. The cost deviations and variations between the multiple models are, in fact, not at all surprising, and should be expected when applying the Amalgamation Approach. System engineering and programmatic costs are not included in Figure 1 but have to be added for reliable RLV development cost estimation.

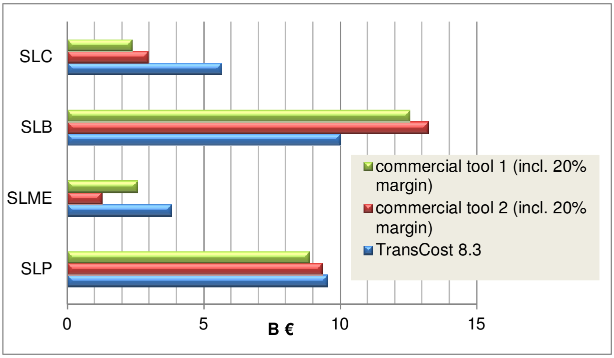

Figure 1: Estimated SpaceLiner development costs for major components obtained by different models

References

[1] Koelle D. E.: Handbook of cost engineering for space transportation systems including TransCost 8.3, Revision4, Germany, TransCostSystems, April, 2013

[2] Trivailo, O.; Sippel, M.; Lentsch, A.; Sekercioglu, A.: Cost Modeling Considerations & Challenges of the SpaceLiner – An Advanced Hypersonic, Suborbital Spaceplane, AIAA2013-5521, Space 2013 conference, San Diego, September 2013

[3] Trivailo, O.: Innovative Cost Engineering Analyses and Methods Applied to SpaceLiner – an Advanced, Hypersonic, Suborbital Spaceplane Case-Study, PhD Thesis 2015

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SEER for Space: A State-of-the-Art Parametric Cost Model for Spacecraft

Sanchez S[1], Hamaker J[2], Smart C[3], Sick E[4]

[1]*Galorath Federal,* [2]*Galorath Federal,* [3]*Galorath Federal,* [4]*Galorath Federal*

SEER® for Space (SEER-Space) is the latest addition to Galorath's suite of SEER cost estimation models. As the name implies, SEER-Space focuses exclusively on the space domain. By providing estimates at the subsystem level, SEER-Space's estimates are higher level than more granular, component-level models such as SEER for Hardware (SEER-H), to which it is a perfect complement. SEER-Space covers key instruments and spacecraft subsystems and estimates the entire lifecycle cost.

SEER-Space is based on a comprehensive variety of recent missions drawn from the NASA cost database as well as additional data sources and extensive research by Galorath subject matter experts. It allows early estimation of space missions when little information is known (pre-phase A, before DoD Milestone A), and may be used during later phases equally well. The model is built on the latest statistical methods including cross-validation to avoid overfitting to the sample data and provide confidence that the Cost Estimating Relationships (CERs) will generalize well when used for prediction.

SEER-Space covers all elements of NASA and DoD Work Breakdown Structures, employing a standard knowledge base template structure that provides a more efficient default starting point for estimating most instrument and spacecraft buses.

SEER for Space is able to model NASA Class A, B, C and D standards, and assess the additional engineering development effort required to mature a technology that has only achieved Technical Readiness Levels between 4 and 6. It is capable of modelling both Earth and deep space missions and can consider numerous types of spacecraft such as orbiters, flybys, landers, and rovers.

SEER-Space comprises all standard instrument types plus recent advanced applications: radars, including synthetic aperture; lasers, including optical transceivers; LIDARs; special elements for telescopes and cryocoolers.

Instrument Processing Electronics is modelled separately, to allow for better trade-off of instrument suites as necessary.
SEER-Space is unique in its ability to estimate instrument suites as well as spares. The model allows for the accounting of hardware contributions made to a mission (from part level to whole instruments) and supports the analysis of different means of acquisition such as competed versus directed projects, prime contractor versus university-built, foreign contributions, and more. It can also assess heritage benefits (major modification vs minor modification).

