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Joint Supply Cost Models

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Abstract – **This paper describes the benefits of a Boeing Supplier Management (SM) Finance enterprise initiative known as Joint Supply Cost Models (JSCM). Through the JSCM process, multiple linear regression using price, contractual, and technical attributes is employed to estimate the recurring price of externally procured products. This predictive parametric estimating tool serves many purposes for efforts not subject to the Truth in Negotiations Act (TINA). The tool supports Boeing's cost reduction initiatives by identifying where Boeing could be potentially paying too much in comparison to the market average, supports supplier negotiations by comparing a supplier to the market average, and provides insight for Boeing engineers into technical cost drivers. The JSCM Enterprise modeling process can serve as a template for future Enterprise modeling efforts outside of the Finance organization.**

Index Terms – **Affordability, Cost Drivers, Cost Model, Estimating, Finance, Modeling, Multiple Linear Regression, Parametric, Partnering for Success, Predictive Analytics, Should Cost, Supplier Management**

I. Introduction

Joint Supply Cost Modeling is the process by which a linear regression model (multiple or single variable) of the current recurring price of an externally purchased commodity is developed to enable the identification of the commodity's "market[1] average" and "should cost region". A majority of Boeing's costs are sourced from external suppliers and this analysis can identify cost drivers and affordability opportunities whereby utilization of the models can make positive impacts by reducing cost.

The Background section will identify rationale behind the business need for JSCM tools, the business units and functions tasked with supporting the initiative, and describe the selection of commodities to undergo analysis.

The JSCM Process section will provide in-depth documentation of the process steps taken to create the models.

The JSCM Product Usage section will provide information regarding how the models are stored and distributed as well as specific examples of usage.

The Conclusion section will provide final thoughts related to JSCM and how it can affect the market and reduce cost.

II. Background

A. Cost Modeling and Should Cost Introduction

Cost modeling is a standard practice in Finance groups in The Boeing Company. It is the process by which the dependent variable, cost or price, is predicted mathematically with an equation consisting of one or more independent variables such as physical dimensions, material properties, and annual buy quantity. This practice is a direct result of Boeing's desire to achieve data-driven, timely, usable, and comprehensive methods.

The Federal Acquisition Regulation (FAR) contains guidance on should cost reviews. According to the FAR, should-cost is a specialized form of cost analysis where the goal is to promote both short and long-range improvements in the contractor's economy and efficiency in order to reduce cost of performance of Government contracts [1].

JSCM defines a "should cost region" as the region below the market average line derived from the Boeing market commodity regression model.

While the JSCM version of should cost differs from that of the FAR, the output can assist in identifying affordability and cost reduction opportunities when a commodity's model contains a diverse set of suppliers.

B. Need for a JSCM Team

When trying to predict the price of a new part, or assessing whether a supplier's proposed price is "high" or "low" in comparison to the current Boeing marketplace, using facts and data to find trends is a standard approach to the problem. The cost modeling described in the previous section is one approach within Supplier Management Finance to this

[1] Boeing Market as defined in this paper refers to the Boeing marketplace where data comes from purchases Boeing Supplier Management makes from external suppliers.

problem. These models have provided robust methods for evaluating best-in-class suppliers and supporting negotiations. In many cases, models are created, but due to employee rotation or other circumstances the models are not maintained and become obsolete. Obsolescence can be caused by many factors: an airplane program ceases production, a new supplier for a part, or any other number of factors. Relevancy of these models decreases as the age of the data used to create the model increases.

Executive level management within The Boeing Company recognized the benefits of these cost models but also the need to maintain them to ensure they can be consistently and confidently utilized over time.

A primary focus of Boeing Supplier Management has become the aggressive reduction of costs across the supply chain [2]. Understanding the marketplace for each commodity provides insights into where opportunities for cost reduction exist. Cost models provide a useful tool in this arena: an understanding of the market average for a commodity based on its technical characteristics. The best and worst performing suppliers can be identified in relation to this market line.

A team was formed that could focus on development and maintenance of the models and tools as well as provide support to the end-users in utilization of the tools.

C. Team Membership and Supporting Organizations

Comprehensive cost modeling requires a diverse skill set and support from organizations outside of SM Finance to achieve results users can be confident in. In order to produce cost models that encapsulate a majority of the Boeing market, the decision was made to make the team an Enterprise team, with support from Boeing Commercial Aircraft (BCA), Boeing Defense, Space and Security (BDS), and Shared Services Group (SSG). For example, both BCA and BDS procure landing gear structures for their respective aircraft. Is there a way to look at the landing gear structure pricing across the enterprise and develop a cost model both business units can use?

Not only does the team span business units, it also spans functions. Technical knowledge of the various products and commodities that the JSCM team studies is greatly supplemented by input from Engineering. Subject matter experts are relied on throughout the process for defining the model, assisting with data collection, and reviewing the final product.

JSCM team members possess a variety of skills. Data analysis and statistics capabilities are beneficial skills to have, but many other skills can enable the model process to flow efficiently. Leadership is another trait that will enable a model focal to communicate and coordinate the development of a model from definition to completion. A clear technical understanding of the product or commodity is also required. The willingness and patience to provide training on complex statistical topics is also a valued skill. The team's background mix of applied mathematics, statistics, engineering, estimating, and procurement financial analysis all come together to create and present a robust set of tools.

D. Product / Commodity Selection

During the brainstorming phase of creating the JSCM team, a list of potential products and commodities was developed to be analyzed and modeled. This list was created through extensive communication within the BCA, BDS and SSG SM Finance organizations. Many factors were considered when developing the list such as: part/product categories, upcoming contracting activities, annual spend, and future product development. The project plan also had to be flexible enough to allow re-prioritization of projects if a special request deems it necessary. Sometimes high level commodity categories were designated with the understanding that sub-sets could be generated during the modeling process. For example, the Fasteners commodity requires many sub-sets of data for the various types of fasteners (nuts, bolts, screws, etc.).

E. JSCM Team Operation and Cadence

With many models in work concurrently, there are opportunities for implementation of Lean practices such as sharing and replication, first time quality, and improvement all while focusing on the customer. The processes are standardized and there are templates for products that must be duplicated with every model on a server for use by the JSCM team. Guidelines and checklists were also developed to implement the steps in the JSCM process and deliver a consistent high quality product that is timely, usable, and comprehensive. Using these Lean practices allows minimization of re-work. Weekly tag-ups help keep the model process flowing smoothly and can quickly identify needs where team members can provide assistance if needed.

The JSCM project schedule is managed in Microsoft Project. The progress of each model and its respective process steps are tracked and updated on a weekly basis. The JSCM project completion date for all models dynamically updates based on the progress of each model. The metrics that are generated from the project schedule are intended to drive change and can signal the need for improvements. The metrics allow an at-a-glance visual aid for project status. It is also flexible enough to re-prioritize projects if necessary. All metrics are shared and discussed with the team on a weekly basis. Fig. 1 is an example of one of the visual tools the JSCM uses to show model development status.

