Cost Engineering for Cost-Effective Space Programmes

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The discipline of 'cost engineering' can be considered to encompass a wide range of cost-related aspects of engineering and programme management, but in particular cost estimating, cost analysis/cost assessment, design-to-cost, schedule analysis/planning and risk assessment. These are fundamental tasks which may be undertaken by different groups in different organizations, but the term cost engineering implies that they are undertaken throughout the project life-cycle by trained professionals utilising appropriate techniques, cost models, tools and databases in a rigorous way, and applying expert judgement with due regard to the specific circumstances of the activity and the information available. In most instances, the output of a cost engineering exercise is not an end in itself but rather an input to a decision making process.

What is Cost Engineering and Why is it Important?

No one who has responsibility for managing major, complex, high-tech programmes with a high development content will dispute the importance of the cost and financial aspects of the work, or the particular difficulty of assessing and controlling costs. Cost will be a constant source of concern, but will be particularly to the fore when considering different technical options, in conducting cost/technical trade-offs, in establishing budgets, in the submission and evaluation of price proposals, in preparing for contract negotiations, and in assessing the cost impact of introducing changes to existing designs. The question is how to tackle these aspects to be best able to predict or assess cost, how to minimise the risk and impact of overspends against budgets, and how to ensure that there is an appropriate balance between technical aspects and the related costs.

With these goals in mind, cost engineering essentially attempts to capture practical experience in a systematic way, to analyse that experience in order to develop tools and models which, together with expert judgement, can be applied under different circumstances to make predictions of likely cost or assessments of whether a proposed cost is reasonable. An assessment of the likely cost and risk is made taking account of past experience with similar activities and the assessment of associated trends, and of any changes in working practices and productivity gains.

But cost engineering extends beyond the estimation and assessment of cost, because these capabilities can also be applied to support the aim of achieving more cost-effective results. Awareness of the related cost is a key factor in the choice of approaches and design solutions, but traditionally the roles of establishing design solutions and of assessing the related costs have been separated both in time and responsibility. Typically, in the first instance the designer produces a design solution, which is then passed to other functions such as manufacturing and testing to add their inputs, and finally ends up with the estimator to calculate the cost of implementing this solution. Unfortunately, this is likely to be too late, as these exercises are often subject to time pressures that do not allow for a solution that is too expensive to be changed in a controlled way, which would normally require the design loop to be repeated.

The alternative offered by cost engineering is to have cost information available when design choices are being made, so that they will be made in the knowledge of approximately what the different potential solutions are likely to cost. This awareness of the likely cost is essential to be able to make effective cost/benefit trade-offs. In other circumstances where cost is a critical factor, this awareness of costs can be applied in a design-to-cost approach whereby the cost influence directly drives the choice of solution.

Cost engineering therefore embraces many facets of project management and engineering. The European Aerospace working group on Cost Engineering (EACE), in which ESA actively participates, has developed a Cost Engineering Capability Improvement Model (CECIM) in which 20 domains and more than 120 processes are identified which can be said to fall within the broad scope of cost engineering. Responsibility for these tasks varies from one organisation to another; in ESA responsibility for the schedule analysis/control and risk-assessment elements usually rests with the function within a project management team known as 'Project Control'.

Cost engineering is a discipline with relatively few full-time practitioners, who are to be found mainly in larger organisations. Therefore, cost-engineering groups and professional bodies like EACE - originally known as the ESA/Eurospace Working Group on Cost Engineering - are very important in helping to maintain the level

Cost-Estimating Methods

There are many different approaches and methods for estimating or assessing costs, all of which have advantages and disadvantages under particular circumstances. Factors determining the most appropriate method will include the nature of the activity to be costed or assessed, the degree of familiarity of the organisation with the item or activity to be costed, and the extent to which reference can be made to previous exercises, the availability of reliable design information and the time available to prepare the estimate. Other key aspects are the stage in the overall cycle at which the estimate is being made, the specific customer requirements in terms of presentation of cost details, and the degree of accuracy required. Usually several methods will be applied as a "sanity check" on means to verify that the results are valid. The most common approaches to estimating/cost assessment are:

- "Rule of thumb" approach
This approach is often used for the rough and rapid sizing of an activity in terms of cost. Its application is usually limited to very specific areas of activity and it implies expert judgement and close familiarity with that field of activity. It is not very sophisticated, but the rapidly available cost approximation may be sufficiently accurate in certain circumstances.