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Evaluation of parametric cost estimations for preliminary design stage of reusable booster stages

Wilken J[1], Stappert S[1], Sippel M[1]
[1]DLR

Currently the German Aerospace Center (DLR) is investigating different types of reusable booster stages within the ENTRAIN (Europe's Next Reusable ArIaNe) study. In the scope of this study a range of return options (winged and ballistic re-entry), propellant combinations (LOX with LH2, LCH4, LC3H8 and RP1) and staging velocities are evaluated parametrically in order to identify promising combinations for future reusable European launchers. While for the assessment of the performance credible and validated estimation methods are available, the validity of cost estimation methods for these preliminary designs is less clear. However, this is critical for reusable launch vehicles, as their success depends on the actually achievable cost reductions.

Objective
While a wide range of possible methodologies to estimate cost of future launch systems exist [1], all come with their individual restrictions and specific requirements. Usually, at this design stage parametric modelling with models such as TransCost would be a promising method. However, within this model Cost-Estimation-Relationships (CER) based on very few data points of reusable launch systems are used to determine the total launch service costs of the launcher concepts. Further uncertainties arise because these data points are

not derived from existing systems but from concept studies themselves. In order to explore these uncertainties, the TransCost model is applied to a range of semi-RLV's designed within the ENTRAIN study. The focus will lie on the relative comparison of the different launcher options. The validity of the results is discussed and methods for improvement evaluated. Factors specific to RLV, such as number of reuses of stages or engines and the impact of refurbishment costs are investigated parametrically with special care. The impact of uncertainties within the CERs themselves is also evaluated.

References

[1] Trivailo O, et al. Review of hardware cost estimation methods, models and tools applied to early phases of space mission planning. Progress in Aerospace Sciences (2012), doi:10.1016/j.paerosci.2012.02.001

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Knowledge Management Applied to Cost Management for Agencies & Industries

Navarro A[1]

[1] *Price Systems International*

Knowledge Management is key for Institutions & Industry.
The program acquisition processes need improved control and access to information, as well as transparency. Program's estimates require increased accuracy. Bids' preparation and evaluation must be improved.
This paper will describe the Knowledge Management as seen by PRICE Systems and how it applies to program cost management.
It will also describe an implementation road map and identify success factors and show stoppers.

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CNES - Cost assessment of project development phases

Millet B[1]
[1]*Cnes*

CNES is in charge especially of developments of project devoted to “Science” (to answer humanity's fundamental questions about the origin of the solar system, galaxies and life) and “Observation” (to study the Planet Earth through its physical characteristics of, its atmosphere, its oceans, its land masses). The development phases of those projects are conducted in respecting the responsibility sharing between all partners if any, and the famous tryptic: schedule, performances and cost.
Regarding the third item of this tryptic, the cost assessment and the expenditures reporting are keystones of the project monitoring. Because the agency budget is limited, a relevant cost estimate of one project is required; an under-estimation or an over-estimation of the cost jeopardize the agency capacity to develop other programs.
CNES has developed a method which is shared within the French space agency and used by the project managers in charge of development phases. This method is based on different steps. First of all, the product structure, the function structure and the work packages have to be exhaustively identified. In a second step, the cost range (defined by both limits: minimum and maximum) of each item is assessed. The third step consists of statistical calculation (Monte Carlo simulation) of the global cost, taking into account all individual cost range. This calculation allows to determine the amount of money we have to add to the minimum cost to cover potential uncertainties with a confidence level of 60% which leads to consider the best estimate of the expenditures. The maximum global cost is statistically computed with a confidence level of 90%; this new cost might support hazards. As part of the fourth step, the best estimate of the global cost is break downed with respect to the initial structure, using a simple rule of three (proportional calculation). Then, it is required to establish the yearly profile for each individual expenditure taking into account a realistic activity scheduling. The profile costs dedicated to the hazards are classically considered to be spent, if needed, for the last few years of the development phase. On a regular and frequent basis, the cost assessment file is updated taking into account the

past (based on the real expenditures) and the future by adjusting the individual cost assessments and the level of uncertainties.
The CNES method has been handling for several years and after few adaptations, the CNES management is satisfied by such a method because it contributes to make the correct decisions in a timely manner.

