METHODOLOGY AND CHALLENGES IN BOTTOMS UP SHOULD COST MODEL VALIDATION

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Abstract

In today's highly competitive environment, the market determines the sales price. If corporations don't address product cost, profit margin will continue to shrink. Thus getting detailed knowledge of what goes into the cost of a product has become very important. Bottoms up should cost enables corporations to better understand cost structure of their product. For should costing to be trust-worthy and useful, a validated cost model is mandatory. A bottoms up should cost model is comprised of components like material, machine, process, and cost algorithm. In order to validate models, one needs to validate all these components to match the physics of the process and rates applicable for the particular organization or region of manufacture. Due to innumerable variables involved and lack of well-defined baseline data, validating a cost model is very challenging. In this study we present a systematic and physics based approach that can be adopted by organizations to validate should cost models. We discuss the process and challenges involved in doing such a validation and showcase key use-cases of a validated should cost model during sourcing negotiations and design to cost studies.

Introduction

Measure of profitability is perhaps the most important metric for organizations that are in the business of selling products/services/equipment. Except for first entrants and market monopoly products, product price is bound by market factors like affordability and benchmarking. Hence there may not be much wiggle room. Thus a key controllable factor in determining the profit margin is the cost of manufacture. This factor is a function of multiple things such as design tradeoffs, manufacturing process optimization, supplier selection, supply chain optimization, etc. Many of these variables only become evident during the later stages of product design. It is no wonder that companies today are highly focused on squeezing the most value from these factors by developing reliable should cost models for their products. This puts a lot of pressure on the company to have robust bottoms up should cost models that enable reliable, accurate and physics based predictions.

Bottoms up should costing is a robust multi-disciplinary, collaborative and iterative process to optimize design and product cost to get detailed should cost estimates. Developing this model is challenging and is often compounded by the spectrum of components that are manufactured in big companies like GE. Component sizes can range from parts that can be held in ones palm to components the size of a building. Typically an external tool provider is unable to come up with models that estimate cost reliably for the entire product range. This has made cost model validation a critical need. Expectations from a cost model validation are to have two major outcomes - A) Deep understanding of capability of the cost model in terms sweets spot and deficiencies, B) Identify and execute initiatives to broaden the coverage of these cost models.

In the last few years there have been significant advancements in commercially available should-costing tools offering features like automated geometry extraction, automated alternate manufacturing process assessment, advanced material and machine databases etc. By harnessing all these advanced features quick real time should cost assessment has become a reality. Traditionally should-costing was done by specialists called should-cost analysts who have deep manufacturing expertise. In model-based-manufacturing and integrated design age, cost is being evaluated as one of the design parameters right from preliminary design stage. Designers who typically do not have deep understanding of the manufacturing processes need robust should-cost models that are easy to use and give accurate, directional feedback on design trade-offs. Thus having validated cost models is important to be able to empower design engineers to take knowledgeable decisions based on recommendations from these cost estimates.

In this paper we will use bottoms-up cost models from commercially available should costing tools. The following sections will describe the process of validation of bottoms up should cost models, criterion for success and challenges involved.

Literature Review

Bottoms-up cost estimation is one of the most detailed techniques among cost estimation methods (Anon., 2008, 18) [1]. The cost incurring component is broken down into discrete elements, the cost of every activity is determined and all the assumptions are outlined .Thus the product stakeholder can review and verify the models. As this is the most accurate, reliable and comprehensive approach, it is the widely used technique for cost estimation.

It is the cost estimator's (model developer) responsibility to test, understand, and validate the knowledge base and data used to derive estimates. The scope of the cost model, how to use it, the approach for integrating the data and cost transfer functions should be well defined. The dollar amount on any estimate is not useful without the data about basis of estimation (BOE) (Dysert and Elliot, 2002, 17) [2].BOE is the information about the parameters that tells the estimator what is included and not included in the estimate. Cost model validation is nothing but coming up with the BOE and getting it reviewed with all the stakeholders. The process of validation answers the following questions about the estimate - What estimating methods, techniques and procedures were used? Are they appropriate for the level of information available? Is the level of detail in the estimate sufficient for the purpose? What adjustments were made to the estimate for location, complexity etc., and are they reasonable? Are the materials prices labor rates, productivity reasonable, in line with expectations, and applied consistently through-out the estimate?