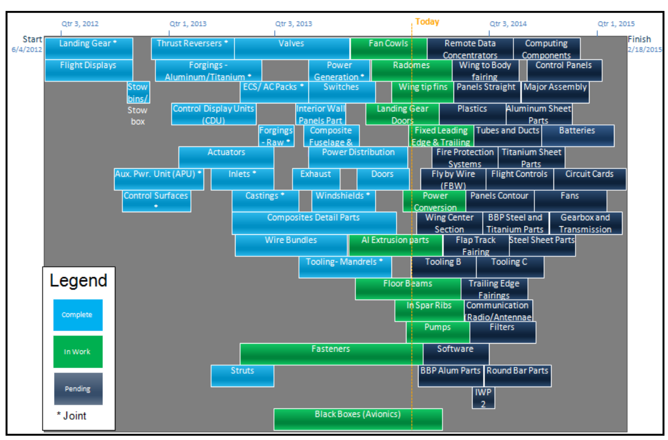

Figure 1. Project Status Visual Aid

The top horizontal axis represents time, ending with the projected end date for completing all planned cost models. Rows represent the team's available resources. Each box represents a procured commodity cost model, with the length of the box corresponding to either the actual or planned duration of the model's development. For example, the box labeled "Landing Gear" shows the approximate start and finish of all the activities that went into creating the landing gear cost model. Light blue boxes represent completed models, green represents in-work models, and dark blue is for models that will be developed in the future. Visual aids like these can provide useful yet easy to understand information quickly. The process steps for creating a JSCM will be described in detail in Section III.

F. High Level Vision for the JSCM Product

As discussed previously, the product was envisioned to be a linear (or multiple linear) regression derived from ordinary least-squares (OLS) regression. This technique is an industry standard for modeling a relationship between one or more explanatory variables (X) and a response variable (Y) by fitting a linear equation to the observed data (nonlinear regression techniques are also employed where necessary, and the methods are detailed in the Model Development section within Section III of this paper). The response variable for JSCM is the current production price of a part actively purchased for a Boeing program currently in production. The goal of the analysis is to explain as much variation as possible in the response variable using the explanatory variables, known hereafter as "attributes" or "parameters". See Fig. 2 for a graph that provides a high level visual representation of the JSCM product:

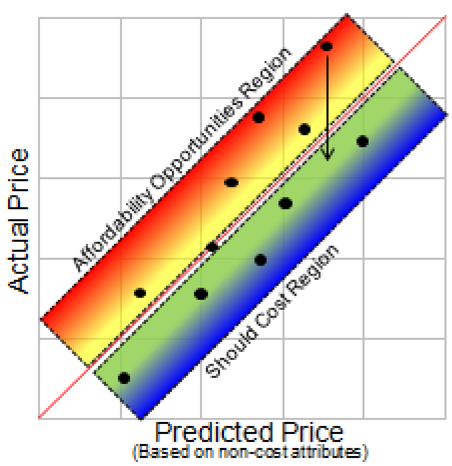

Figure 2. JSCM Product – Actual vs. Predicted Graph

This graph is known as the "Actual vs. Predicted Graph" and is a standard output of the JSCM process. The Y-axis represents the current production price Boeing pays for a part and the X-axis is the predicted price which is calculated from a regression equation based on one or more parameters. Individual data points on the graph represent an individual part that Boeing purchases. Points above the line represent potential affordability opportunities that allow Boeing to engage in a "should cost" discussion with the supplier with respect to the remainder of the Boeing market. The regression line is known as the "market average" for the particular commodity. Development of this graph and the overall modeling process is detailed in Section III.

Since the decision was made to solely model the supplier or external market, no Boeing internally fabricated or assembled parts are included in the analysis. The topic of evaluating internally fabricated and/or assembled parts and how it relates to the JSCM product is discussed further in Section IV: JSCM Product Usage.

G. Data Sharing

The Truth In Negotiations Act (TINA) requires Boeing to provide cost or pricing data for U.S. Government procurements exceeding $750,000 [3]. As an enterprise-wide team, the JSCM team must take proper precautions when sharing data from BCA with other organizations. The JSCM team ensures that Boeing procedure, PRO-6547 "Limitation on Sharing Boeing Commercial Airplanes Financial Information External to Boeing Commercial Airplanes", is followed and BCA financial data is not shared with other business units in Boeing and potentially become subject to TINA. Due to this, the data collection phase requires extra attention when collecting information for the data collection template. This precaution is taken throughout the entire JSCM process, not just during data collection. In addition to this, since the JSCM tools contain relationships that are based in part on BCA pricing data, the tools are not to be used in an analysis supporting a TINA compliant proposal which causes differences in product usage between BCA and BDS (more detail is provided in Section IV B Model Usage). BCA pricing data used to create the cost estimating relationship would require submittal to the U.S. Government for the proposal to be TINA compliant. The next section discusses the in-depth process of creating these models.

III. JSCM PROCESS

This section will take the reader through the process for creating a Joint Supply Cost Model. The major steps detailed in this section are: A. Model Initialization, B. Modeling Effort, C. Model Review and Approval, and D. JSCM Output – Tools for the Analyst.

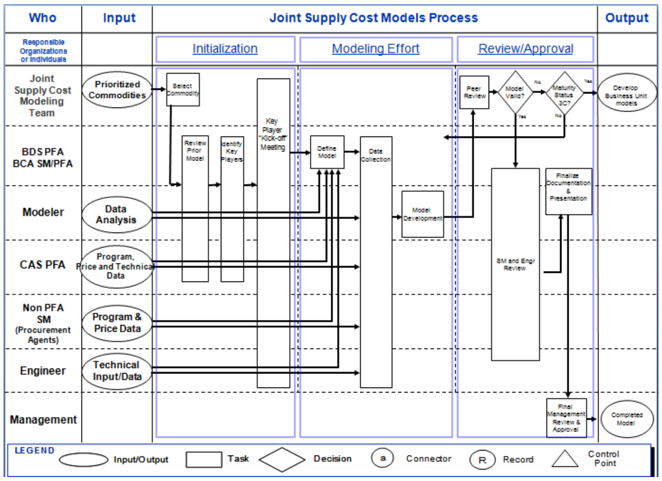

Figure 3. JSCM Process Schematic

A. Model Initialization

Fig. 3 shows a high level process schematic for the development of a JSCM. The first major phase, model initialization, consists of several sub-steps that serve to begin development of a model. To start the process, a commodity is selected from the pending list of commodities for analysis and assigned to a model focal. The model focal is the person who will create the regression model for the commodity, also known as the "modeler". The modeler has knowledge of basic statistics and a general technical understanding of the product to be modeled.

While the list of JSCM projects was considered comprehensive early in the formation of the JSCM team, communication with commodity SM Finance leaders is still essential and conducted via "pre-modeling" activity. This ensures that the scope of the commodity is thoroughly defined and that any supplier and/or contractual nuances are brought to the forefront early. An example of findings generated from this pre-modeling communication is demonstrated with the model for pressurized doors. Many doors on BCA aircraft are purchased as part of a higher level assembly where lower level cost breakouts are not visible to Boeing. Information like this is valuable early in the process and spurs discussion on the customer's[2] needs, statement of work (SOW) scope, population/observation size for the regression model, and other topics.

In many cases, the JSCM team is analyzing a commodity that has previously been studied from a cost modeling perspective, but with age has become obsolete. If a previous commodity's cost model exists, the model focal will read through the documentation to gain perspective on parameters collected and challenges faced.

Another step in the Model Initialization phase is conducting interviews with Subject Matter Experts (SMEs) from both the Finance and Engineering functions. Financial SMEs consist of Procurement Financial Analysts (PFAs), Procurement Agents (PAs), and Estimating individuals who are familiar with the commodity, the particular supplier, or both. Logically, Engineering SMEs (both design and manufacturing engineers) can provide a thorough description of the product and insight into what drives cost from a technical, design, and manufacturing perspective. JSCM team members, PFA, Engineering, and management from BCA, BDS, and SSG form the key contributors that play essential roles in each of the various stages of development of the model.