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Macro Parametric costing vs bottom up one - Additional approaches

Marsal P.,Yy X.
Thales Alenia Space

1. Introduction

The purpose of this presentation is :

To characterize their respective application domains
To advance the complementarity of both methods

2. Methodology

Study of the various project phases and so maturity project aspects

Macro parametric cost estimate

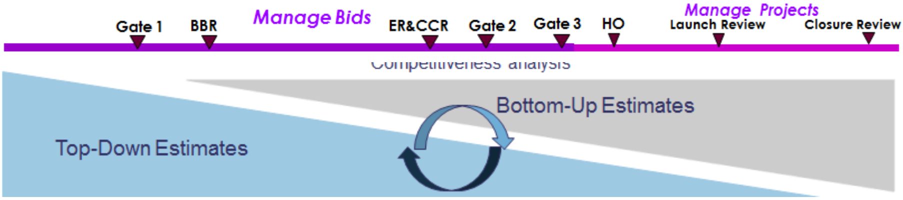
- Get early and quickly a Rough Of Magnitude for the full project
    - Check that the solution is consistent with the budget
    - Compare different solutions and scenarios
    - Understanding the main cost drivers
    - Securing internal estimates by comparison and eliciting assumptions
    - Enabling macro -optimisation

Bottom-up approach

- Collaborative cost estimate from Bid Baseline Review

- Check that the solution is consistent with the budget
- Compare different solutions and scenarios
- Estimates based on local techniques and capitalised
- Basis for team commitments
- Enabling detailed optimisation
- Ensuring a better insight of risks

Each approach has got its own benefits.



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Cost calculations for a multifunctional space interface

Meinert T
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In the framework of the project "intelligent Building Blocks for On-Orbit Satellite Servicing" (iBOSS) which develops a modular satellite system a multifunctional interface was designed. An iBOSS satellite is built up out of a certain number of cubes whereby each cube contains one satellite component. Each individual cube is not self-sufficient survivable and only in combination with other cubes, a fully operational satellite is achieved. In this way on-orbit servicing, reconfiguration and other assembly configurations conducted by an autonomous robotic servicing satellite is fulfilled. This modular cube-based concept is only possible through the multifunctional "intelligent Space System Interface" (iSSI). The iSSI is a "4 in 1"-Interface and establishes a mechanically stiff connection and transfers electrical power, data and thermal energy between the modules. Additionally, the iSSI can also be used as an end effector for the robotic servicing system. The iSSI has already finished the qualification process and is now on TRL 6.

For the iSSI a pre-mass production process was carried out. Therefore, the qualification was not performed by a prototype but by this pre-mass production model. The capabilities of the iSSI call for two considerations which are not common in the field of space engineering. First, economies of scale due to the mass-production can be exploited. For cost evaluations of the future iBOSS-satellites, the cost for the iSSI has to be estimated based on the costs of the prototype and the pre-mass production model. Second, the unique character of the iSSI enables the possibility using the iSSI for other space or terrestrial applications. Especially for terrestrial applications, the iSSI will need a rescale in its size due to different mechanical requirements. Furthermore, some of its four interfaces may not be needed. Therefore, a cost estimation for a mass-produced, rescaled iSSI enables the analysis of future markets. To analyse the two abovementioned research questions, first the cost drivers of the existing iSSI prototype and the iSSI pre-mass production model are investigated. By this arrangement the first evaluation of possible economies of scale is achieved. A regression analysis and a price function method are developed with the cost drivers. Both results are compared to identify further needed information. Therefore, an efficient calculation method can be developed to estimate the costs for a rescaled iSSI and also for other space technologies which might be transferred to a terrestrial application.

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