If the goal of the estimate is to predict the probable cost of a component/product, the goal of cost model validation is to ensure that high quality and sufficiently accurate estimates are generated using the cost tool. The process ensures that proper methods, techniques and data have been used in building the models developed in-house by organizations or in commercially available bottoms up software's.

In-house cost models

The validation is based on a metrics report showing the key estimating metrics and comparing the same with some benchmark set by experts and stake holders. The report is reviewed and major differences are subjected to in-depth analysis. The reason for deviation is analyzed and the process of cost model building is reiterated. More relevant data is collected and additional information is included until the estimation metrics becomes comparable to the benchmark

Third party cost models

The validation requirements for cost-models, data required and procedures are generally suggested by the 3rd party should-costing tool developer. The Cost assessment module (CAM) of any should cost tool is the collection of data(factory, machines, rates, tooling) and logic(Cost Transfer functions, Manufacturing rules) for different production scenarios of various regions

The 3rd party provides the generalized CAMs as a baseline. Each of these would represent a manufacturing environment in a particular region and the representation is generalized over different scenarios in the region. Depending on the customer needs, the CAMs are to be configured for specific factories of interest. The process of configuring a CAM involves replacing various "out-of-the-box" aspects (data & logic) of the CAM with customer-specific content. The CAMs can be configured to closely represent the manufacturing scenario of a particular plant. The configuration can be done at different levels based on the should-costing need. Increase in level indicates that the configuration is more specific making the assumptions, data and logic very specific to the production environment in question. Table 1 (Burke, 2009, 2) [3] summarizes the data sources of cost drivers for various levels of customization.

Customization level	Process Groups, process sequence & feasibility rules	Material list & unit cost	Machine list & overhead rates	Tooling	Cost transfer functions
Baseline	Out-of-box	Out-of-box	Out-of-box	Out-of-box	Out-of-box
Level 1	Out-of-box	Customized	Out-of-box	Out-of-box	Out-of-box
Level 2	Customized	Customized	Customized	Out-of-box	Out-of-box
Level 3	Customized	Customized	Customized	Customized	Customized

Table 1: Data sources for various levels of configuration [3]

Based on the level of accuracy and the need of the estimates, the amount of data to be collected and the extent to which CAM configuration is to be done varies significantly as shown in Table 2 (Burke, 2009, 2)[3].

Customization Level	Relative Accuracy	Types of should cost studies				Validation Method
		Target costing	Design-to-cost studies	Product cost-out studies	Supplier negotiations	
Baseline	Good	X	X			None needed
Level 1	Very Good	X	X			None needed
Level 2	Better	X	X	X		20 parts per process, focus on validating input data quality, data trends and relative part to part differentials vs, historical numbers
Level 3	Best		X	X	X	30 parts per process ,focus on matching the absolute values of should cost predications vs. facility or supplier cost numbers

Table 2: Different levels of configuring CAM's, their uses and validation methods [3]

Validation Process

Cost model validation consists of following steps

a) Identify the scope of validation and form a project team

b) Select 20 or more 'mature' parts

c) Cost selected parts and plot should cost vs. actual cost

d) Deep dive analysis on outlier points - Find process gaps

e) Address gaps in cost model to align with the physics of the process

The steps in the validation process are iterative. For example, deep dive analysis can bring out non-uniformities in the way should cost is done on similar parts which makes a benign part flare outside the distribution. The following section describes each step in detail.