Finally, a "kick-off meeting" is held where the key contributors gather together in one meeting to review and agree to the scope, project schedule, and technical support required for the development of the model.

After these initial steps, the model focal is ready to move to the next phase, Modeling Effort.

B. Modeling Effort

The Modeling Effort is the second major stage of the project where the model is defined, data is collected and a cost model is created through statistical regression. Modeling Effort consists of three sub-steps: B.1 Model Definition, B.2 Data Collection, and B.3 Model Development.

B.1 Model Definition

Through additional meetings with the key contributors identified in Section III.A Model Initialization, the JSCM team conducts the model definition phase of the process. The goal of this phase is for the team to create a data collection template to be populated with technical and pricing data in the Data Collection phase that follows Model Definition.

To fully define the model, the JSCM team collects the complete list of parts that Boeing procures for the particular commodity for pre-selected programs across the enterprise Supplier Management organization. This is known as defining the "parts list" or "population". In statistical terms, the dataset of individual prices for these parts is the "response" or "dependent variable". For example, in the JSCM model for landing gear structures, the model focal collected all applicable part numbers for the nose and main landing gear for BCA programs 737, 747, 767, 777, 787 and BDS programs F/A-18E/F/G, F-15, C-17, and V-22.

The next step is for the key contributors to work together to define a list of attributes to collect for each of the parts. In statistical terms, these are known as our "independent variables" or "parameters". To define technical attributes, support from engineering is crucial, as engineers understand the product from a detailed technical perspective. As mentioned above, the JSCM team is looking for attributes that could drive cost into the part. An example of an attribute to collect is length of an aluminum extrusion. As the length of

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[2] Customer in this instance refers to the JSCM team's customer for the tools that it creates. The JSCM team's customers are primarily Boeing SM Finance, Engineering and Estimating functions.

the extrusion increases, one would naturally expect the price to increase.

Additional independent variables are descriptive and financial attributes. Examples are “supplier for the part”, “shipset quantity” (quantity of parts on the aircraft), “quantity purchased per year”, and “cumulative purchased quantity to date”. Attributes related to quantity can provide insight into discounts when purchasing higher quantities of a product.

Finally, “aftermarket” impacts on pricing can be explored with attributes. Production pricing for certain types of commodities could be impacted by the aftermarket demand for spare items.

The product of model definition is a data collection template that is sent to the key contributors to facilitate data collection. As a supplement to this template, each of the attributes is clearly and concisely defined so that there is no ambiguity in the meaning of the attribute.

Table 1 is a simplified visual example of the landing gear structures data collection sheet after model definition has been complete. In the actual landing gear model, many more attributes were collected, but for visual simplicity only six attributes are shown. Columns three, four, and five (in yellow) represent examples of financial related attributes, while columns six, seven, and eight (in orange) represent examples of engineering or technical attributes.

Program	Part	Supplier	Price $2012	Quantity Purchased per Year	Gross Structural Weight (lbs)	Number of Joints	Number of Posts
F/A-18 E/F	Nose LG						
F/A-18 E/F	Main LG						
F-15E	Nose LG						
F-15E	Main LG						
V-22	Nose LG						
V-22	Main LG						
C-17	Nose LG						
C-17	Main LG						
737	Main LG						
747-8	Body LG						
747-8	Wing LG						
767	Main LG						
777	Main LG						
787-8	Main LG						
737	Nose LG						
747-8	Nose LG						
767	Nose LG						
777	Nose LG						
787-8	Nose LG						

Table 1. Example of a Data Collection Template

At this point it is worth discussing “unique” parts. While an airplane may have two wings, they are in fact symmetric and from the JSCM perspective the wing represents one part, but has a quantity of two populated in a field (or attribute) titled “shipset quantity”. For example, the F/A-18E/F has one nose gear and two identical but opposite main gear. The JSCM team does not create two observations (or data points) for the two identical main gear assemblies. Instead the two main gear assemblies are consolidated through a process known as “mega-parting” into one row. The consolidation is accounted for in the “quantity per aircraft” field (and hence a “quantity purchased per year” field). This transformation is visually shown in Fig. 4. All other attributes such as weight are collected as they relate to one individual part. Mega-parting assists the modeler in statistically discovering economies of scale in terms of quantity. This elimination of similar parts also eliminates overstating the importance of a part in a model. For example, in Fig. 4, before mega-parting the nose gear has a price with attributes contributing to the overall relationship in the cost model; without mega-parting both the left and right Main Gear which would have the same price and attributes would have twice the influence on that relationship.

Pre Mega-parting		
Program	Part	Quantity per Aircraft
F/A-18E/F	Nose Landing Gear	1
F/A-18E/F	Main Landing Gear **Left**	1
F/A-18E/F	Main Landing Gear **Right**	1

Post Mega-parting		
Program	Part	Quantity per Aircraft
F/A-18E/F	Nose Landing Gear	1
F/A-18E/F	Main Landing Gear	**2**

Figure 4. Example of Mega-parting

The next step in the process is to fill out the data collection sheet through “Data Collection”.

B.2 Data Collection

The goal of the data collection phase is to fully populate the template developed in the model definition phase discussed above.

Data Collection and Model Development phases can be the most time consuming steps of the process and are allotted the largest percentages of work time in the JSCM schedule. Depending on the number of observations (parts), number of attributes, availability of existing data, ease of data collection, assistance from partnering function, and other factors, the data collection phase can take several weeks to complete. In some cases, as data collection proceeds, additional attributes are discovered or recommended that were not identified in the model definition process. In cases like these the JSCM team modifies the template and it is redistributed out for collection of the additional data.

In general, financial data can be collected once the part number is known. Being part of Boeing Supplier Management, the JSCM team has access to current purchase order information from several databases that summarize information from procurement systems. These databases allow the JSCM team to pull up-to-date pricing, quantity, and supplier information for the parts under observation. Pricing data is always verified with the appropriate PFA or PA responsible for the part.

Technical attribute data is generally more challenging to collect and often relies on assistance from engineering and technical organizations outside of JSCM. That being said, there are many reliable sources for Boeing technical data. Other sources within Boeing can also provide valuable information on any aftermarket impacts for a particular commodity.

Data types vary based on the information needed to be collected. Data can be categorical or numerical. Examples of categorical data are “Supplier Name”, “Material Type”, or “Name of Buyer”, where the data entered is descriptive of a particular grouping. Numerical data is discrete or continuous. Discrete numbers are data which only attain values from a list (similar to categories). An example is the count of fasteners on an assembly, as there cannot be half of a fastener. Continuous data are numbers which have the capacity to attain any number on the real line even if not currently represented in the data; such as having 1, 1.5, or 3.141592 pounds of weight, but the value could conceivably be any other positive real number. Data types used in JSCM modeling are continuous numbers, as dictated by OLS regression. That being said, descriptive data provides valuable information and can be transformed into useable continuous numbers for modeling. An example of this would be the “material type” attribute. Potential inputs for this field could be titanium, aluminum, steel, and other. If the modeler wanted to use this information in the regression model, four columns could be created titled: “titanium 1/0”, “aluminum 1/0”, “steel 1/0”, and “other 1/0”. In the “titanium 1/0” column, the user inputs a 1 if the material type of the observation is titanium and 0 if the material type is any other, and follows a similar procedure for the three other columns. The modeler has translated a categorical attribute into four numerical columns that can now be used in the regression model.