- Detailed "grass-root" or "bottom-up" approach
With this method, detailed estimates are made at relatively low levels in the work breakdown structure, typically at work-package or task level. This approach is closely related to scheduling, planning and resource allocation and is both time-consuming and costly. It requires a good knowledge of the activity and there also needs to be a reasonable level of definition for the exercise to be meaningful. Very often, and certainly in the case of ESA tender actions, such an approach has to be followed by bidders in order to be able to present the detailed costing information that the Agency requires. One potential problem, apart from the time and effort involved and the spurious accuracy implied by the process, is that the inclusion of contingencies for each element may well lead to an excessive amount of aggregate contingency, resulting in an unrealistically high estimate.

- Analogy
This commonly applied method essentially relies on being able to ascertain the cost of previous activities or items and using that as a reference for predicting the cost of a proposed new activity or item. It therefore depends on the accuracy of existing data, on being able to identify differences between the present and past activity or item, but also on taking due account of any observed cost trends and any changes in circumstances that might have a bearing on costs.

- Competitive supplier proposals
Where it is intended to subcontract an activity, committing subcontractor proposals submitted on a competitive basis are likely to be the most reliable estimate possible. However, customers should retain the ability to estimate and analyse the cost of work to be subcontracted, particularly when there is little or no real competition, or where there is the likelihood of subsequent customer-generated changes.

- Parametric approach
Parametric estimating entails the analysis of cost, programmatic and technical data to identify cost drivers and develop cost models. The approach essentially correlates cost and manpower information with parameters describing the item to be costed. This process results in sets of formulae known as "Cost-Estimation Relationships" (CERS), which are applied to produce cost outputs for different elements of an estimate. Parametric models may be developed by any organisation from analysis of its own data, but there are also external models available, some of which are marketed on a commercial basis. In the case of commercially developed models, it is important that they are calibrated by reference to specific data from the user organisation. Whilst there may be significant costs in developing such models or licensing commercial models, they have a number of advantages, particularly in that they allow estimates or assessments to be made fairly rapidly and at little cost.

of expertise and awareness of new tools and techniques. The ESA Cost Engineering team also has frequent and close contacts with NASA cost-engineering groups within the framework of an agreement on cooperation in cost-engineering practices.

Cost Engineering in ESA

In ESA there is a centralised Cost Engineering Section within the Cost Analysis Division, which forms part of the Agency's Directorate of Industrial Matters and Technology Programmes. This centralisation ensures that there is systematic gathering of cost, technical, programmatic and schedule information for all areas of activity according to a standard format. It also facilitates the development and application of methodologies and tools that would not be cost-effective for individual Directorates to do because of the relative infrequency of major procurement actions in each Directorate. Moreover, the fact of being involved in the full range of ESA domains permits a cross-fertilisation of experience.

A further feature is that the Cost Engineering Section is neutral, being hierarchically independent of the customer Directorates and therefore able to offer an independent assessment that is unbiased and objective, something which may not be possible for engineering/project staff closely associated with the activity. In any estimating or assessment exercise, the Section's sole motivation is to produce the fairest estimate possible based on the available information.

Over the last four years or so, the Cost Engineering Section has made significant changes in its working approach. One problem was that whilst previously the Section was fully involved in assessing the cost of proposals submitted by industry it was not getting involved sufficiently early in programme life-cycles and its tools and databases were not being fully exploited and were not contributing optimally to the effort of finding cost-effective solutions for the Agency's projects. A strategic decision was therefore taken to try to become more involved in projects in their formative stages. Fortuitously, this coincided with the setting of the Concurrent Design Facility (CDF) at

What Cost Engineering now does for its Users

- Programme preparation

Programme Directorates often enlist the services of Cost Engineering when putting numbers together in order to present the financial elements of a programme proposal to Programme Boards. This may involve coming forward with preliminary cost estimates when there may be few or no inputs from industry yet available. An example would be the early consideration of candidate projects for future Science missions.

- ITT preparation

The costing requirements expressed in ESA Invitations to Tender (ITTs) for major projects are quite standard in terms of the need to complete the Price Breakdown Forms (PSS-A forms) and to submit the financial proposal (ECOS files). There is also a standard format for expressing the costing requirements in early phases with respect to the format and content of the cost estimates that the Contractor is to produce.

- Participation in TEBs

Cost Engineering is systematically involved in the main procurement actions as Tender Evaluation Board (TEB) or Cost Panel members. The first responsibility when industrial financial proposals are received is to interpret them (using the ECOS files) in order to give Panel/TEB members the best possible understanding of the price as proposed by the bidder. In addition, a "should cost" analysis is usually prepared to support the assessment of the cost which has been proposed and to subsequently allow the ESA negotiation team to orientate its discussions with the selected or short-listed bidders. The Cost Engineering Section also works closely with the Industrial Cost Auditing Section with respect to determining the acceptability of the rates and overheads, profit rates and price-revision formulae proposed by tenderers.