A) Identify the scope of validation and form a project team

Before starting the validation project, the team convenes and decides the scope of validation. The scope can be as small as a step in a process, for example molding step in casting or as wide as validating an entire process group like Casting/Forging. Defining the scope is the most important part as it influences the execution of the remaining steps like constitution of the project team, part selection etc. It is very typical for the scope identification to be preceded by cost driver analysis of the process based on available data or feedback from should cost analysis teams to determine the scope of validation. This analysis is described in point C) below. The outcome of this step is a problem statement that calls out the scope of validation and the improvement desired by the team in qualitative or quantitative terms. An example of problem statement would be to validate Sand Casting process for parts spanning the entire product range of a business to fall within +/- 25% of actual cost for matured components.

Expert	Criteria	Responsibilities
Product Expert	Product owner/Design owner who knows the design characteristics of the product and can provide consultation on the key design requirements and process restrictions on the part like cleanliness requirements etc.	Provide CAD Model, Actual cost company is paying to supplier, material used, production volume Act as the business point-of-contact and provide the team information on design history of the components
Tools Expert	Expert in cost model tool design and coding. Has a good understanding of coding practices. Can carry out cost algorithm changes and come up with effort estimation for implementing changes	Lead deep dive analysis and extract detailed should cost data from tool Implement algorithm changes
Process Expert	Manufacturing engineers who are experts of the process and/or Supplier quality engineers who are aware of supplier manufacturing process	Mentor team on manufacturing process best practices, yields etc. Provide insight into supplier nuances while analyzing outliers Provide guidance on sourcing process data like cutting rates, tooling data etc.

Table 3: Should cost validation project team description and responsibilities

After the scope of the validation is frozen, the next step is to put together the validation task force. Validating a cost model involves analysis of the inputs that go into costing. Hence it is very important to ensure that the validation task force has internal expertise in these areas or has people who have access to the experts and data required to carry out this activity. This team should comprise of 3 key functionalities. The selection criteria and responsibilities of these team members are described in Table 3. The success of should cost validation depends heavily on insights provided by process and functional experts and later on the tools team for implementation of these model changes in the algorithm.

In the case study being showcased in this paper, the project scope was validation of: "sand casting process for small to very large castings made of various ductile iron, cast iron and Aluminum alloys produced in low volumes across 7 geographic regions". The project team constituted of a tool development expert, a program manager for should-cost studies for the business, product design engineers, casting supplier qualification engineers, a casting manufacturing expert and a team of should cost engineers. The tool development expert and program manager were the permanent members of the team while the remaining members were brought on board for consultation from time-to-time on need basis and for final project wrap-up.

B) Select 20 or more 'mature' parts

Mature parts are defined as parts that have been in production for long enough and hence can be assumed to have a well deflated price paid to supplier. In this study should cost validation is done by comparing with actual cost paid to the supplier. Selecting mature parts also minimizes the chance of including outlier cases like prototype parts which are bound to have a very high cost due to low batch size/high defect rate at the beginning of the learning curve/special inspection requirements.

The rate of maturation for components varies from industry to industry. In automobile industry the rate of maturation of actual cost is much faster compared to low volume, high complexity industries like gas turbines or aviation industry.

The team has to keep in mind that the more mature the part group is, the more accuracy you can aim for. If the parts considered are very early in the maturation cycle, there is bound to be more profit margins that have not been deflated yet, making the chasm between should cost and actual cost wider. In some cases where mature parts are not available, well-negotiated quotes can be used for the study. This would however make it difficult for the validation team to differentiate between higher supplier margins and cost differences caused due to real cost model gaps.

Depending on the industry and type of part, the validation team decides the criteria for the mature part. In addition to this, a mature part should have the following information to be considered for validation study.

- Actual cost
- Geographic location of the supplier
- Production volumes
- Material type and unit cost are available
- Recommended manufacturing process plan
- Special manufacturing requirements

Different should cost tools, have different data requirements for doing a cost study. The part selection criteria should include all the requirements for costing and manufacturing spec for the part. The project team should ensure that the entire product spectrum is well represented in the part group. A good mix of different Material types, Weight ranges, Part sizes, Part complexities should be considered. This selection defines the boundary conditions for using the validated cost models with high level of confidence.