Depending on various challenges involved with acquisition of technical data, it may not be possible for 100% of the data to be collected. Missing data is noted and documented during the Data Collection process. Missing data affects Model Development; observations are excluded from analysis if an attribute with missing data is considered in the regression.

When the data collection template has been populated and validated, statistical analysis can begin through the Model Development phase of the JSCM process.

B.3 Model Development

After data has been collected by the model focal, the process of developing the final model begins. Model development complexity occurs during normalization, model derivation, data collection iterations, and peer reviews. The Model Development consists of nine sub-steps: B.3.1 Data Normalization, B.3.2 Initial Analysis, B.3.3 Cluster Analysis, B.3.4 Ordinary Least Squares Regression, B.3.5 Nonlinear Regression, B.3.6 JSCM’s Statistical Software, B.3.7 Outlier Analysis & Data Exclusion, B.3.8 Final Attribute Selection & Model Criteria, and B.3.9 Iterations, Joint Status, Final Product.

The intent of this section is to illustrate the JSCM team’s structured process and the depth and breadth of considerations given to every commodity’s dataset. It should be understood going in, that while the process is intended to have a natural flow and progression, the nature of statistical analysis is such that a process could potentially reach the final stage and be sent back to the beginning.

B.3.1 Data Normalization

Given the potential variability of data received from multiple sources, data received must be validated and normalized by the model focal. Validation ensures the multiple sources of data provided are accurate; this can apply to base units of data, method of entry (numeric versus alpha-numeric), completeness of entered data, etc. Once the focal has determined the received BCA, BDS, and/or SSG data to be valid, it is combined into a single data set.

Normalization is then considered because economic and contractual differences might be influencing observations. Economic differences generally occur as collected pricing or quantities atypical of the majority of data. Factors are used to escalate pricing or modify the data to common economic states; colloquially referred to as “apples to apples” comparisons.

Three adjustments are typically considered:

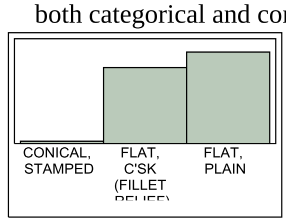
1. Base Year – price is adjusted from an atypical year to an established base year for the model using a Boeing pricing wedge.
2. Learning Curve – if production has not achieved a minimum unit of production, an adjustment is made down to a predetermined unit number.
3. Contracting – Unique contracting situations occur for suppliers, programs, and business units. Adjustments to account for these differences are considered. Examples are Performance Payments, Multi-Year contracts, payment schedules, warranty differences, spares agreements, etc.

In general, manipulation of the raw data is avoided. To represent the truest state of the market, primary data must be used. Any manipulation of the data (beyond correcting errors) alters the interpretation of the data from its primary state to a secondary state. Secondary data is less desirable due to the now subjective manipulation. While many of the adjustment techniques are accepted as standards in the industry, secondary data is not as precisely interpretable.

B.3.2 Initial Analysis

The adjusted dataset is put through several stages of analysis to identify potential issues, patterns, variability, associations, and distributions. This phase focuses on individual attributes collected in the dataset:

- Univariate Analysis –Simple descriptive statistics such as mean, standard deviation, and min/max are used to form a basic understanding of the distribution of the attribute. This information is supported with a graphical depiction of the data using a histogram for both categorical and continuous data.

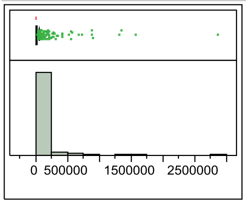


Frequencies

Level	Count	Prob
CONICAL, STAMPED	3	0.00602
FLAT, C'SK (FILLET RELIEF	224	0.44980
FLAT, PLAIN	271	0.54418
Total	498	1.00000
N Missin	22	
3 Level		

Figure 5. Example of Univariate Analysis of Categorical Data

RFQ Quantity



Quantiles		
100.0	maximu	2874433
99.5%		1465585
97.5%		539878
90.0%		127558
75.0%	quartile	11673
50.0%	median	1513
25.0%	quartile	276
10.0%		60
2.5%		14.85
0.5%		2.495
0.0%	minimum	1

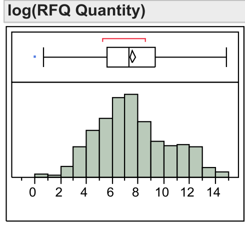
Summary Statistics	
Mean	51922.81
Std Dev	199981.35
Std Err Mean	8961.3788
Upper 95% Mea	69529.667
Lower 95% Mea	34315.954
N	498

Figure 6. Example of Univariate Analysis of Continuous Data

These visualizations also identify extreme values (outliers) within each attribute or identify potential data entry issues/errors within the data.

- Transformations – Biased or skewed distributions of data may need to be transformed to create a more normally distributed attribute for use in analysis. The data is still considered primary in this case. The most common application is transforming the average annual quantity buy (Fig. 6) logarithmically (using the natural logarithm) to achieve a normal distribution (Fig. 7).

log(RFQ Quantity)



Quantiles		
100.0	maximu	14.8714
99.5%		14.1947
97.5%		13.1989
90.0%		11.7563
75.0%	quartile	9.36501
50.0%	median	7.32185
25.0%	quartile	5.6204
10.0%		4.09434
2.5%		2.6775
0.5%		0.89385
0.0%	minimum	0

Summary Statistics	
Mean	7.5868772
Std Dev	2.7510641
Std Err Mean	0.1232781
Upper 95% Mea	7.8290877
Lower 95% Mea	7.3446666
N	498

Figure 7. Example of Log Transformed Data

Transformations do not replace any data, but are added to the data set as an attribute.

- Interactions – Data may be linked intrinsically with other data and the result may be a more powerful cost driver when considered together. This situation is an extension of transforming a variable wherein the added variable involves data and a function, but this case incorporates more than one original attribute. Consider volume; this is an interaction of three separate attributes (length, width, and height) combined with a multiplicative function. Another example is the use of index variables (true/false, 1/0) with another attribute. If Titanium weight is thought to be a cost driver beyond solely weight, we can "interact" the titanium index with weight by multiplying the two attributes. This creates the new variable of Titanium weight.

Once analysis has been performed on individual attributes, analysis can begin on the data set as a whole. One of the major steps is ensuring that the observations represent a homogenous data set.

B.3.3 Cluster Analysis

When developing a model, it must represent a homogenous set of observations. This ensures that the relationships derived are meaningful and interpretable. However, determining what is homogenous is difficult. Attempting to model two combined but unique sets (groups, clusters, statement of work [SOW]) of data can give the appearance that no significant relationships can be derived wherein they might be masked by the non-homogenous data set. Other relationships might be suspected, however the resulting analysis determines that there is no statistically significant difference between the groups. The consideration of clustering is essential to investigate and, if necessary, resolve complications.

Cluster Analysis is the process of identifying groups of data. Identification of groups, however, does not determine whether they are the root cause of a problem in the modeling process. There are four primary methods for identifying clusters; two of which are judgment based methods while the other two are statistical algorithms:

1. SOW – Data may be collected at too general of a level to be considered homogenous, or during model definition attributes which were considered to be cost drivers actually determine unique processes which are not relatable. For example, sheet metal parts have been found to be more adequately modeled separately by material type.
2. Univariate Analysis – Observations are made about whether the data resides in two or more groups. Referred to as multi-modal data or having multiple modes, the number of these observed modes indicates the possible number of clusters. This is seen only in continuous data.
3. Hierarchical Clustering[3] – This is a statistical application wherein an attribute is assumed to be the basis of grouping and then software is run to perform the clustering given some specified methodology. The output is a dendrogram which allows a user to specify how many clusters are to be identified and marked by cluster.