- General support to Projects

For the early phases of major projects, Cost Engineering has the capability to define and animate Design-to-Cost exercises in cooperation with the Contractor and the ESA Project Team. There is also the possibility to carry out an internal independent cost-estimating exercise involving the Project Team members, thus combining the benefits of cost-engineering tools and experience and the specific knowledge of those closest to the work. This may be then be used in support of decisions concerning the project, or to provide inputs in order to reinforce the Agency's negotiating position.

- Participation in Reviews

Cost Engineering is sometimes invited to participate in design reviews, especially when there are some deliverables related to cost estimates or where there are cost implications with solutions adopted. This usually involves providing independent assessment and analysis of the concepts proposed by the Contractor.

- Participation in CDF activities

Cost Engineering participates in CDF activities as a member of the core team. In some ways this is the most fulfilling role as it is very much proactive, permitting the cost engineer to make a real contribution to finding cost-effective design solutions.

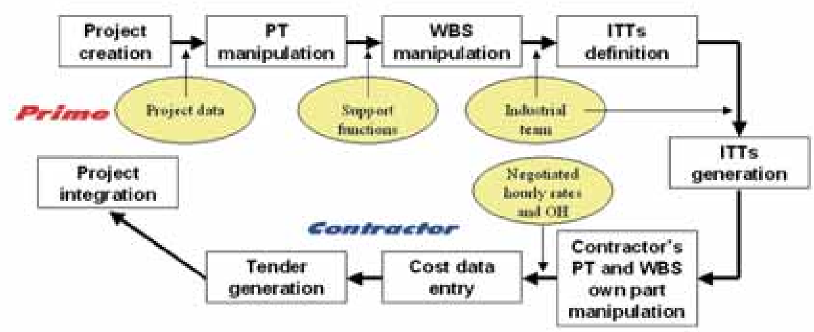
ESTEC on a trial basis at the end of 1998, when Cost Engineering Section was invited to participate as part of the core team. This was a real step forward because, by being involved from the outset in each study, it became possible to participate in a pro-active manner, making timely cost/benefit analyses allowing the early identification and discarding of unaffordable solutions.

There are instances where the Section is requested to prepare completely independent cost estimates as an input to the Project team. However, in the same way as its involvement in the CDF, the Section has also been able to become more proactive in other programmes where it has worked together with project teams and their technical support, co-ordinating the preparation of an in-house estimate benefiting from the input of all available experience.

Tools of the Trade

The Cost Analysis Division is the custodian of the ESA PSS-A series of price-breakdown forms required in the submission to the Agency of all price proposals. The use of these forms ensures the breakdown of cost so as to give adequate visibility, but also a standard breakdown and presentation as regards the different categories and elements of cost. The Division has had developed software called ECOS (ESA Costing Software) that allows bidders to prepare and present their financial proposals in an efficient and rigorous manner. Both Industry and the Agency have a strong interest in using ECOS, because the complexity of the Industrial teams for major space programmes makes the calculation and aggregation of the financial contributions a difficult exercise. An important feature of ECOS is the computerised integration of data at successive levels of the contractual hierarchy, thereby avoiding the onerous task of manual integration of data from several sources, a task that is both time-consuming and error-prone.

ECOS also imposes a product-tree approach to the work breakdown, so that there is a uniform definition of the project's constituent systems, subsystems and equipment. A major advantage of this is that it ensures a degree of standardisation so that there is a consistent approach to cost/work breakdown not only through the contractual hierarchy on a particular project, but also between projects.



ECOS PROCESS FLOW

Several other space organizations, including the Italian Space Agency, also regularly use ECOS for their own purposes. One of the strong features of ECOS is the ability to compare normalised work-breakdown structures. For both ESA and Industry, it guarantees the ability to identify each activity properly through a checklist system, and it also provides the possibility to compare similar activities from one project to another.

To be effective and bring the right level of expertise to all of its activities, the Cost Engineering Section is constantly developing or acquiring the most extensive and pertinent set of cost models possible. The first step is to properly organise the accumulation of reference data, and this is done mainly using a cost/technical/ programmatic database called CEDRE (Cost Engineering Data Repository for Estimates). This database has some normalisation features that allow the data to be pre-processed, before being exploited in the development of cost models for the different applications. These cost models are then integrated into a cost-estimating software system such as RACE (Rapid Advanced Cost Estimate). This development allows the Section to produce cost estimates for a complete spacecraft, based on the mission requirements and payload definition, very rapidly, with a level of accuracy commensurate with the decision-making needs.