For the Sand casting validation project, 20+ sand cast parts that had been in production for more than 5 years were considered. These parts ranged from small to very large size parts that require manual floor molding process. The part complexities ranged from very simple with no core parts to very complex parts that require tens of complicated cores. Good representation of commonly used materials was included. Parts were picked from all geographic locations from which sand castings are sourced. The Design engineer and Qualification engineer for every part were consulted for inputs on special manufacturing requirements for the part. The should costing team had access to part drawings that called out special manufacturing requirements such as inspections, tolerance specifications etc.

C) Cost selected parts and plot Should cost vs. Actual cost

The existing cost model was applied on the sample parts and the estimates were generated. The results are plotted. The tolerance on deviation of should cost from actual cost is applied and the region of acceptance is determined.

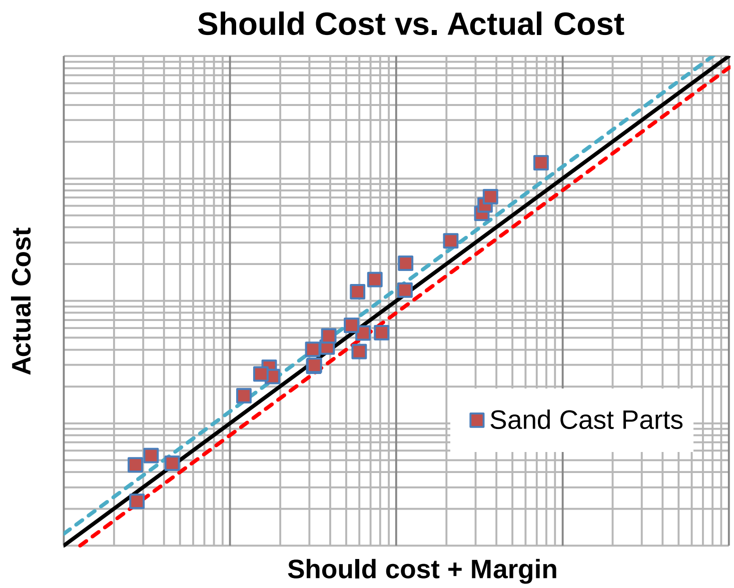

Figure 1: Example of Should cost vs. Actual cost graph

Usually a log-log plot is used to accommodate wide cost range of data points. An example of this plot is shown in Figure 1 for the sand casting part group. The X-Axis represents should cost with an acceptable profit margin. The Y-Axis represents the actual cost of the part. The area within the dotted lines with slope=1 represents the acceptable region of deviation. Data points falling outside this area are considered to be outliers. The graphical representation makes it very easy to understand how well should cost and actual cost compare with each other.

D) Deep dive analysis on outlier points - Find process gaps

The group of parts outside the region of tolerance is investigated for common trends. Grouping of parts can be done based on the deviation of should cost from actual cost. For the various parts within each of the groups formed, the following may be investigated.

- Commonality in sub-operation contribution
- Similarities in geometric properties like height, length, surface area, diameter
- Material properties like weight ,density, utilization
- Feature complexities
- Requirement of some unconventional manufacturing processes.

This analysis enables the modeler to find out the major drivers of cost and also to establish the strength of the cost model. In the current example, the entire part population is investigated to find out the process cost drivers. To do this, the should cost breakup for individual process step are scored with points ranging from 6-1. The sub-process that has maximum contribution gets 6 points and the process that has least contribution gets 1 point. All the scores for the part group are added up. The sub-process that gets the maximum count is the cost driver for the process. This kind of analyses provides a lot of insight into the behavior of the models. In our study we see that Melting, Molding steps are the cost drivers for all parts. Finishing process takes the 3rd place. Analysis of Material, Labor, Overhead cost split showed that the % contribution from Material cost is lower than expected. This led the team to investigate the material utilization algorithm which turned out to be lacking for very large parts.