[3] The JSCM team uses the Ward Method as its standard approach due to its robust nature and resistance to outliers.

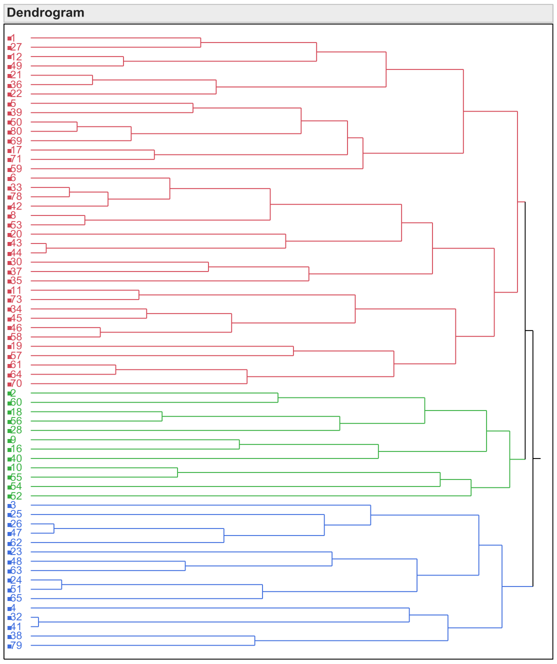


Figure 8. Example of Dendrogram with Three Clusters Colored

This method is preferred for continuous variables where there are no obvious group delineations. The resultant sets have distinct upper and lower bounds which define the cluster.

4. K-Means Clustering – This is a statistical process wherein the model focal pre-determines a number of means to be the count of clusters. An algorithm is run to minimize the total distance of each observation to the mean of the nearest group. This technique is generally utilized with multi-modal relationships.

These methods will derive technically and/or statistically valid clusters for the total dataset. The model focal must determine whether the original data is homogenous, or if these groupings indicate non-homogenous data sets. If it is determined that the data is not homogenous, separate groups are created and the development process is restarted with two separate models. The goal, however, is to keep the data combined and only separate if necessary.

B.3.4 Ordinary Least Squares Regression

Linear Regression analysis is the foundation for developing parametric models. The analysis is performed through the selection of variables and processed to yield an estimator. The primary process for deriving said estimator is Ordinary Least Squares (OLS) analysis. This method requires a dependent or response variable (price generally) and a series of independent variables or attributes (collected data) given a set of observations (part population). The traditional form to represent this actual data is as follows for a design of *n* observations and *p* variables (including an initial intercept term):

$$\mathbb{Y} = \mathbb{X}\beta + \varepsilon$$

Equation 1 – Data Represented as Linear Model

- $\mathbb{Y}$ is a *n* x 1 vector of responses (price).
- β is a *p* x 1 vector of parameters to be estimated.
- $\mathbb{X}$ is a *n* x *p* design matrix – made by combining a column of ones with each column of variables' values as *n* x 1 vectors.
- ε is a *n* x 1 vector of error terms.

The reason for using OLS analysis is the method produces a model that containing a vector of maximum likelihood estimators[4] for the parameters in β while also yielding minimized errors in ε. The resultant price prediction vector $\hat{\mathbb{Y}}$ ("hat" denotes estimated values) provides the values which are then compared against the actual pricing used in the model as the dependent variable. This comparison: $\mathbb{Y} - \hat{\mathbb{Y}} = \hat{\varepsilon}$ produces the measure of error from the model's prediction (which is minimized during the OLS procedure).

The outcome of this process[5], given any dependent and independent variables, is a series of linear formulas which are condensed into a system of equations defined by the general matrix form:

$$\hat{\mathbb{Y}} = \mathbb{X}\hat{\beta}$$

Equation 2 – Estimated Response with Estimated Parameters

If we consider only the first observation with two variables and expand, we get:

$$\hat{y}_1 = \hat{\beta}_0 + \hat{\beta}_1 * X_{11} + \hat{\beta}_2 * X_{12}$$

Equation 3 – Linear Equation of First Observation with Estimated Parameters

The prediction for the actual output of the first observation, y_1, is the result of whatever parameters (known as betas) were estimated through OLS and the actual values of the first observation. This model is linear due to the estimated parameters being used as scalar multipliers of the values of the first observation. If any transformed variables mentioned previously were used the model would remain linear due to

[4] Generally accepted by statisticians as best classification of estimators

[5] Refer to any linear regression text for the linear algebra derivation and methodology discussions. The JSCM team does not deviate from traditional OLS procedures.

the betas remaining as a scalar. For example, if we transformed column X_1 to a quadratic form X_1^2 and changed the previous formula:

$$\hat{y}_1 = \hat{\beta}_0 + \hat{\beta}_1 * X_{11} + \hat{\beta}_2 * X_{11}^2$$

Equation 4 – Linear Equation of First Observation with Quadratic Transformed Term

This would still be linear due to the use of the betas. Note this process does not by default produce the best model given all of data collected, but must be determined through the statistics which can be calculated given the outcome whether the model passes minimum criteria (subsection B.3.8).

An extension of OLS, Stepwise Analysis, is commonly used as it combines the methodology of OLS with the capabilities of modern computing power. The statistical analysis tool used by the JSCM team, JMP, allows dynamic consideration of the impact of adding any variable in a list given any other number of attributes currently included in the model. This is done by displaying what the significance[6] of any one new attribute would be given the current attribute list. Parameters listed in the stepwise tool are synonymous with attributes for JSCM. Checked "Entered" boxes are included attributes, while others are potential additions.

This methodology focuses on including statistically significant (threshold p-value < 0.05) attributes and minimizing the Sum of Square Error (SSE) but does not consider the reasonableness of adding an attribute or the quantity of attributes. Attention must be paid to the inherent logic of each attribute included.

B.3.5 Nonlinear Regression

Sometimes, an OLS analysis will not produce the best fitting model. A nonlinear approach is then considered. This method is based off of a more complex, iterative, and analytical process. Once an initial formula is established, the possibility of improved fit by use of a nonlinear parameter might exist. This parameter deviates from the previously discussed example of a linear regression model where the estimated parameter is not used as a scalar or intercept term. These nonlinear fit methods are not OLS because matrix multiplication fails to capture the complexity of the system of equations to be optimized. This method is relatively new in the field as it is more computationally intensive than OLS [4] [5]. The algorithm uses analytic Gauss-Newton method to minimize the model error utilizing gradient fields. The simplified process is as follows:

1. Parameterized formula established with seed values for parameters.
2. Sum of Squared Error (SSE) measured for initial model state. Process is designed to minimize SSE.
3. 1st derivative calculated for model.
4. Seeded values establish location in gradient field, yielding slope value. This is the change in SSE.
5. Steps are taken in the most negative direction given location by adjusting parameter values.
6. Repeat steps until the gradient is or SSE change meets criteria to justify the local minimum SSE.
7. Save estimated parameter values.