A lot of focus is placed on determining the value for money of proposed design concepts. There is therefore currently a broad action within ESA aiming at developing design-to-cost oriented models, with Cost Engineering working together with staff of the Directorate of Technical and Operational Support and other ESA Directorates. The Cost Engineering Section's participation in the CDF studies is also a major help in making progress in this area.

The cost-engineering tools used are not limited to internally developed cost models. The Section also makes extensive use of commercially available parametric packages such as PRICE, which includes a series of specialised cost models for hardware and software. These commercial parametric tools are sometimes very convenient for filling-in gaps in the more specialised set of internally developed models. Also, a number of models for specific activities and systems have been obtained free-of-charge as a result of ESA's cooperation in the development of those models.

The maintenance of a permanent state-of-the-art cost-engineering infrastructure also leads to the use of some integrated solutions, such as the Ace-It product. This tool, acquired under license, permits a number of different cost models to be managed in an integrated manner and also addresses the documentation and reporting needs.

The Accuracy of Cost Estimates and Cost Assessments

"It is the mark of an instructed mind to rest satisfied with the degree of precision which the nature of the subject admits and not to seek exactness when only an approximation of the truth is possible."

Aristotle

For any cost-estimating or cost-assessment exercise the achievable level of accuracy will be dependent on the level of understanding of the problem, the completeness and the correctness of the information relating to the cost-driving parameters, and the quality of the cost model itself.

The desirable level of accuracy is that which is sufficient to allow a correct decision-making process.

In many situations it will be sensible to give a range of projected costs from a "lowest" cost, to a "most likely" cost and a "highest" cost. This is known as a three-point estimate-with the width of the range or spread being indicative of the perceived degree of uncertainty as determined by a risk-assessment exercise.

Estimating the cost of project software is a great challenge. The difficulty in accurately predicting the size of software, the rapid evolution in languages and programming tools, the reuse of existing software modules and the inclusion of COTS (commercial off-the-shelf) products makes estimating software development costs really problematic. The Agency has therefore been striving for some years, with the help of the INSEAD business school, to establish reliable software development metrics for cost estimating and assessment purposes. INSEAD routinely gathers data on software projects not only in the space domain but also in other hi-tech sectors, and analyses it in order to produce predictive models.

Benefits of Cost Engineering for ESA and Industry

ESA and its industrial contractors have a mutual interest in practising and promoting cost-engineering in support of the goal of achieving cost-effective performance. Space projects tend to be inherently complex and costly, and so being able to control costs and to achieve cost-effective missions is extremely important for the Agency and its Member States who ultimately provide the funding.

The industrial companies participating in the space programme also need to be able to properly assess costs and to achieve cost-effective solutions for their own financial health. If they fail to do so, they risk becoming uncompetitive in both institutional and commercial markets and unprofitable, either because they feel obliged to accept work on the basis of uneconomic prices in order to secure orders or because they have unwittingly underestimated the costs.

Therefore, in addition to endeavouring to consolidate and improve its own cost-engineering capabilities for its own purposes, ESA is also actively encouraging the development of the cost-engineering capabilities of its contractors. Apart from identifying cost-engineering principles and practices in its own Project Management Manual, in its support of the ECSS Management Standards, ESA's General Conditions of Tender for major projects will in future require not only the presentation of cost and pricing information in a certain format, but also the identification of the cost-estimating methods and tools applied by the contractor for the different elements. This should give both the contractor and ESA greater confidence in the costing details and make it easier for both parties to agree fair and reasonable prices.

Conclusion

Cost Engineering in ESA is established on a sound footing and is extending the scope and level of its activities with a rapidly increasing internal customer base. Whilst cost estimating and cost assessment remain fundamentally important activities, there is also a new focus on the added-value coming about as a consequence of earlier cost-engineering involvement in programme life-cycles. Its operations within the context of the CDF are a good model to illustrate its value and potential in this respect, namely working in a proactive way and making a major contribution to identifying affordable solutions to achieve programme objectives.

However, there are many other situations regularly encountered in the Agency's programmes where cost engineering is increasingly demonstrating its added value. It can be expected that in the future, with restricted budgets, with a changing industrial environment in which effective competition may not always be possible, and with an increasing momentum of technological development and programme complexity, the need for and benefits of effective cost-engineering services will become even more evident.

Having established a sound basis in organisational terms, with the changes in its working practices that have taken place over the last four years, the cost-engineering service is now in a good position to move forward, taking advantage of the rapidly developing software tools and consolidating its own experience in order to meet the challenges and opportunities that lie ahead. esa