E) Address gaps in cost model to align with the physics of the process

Process gaps typically fall into 2 categories. The types and action to be taken are as follows,

- Process does not exist in the tool – Develop cost model from the scratch
- Process cost model estimates do not align with manufacturing experience – Improve existing cost models to align with physics of the process.

The manufacturing process routing is one of the major drivers of the cost. Since it is very clear that cost-estimation involves a lot of uncertainty and risk, for good accuracy and quality of the estimates it is very important to see that actual manufacturing process and the one that is modeled are as close as possible. Experts from manufacturing and sourcing teams should be very involved in this step of the process validation. Gaps are to be identified and included in the model to ensure the conformance of model and assumptions with the actual production scenario. Manufacturing literature, handbooks, machining standards, interviews of manufacturing process experts, analysis of historic process data from manufacturing shops where available are some of the typical resources used in addressing process gaps.

In the validation of the Sand Casting parts, several process improvements were identified such as improving utilization algorithm that was biased towards small mass parts, updating cost models for cleaning, shakeout times, updating the rates of molding sands being used in the cost model. After addressing these gaps the team found that should cost has a much better correlation with actual cost of mature parts.

Challenges

Cost model validation improves the prediction capability of the cost models by enabling expanded real time monitoring and adjustment of processes, statistical evaluation, increased confidence and reproducibility. As the process involves a multi-disciplinary population, success depends on various factors. This section gives an insight into five of the key challenges when validating bottoms up should cost models.

Availability of reference process data

Data collection is the most time-consuming and critical step in cost validation. Data is needed at all stages of validation to understand the process, for determining the cost drivers and for analyzing the outliers. The data needs are not clear at the beginning but evolve as the process continues. It always takes an expert to define the quality and quantity of data for validating a given model for the defined scope. Having a project team with experts who are resourceful can be a real boon for the team.

Involvement of subject matter experts from different areas

Uncertainty is the underlying driver in any analysis. It is critical to review various assumptions and their applicability for the process in question with experts in different areas of focus. The experts need to be interviewed and the data that is reviewed will help in defining the scope and reliability of the process models. To get experts' time and bringing together the expertise from different disciplines is the major challenge in the validation process.

Availability of exhaustive real cost information and supplier data

This approach is completely data driven and heavily relies on the accuracy of available data. Lot of data from suppliers is to be collected and normalized. It is required to get access to various data sources of the supplier like Basic Accounting Records, Cost Reports, Historical Databases and libraries, cost proposals etc. Getting the supplier onboard with the process and extracting the required data becomes extremely difficult and time consuming

Lack of visibility into supplier process

While it is possible to model some uncertainties with the expert advice, it becomes extremely difficult to understand the supplier process without visibility to operational data like environment, performance, facility utilization or project data like production schedules, actual production quantities, production rates, production schedule gaps etc. Engaging sourcing engineers who have a good connect with suppliers is key to gaining these insights.

Determining key cost drivers

The data collected for the analysis is from various sources like surveys, interviews, research, specific cost etc. The correlation between various variables and noise in data may lead to inappropriate selection of cost drivers. The analysis as-well as the data points are to be reviewed with experts. This may assist in identifying the risks early and potentially save time for data collection.

Conclusion

In this paper we have demonstrated the process of bottoms up model validation and challenges involved. We also have showcased a case study of how these models where validated to support supplier negotiation and design to cost. The process demonstrated is general enough to be extended to any other model validation exercise. We found the latest commercially available costing software's to be powerful enough to enable configuration of the cost models to suite business needs.

As can be inferred from this paper, cost model validation is highly iterative and mandates a high level of collaboration between sourcing, manufacturing and design departments within businesses. Without adequate levels of buy in from these departments, validation process cannot progress smoothly.

Criterion for success of model validation effort is continuous and simultaneous usage of these models by design and sourcing teams in their day to day activities, so that a continuous loop of feedback and improvement ideas is established. It's important to remember that should cost need not match the price that you pay but must correlate with the price. It should be used a leverage to bring the cost down and not as a predictor of accurate cost.

References

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