Nonlinear analysis is utilized on the JSCM team in two primary functions. First is fitting exponents. This is similar to the simple quadratic transformation shown previously. However, the exponent is more precise in its derivation and is optimally fit for the proposed model. If this method is used, then a degree of freedom has been lost due to the estimation of the exponent. Once the exponent has been fit and saved, OLS can still work to derive the equations which will yield the statistics used for analysis[7].

The second method of fitting a nonlinear component is the quantity discount model[8]. First consider a system where *U* is a unit price, *F* is fixed cost, and can be attributed through a constant proportion *a* to *V* which is variable cost. Though this assumption is weak in nature, the concept that $F = aV$ is important here. This method implies a cost relationship of $C = F + Vq$ where *C* is total cost of production with lot size of *q*. We can then derive the association of unit cost to *V*, *a*, and *q*:

$$U = \frac{C}{q} = \frac{F}{q} + V = \frac{aV}{q} + V = V\left(1 + \frac{a}{q}\right)$$

Equation 5 – Unit Cost's Association with Variable Cost

- *C* is the total cost of production
- *q* is the lot size
- *F* is the fixed cost
- *a* is a constant proportion
- *V* is the variable cost

This association shows that if we can find some *V* we can adjust the outcome by some proportionality based on the quantity produced. Substituting the prediction equation from

[6] Significance in this platform is done with an F-test and considers the current model to the improvement achieved by including the extra attribute.

[7] It is significant to note that the strength and comparability of Nonlinear and Linear Regression results and measures of error are under academic debate. However, the debate does not directly concern the validity of the overall process and underlying theories and is widely used in real-world applications.

[8] Similar to the Economic Order Quantity (EOQ) theory. This term is not used to avoid confusion about the basis of SM procurement decisions which are not primarily concerned with EOQ.

OLS for *V* we can use nonlinear regression to estimate an equation which can account for attributes like before, but also incorporate quantity discounting theory. The challenge is that each observation would have its own proportionality constant. This requires a modified formula from Equation 5 which enables the nonlinear regression to find the best fitting proportionality constant given any one part's average annual quantity. Using nonlinear regression allows the parameters to best fit the data.

The benefit of applying the quantity discount in this manner is that the dataset itself provides insight into the most accurate or 'best fit' discount. Other methods to apply a discount generally attempt to apply some factor developed from another analysis. While these methods produce generally acceptable results, the discount factor is applied based on expert opinion. This quantity discount method allows for a data driven approach to be taken and keeps the pricing data in its primary state.

Once the quantity discount formula has been appended to the OLS equation and the parameters are now fitted in its nonlinear form, the resulting relationship between models looks similar to Fig. 10 in relation to quantity and price.

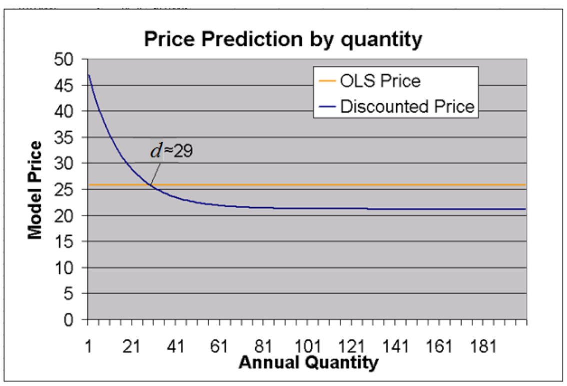


Figure 10. Quantity Adjusted vs. OLS Formulas

The intersection of the OLS Price line (flat) and the asymptotic Discounted Price line occurs at the parameter *d*. Before the quantity *d*, an observation has an inflated price on the discount curve, but once the average annual quantity buy of the observation surpasses *d* the price starts to drop down towards the asymptote established by parameter *c*. Abstractly, the formula takes the OLS equation and compresses the result as quantity increases.

This method of applying a quantity discount is an improvement upon traditional methods where an industry standard is applied using expert judgment. The data itself is responsible for determining the most appropriate discount percentages. However, when used in analysis, two degrees of freedom are used in order to estimate *c* and *d*.

B.3.6 JSCM's Statistical Software

To perform these analyses quickly and efficiently the JSCM team selected JMP as the primary analysis tool. This program is developed by SAS and regularly maintained and updated. The program provides robust statistical analysis and tools as well as advanced data visualization capabilities. This functionality is critical as it is essential for any conclusions drawn from an assessment of statistical outputs to be verified visually or vice versa.

Following are examples of some of the visual and numerical outputs available in JMP. Once a formula and predictions have been derived, it is essential to compare the predictions against the actuals to visualize the fit of data. Fig. 11 shows this Predicted vs. Actual plot.

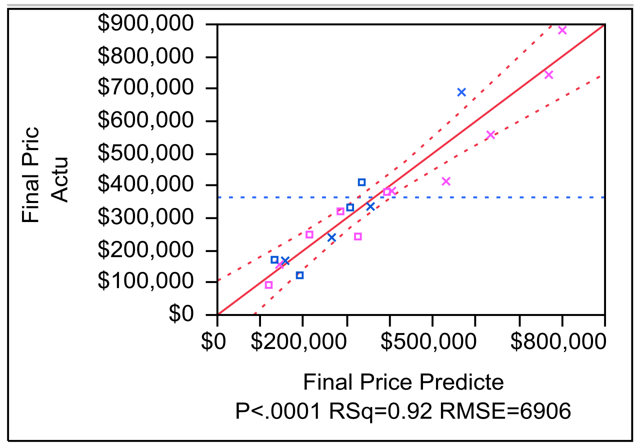


Figure 11. Example of Predicted vs. Actual Plot

Once an OLS or nonlinear fit is accomplished, the statistics must be analyzed for compliance with minimum criteria of acceptance.

Beyond these examples, the program calculates and displays the Analysis of Variance (ANOVA) table, correlation of estimates to test for multicollinearity, residual plots, and goodness of fit summary. Also, the software saves formulas (similar to Microsoft Excel formulas) which assist in the creation of the transformed and interaction variables which can dynamically update if precedent data is changed.

Another powerful aide in analysis is the ability to create scripts (similar to Visual Basic for Applications [VBA] coding) to perform repeated tasks or create new interfaces using the capabilities of other JMP functions. This capability was utilized to create a Boeing designed add-in designated GIST (Grube's Integrated Step-wise Tool) which is the standard platform to perform JSCM analysis. The tool builds off of the most common analyses and statistical checks performed by a model focal during the development phase and integrates them into a single analysis platform. These diagnostics and visualizations allow for the model focal to quickly assess a potential model.

GIST combines the Stepwise platform in JMP with additional statistics and diagnostics both visually and numerically. Examples of some of these outputs are shown in Figs. 13, 14, and 15. These outputs are updated when any potential model needs to be analyzed. Fig. 13 shows a numerical summary in the form of a Venn diagram (on left) of the major criteria for model assessment. Studentized residuals[9], hats values, and Cook's Distance values assessed given the proposed model. The values get compared to threshold limits based on model criteria and then summarized and colorized.

$$D_i = \frac{s_i^2}{p * MSE} * \frac{h_{ii}}{(1-h_{ii})^2}$$

Equation 7 – Cook's Distance

- s_i - Studentized residual for i^th observation.
- p - Number of parameters in proposed model.
- MSE – Mean Square Error of proposed model.
- h_{ii} – Hat value for i^th observation.

Given that p and MSE are constants for a model, this enables the two dimensional view with s on the vertical axis and h on the horizontal. D_i is then viewable through that relationship and can show the trad-off of hat value to studentized residual value before becoming a Cook's Distance violator.

Figure 15 is generated to analyze one underlying assumption of OLS analysis. Residuals (studentized or not) are assumed to be normally distributed. A comparison of studentized residuals to a Standard normal distribution generates a Quantile-Quantile (Q-Q) plot in that the plotted observations should follow a one-to-one line in the plot to be truly normal. The picture is inspected for patterns or too many general deviations from the line[10].

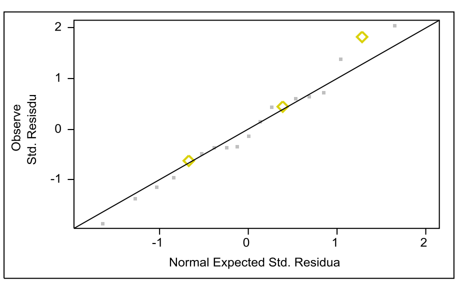


Figure 15. – Normal Q-Q plot

GIST also enables live switching between the Stepwise/OLS framework to the JMP Nonlinear platform. It builds the necessary background functions for quantity discounting and exponent fitting. Additionally, it provides the capacity to test the OLS version against the nonlinear version to determine if there is significant improvement using an F-Test (Fig. 16).

$$\frac{\left(\frac{1443 - 134}{169 - 166}\right)}{1346 / 166} = 5.9$$

Pr > 0.003210110487165

Figure 16. General Linear Test (F-test)

With the implementation and training on JMP and the GIST add-in, model focals on the JSCM team have a powerful suite of tools for advanced analysis.

B.3.7 Outlier Analysis & Data Exclusion

During model development, observations can be discovered which can unduly influence the statistical output more so than the general population which indicates a potential violation of homogenous data. Influences on the resulting model can range from false significance of an attribute to making a model appear inconclusive by its statistics. These observations are considered to be outliers and must be considered for exclusion. If an observation is an outlier, it cannot simply be excluded without documentation or justification. There are three categories of outliers (technical, contractual, and statistical) which each carry their own considerations prior to excluding.

Once an observation is excluded, it is necessary to include it again if the proposed model changes as they may no longer be an exclusion given different attributes included. Inappropriate application of exclusion justification can cause a poor model to appear significant when, in reality, there is no significant correlation.

B.3.8 Final Attribute Selection & Model Criteria

To finish model development, a model focal must choose the best possible model from the available attributes and analysis techniques. To pass the review and approval phase of the JSCM process, these models must pass criteria established by the team as well as logical assessments of the product by the engineering and PFA stakeholders.

The statistical criteria must meet or exceed industrial standards for acceptable criteria in the statistical community whenever a specific Boeing criterion level isn't established. If any of the statistical criteria are not met and the model focal

[9] Studentized residuals are an observed error with the influence of dimension removed to make errors across any model comparable to established criteria. Process divides individual residuals by the magnitude of its leverage.

[10] More complex analysis can be done in JMP if issues are suspected. Univariate Distribution platform contains Q-Q plots for all statistical distributions.

proceeds with a proposed model, they are required to justify and defend the decision in the white paper for the model and call out the deficiency as a weakness in the final product.

A common weakness of commodity models is low observation counts. One of the benefits of having enterprise level models is the ability to collect more observations that allow for more robust models. However, this limitation still persists and must be documented if the observations are limited which in turn limits the number of attributes which can be included. The smaller the ratio (closer to 1:1) the less confidence we have in an adequate model.

Logical criteria are not as objective as the statistical requirements, but are equally as important. To pass, the model must make sense to the peer community, engineering stakeholders, and PFA stakeholders. If the customers do not think the model is logical, the likelihood of the model being used is greatly diminished. These criteria provide the technical validity to a proposed model which is critical to gaining support by the customers and for being defensible under supplier scrutiny. Attributes are commonly included as a proxy for a more difficult cost driver to measure. For example, weight per attachment point can be an indicator of loads or complexity of design requirements. While the latter is known to drive price, the former appears to not make immediate sense as a cost driver. These associations are necessary to resolve and document for passing the logical criteria.

The final model proposed for review will be one with attributes which make technical sense, are statistically valid, and make logical sense.

B.3.9 Iterations, Joint Status, Final Product

Through the model development process (and peer review process) there is the chance that a dataset may not yield a statistically valid model or that the model put forth has other problems which prevent it from being accepted. If this is the case, one or several iterations of model development must be taken. In this situation, the standard practice is to restart the model development process from the beginning as the implications of new data or new analysis strategies will change the fundamental interpretation and outcome of results.

The final consideration given to the proposed model is whether it is a joint (BCA & BDS) model. Models can be statistically sound, but not capture the differences between the two business units. When determining joint status:

- Is there an attribute which is unique to only one business unit?
- Is there a consistent difference between the two? Test with index variable and index variable interaction with primary attribute.
- Do the BDS and BCA observations share price range?

If these questions cannot be adequately addressed, the implication may be that the data set is missing an attribute which explains the difference or that it could be discovered that there is a fundamental difference in price between business units. In the former case, the model focal would need to consult again with experts to discover the root cause if possible and collect more data if available. For the latter case, the difference will need to be comprehensively evaluated, documented, and approved before declaring that the data set should be separated by business unit. At this point, it may be the case that no model can be attained even after multiple iterations. If this is the case the model focal would follow similar steps to finish out the analysis, but would seek approval to publish the data as inconclusive. Inconclusive publications take two forms; weak model or dataset. Weak models are those that have too many issues to pass JSCM team standards, but may be useful to an analyst if no other resource is available to them or that the weaknesses don't pertain to their analysis. Datasets are projects which have been through Model Definition and Data Collection, but no model was able to be created. While inconclusive models fail to yield statistically strong predictive models, they still provide data or insight that may be useful to another organization.

Once the proposed model has passed these checks, the model focal prepares a template for Peer Review. This template requires the model focal to document everything of relevance through all efforts up to the review. This includes documenting all statistics, discussion of exclusion, statement of work definition, data collected, and model weaknesses.

C. Review and Approval

When the JSCM modeler completes model development, he or she is ready for the third major stage: conduct a thorough peer review and obtain first level management approval to publish the model results.

In preparation for peer review, the modeler must create a presentation summarizing the model development and results. The presentation consists of:

- An introduction to the model, which summarizes the commodity being studied and if any previous studies existed.
- A definition of the model that summarizes the programs, part, and attribute quantities, descriptions, and data sources. Any assumptions and exclusions to the data are also mentioned.
- Pictures (where applicable) clearly showing what parts are being modeled
- Statistical summaries of the model that resulted from the model development phase: univariate distributions, actual vs. predicted plot, summary of fit, statistical significance of parameter estimates, correlation of estimates, residual plots, and more.
- Model weaknesses discovered during development of the model.

The peer review team consists of the entire JSCM team, the PFAs responsible for parts in the commodity as well as engineers who are SMEs in the commodity. All are encouraged to provide feedback related to the resulting statistics, attributes found to be significant, usability of the model, as well as any weaknesses in the model.

Upon approval from peer review, the model, along with the model's white paper is presented to first line management for final approval. Management's primary role is to ensure standard formats are followed, verify that critical aspects of the entire process have been adequately considered, and check for compliance[11]. Management review provides a final check fixture of the completeness and compliance of the product prior to being released to the enterprise. With final approval, the JSCM products (discussed later) are then published to the JSCM Repository (discussed later).

D. JSCM Output – Tools for the Analyst

While a prediction equation is a useful tool for an analyst to have, additional files are created by the JSCM team to facilitate use by the end-user. Three major products are created for use by an end-user with each JSCM model:

1. White paper documentation in Microsoft Word of all the steps taken to create the model as published. This document goes into detail about all aspects of the model definition, model development, and results.
2. Microsoft PowerPoint executive summary of the model results. This package is a simplified presentation of the model and is similar to the peer review presentation discussed in Section III C. Most of the time, the contents of the PowerPoint slides are sufficient in explaining the results of the model to an audience of analysts.
3. Microsoft Excel based tool for the analyst to calculate predicted pricing using the formula derived from the modeling process. The intent of this file is twofold. First, JMP licenses are required to view JMP based files as there are no free viewers available and there are a very limited number of licenses available. Second, to provide a tool so that the analyst does not have to be concerned with correctly inputting the predictive price formula into Excel. The tool contains a graph of the actual vs. predicted prices with the capability of overlaying additional points under evaluation. Fig. 17 shows an example of this graph, with the diamond shapes representing the data points used to create the model. The square points are an example of data similar to what might be seen from a PFA analysis and that data is overlaid onto the plot points generating the trend line, which prevents altering the trend line from the one derived in JMP. One point lies above the market average line, while the other lies below.

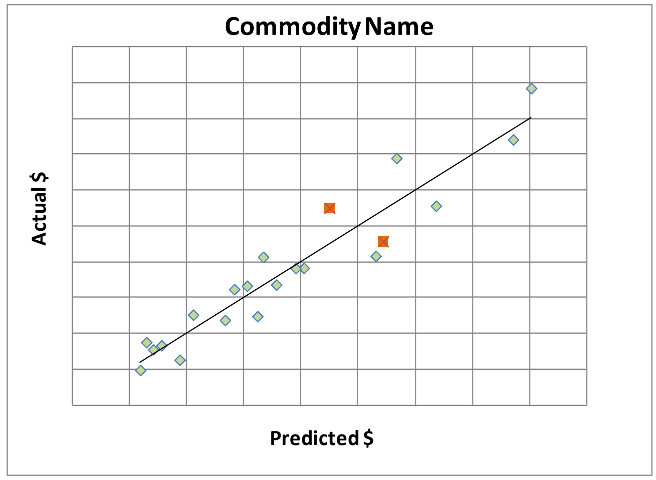


Figure 17. Example of Excel tool with overlaid data points under analysis

IV. JSCM Product Usage

This section will provide information on how the results of the analysis are made available. Also discussed are examples of how the product is used by the end-user. The end-users in BCA, BDS, and SSG are Estimating and PFAs.

A. The JSCM Repository

Upon approval, the white paper, PowerPoint presentation, and Excel tool discussed in Section III D are loaded into an online storage location known as the JSCM Repository and made available to the end user[12]. The JSCM Repository is a secure online resource to house the models and supporting data.

B. Model Usage

There are a myriad of intended uses of the JSCM products that span across the entire Boeing Enterprise. Those uses include, but are not limited to:

1. Supplier Proposal Analysis – Very much like a price analysis, the model can be utilized as an additional tool for the Cost Analyst to establish a relative indicator of supplier affordability in comparison to other suppliers in the market. For BDS, the model output is not to be included in any cost/price analysis write-up. The price analysis is an independent analysis of a supplier's proposal based on a specific last price paid. The model output is worked in parallel and can be utilized as a sound validation of position. It is an external indicator to gauge the position of the

[11] Compliance is outlined in the JSCM team's deviation (2013-027). Compliance considerations not covered there are governed by PRO-6547 and PRO-5356

[12] Based on the end user's business unit and job function, access to the JSCM Repository may need to be requested or, if not possible to access, a modified product example could be provided upon request

official write-up in relation to the marketplace. The PFA is responsible for document control and retention.

2. Pre-Negotiation (PRENO) Authorization – Similar to the proposal analysis, the model can be run and the results utilized in the PRENO authorization review board to give senior leadership an indication as to where the proposal, as well as, detailed analysis positions fall on the regression line in comparison to historical procurements. It is a check-and-balance to gauge position of the PRENO recommendation to the marketplace.
3. Supplier Negotiations – The models help identify a supplier's relative position in the Boeing marketplace. A sanitized version of the model output can provide the foundation for a collaborative discussion with a supplier. For example, the BCA utilized the Landing Gear model in negotiations for their final negotiated settlement. The outcome resulted in a downward shift in the marketplace and established a new benchmark for doing business with The Boeing Company, with regards to the landing gear commodity. Establishing this new benchmark allows for Boeing to identify those key suppliers that are considered best in class and allows for comparison of delinquent or potential suppliers to those model suppliers for the purposes of garnering future business. This collaboration also allows for an open line of communication on cost reduction initiative idea generation.
4. Communication – Similar to Subset 3 Supplier Negotiations, the model output can be used as a concise communication tool internally for a host of discussions. For example, Supplier or Program specific issues (or successes) relating to cost can be communicated with SM Directors and VPs more succinctly and effectively than just using tables or bar charts of data. It can also be used in sanitized conversations with an external party for less formal engagements than negotiations.
5. Competitive Opportunities (for BCA only) – the model outputs can also help a bidder board and competition advocacy board determine what a fair and reasonable price is when conducting a competition.
6. Predictive/Estimating Tool (for BCA only)– the joint models can be a very effective tool in helping an emerging or developmental program establish a market reference price for hardware that has not been procured before. Similarly, an existing program that is going through a redesign phase can use the models to help estimate the cost of the new hardware in comparison to similar and heritage hardware.
7. Engineering Design Cost Drivers – The data gathering and modeling phases of the JSCM process are specifically designed to identify the correlation between hardware technical attributes and price. The model output will allow engineering to pinpoint which attributes impact cost when going through the design phase.
8. Make/Buy Decision (for BCA only) – Similar to the supplier benchmarking benefit of the JSCM output. The model findings will allow Boeing to make a determination as to whether or not it makes sense to produce a product internally in comparison to what the external market would bear for a similar to end item.
9. The Aftermarket – The data collection process can help identify how specific commodities are procured and likewise identify areas of opportunity for a more streamlined procurement process. The aftermarket can be a prime example of where Boeing may have traditionally bought spare parts separately, across multiple platforms, but with the proper analysis spare parts may be bought with production to help bring spares pricing more in-line with production hardware.
10. Partnering for Success (PFS) – The overarching theme for doing business in The Boeing Company now is called Partnering for Success. Efforts like Cost Reduction Initiatives, Design for Cost, and Accelerated Opportunity Capture now fall under the guidance and structure of this single effort. JSCM is an integral part of PFS, inasmuch that the outputs help foster the key conversations that help determine which suppliers Boeing will be doing business with in the future and help bolster Boeing's position in virtually every aspect of establishing the "should cost" position.

V. Conclusion

The JSCM team's process and subsequent products are the result of an enterprise-wide customer demand. The products are statistically based models that use regression analysis to find a correlation between a hardware technical attribute or multiple attributes and price. The JSCM team, which is comprised of BCA, BDS, and SSG members, leverages Boeing's vast technical skill base, procurement expertise, and finance knowledge to deliver a world class set of tools. These models, some of which are already in use, have the potential to fundamentally change the way The Boeing Company conducts business with its sub-tier supply base. The JSCM process bridges the communication gaps between disciplines internally by producing validated, defensible, data-driven cost models integrating technical and financial information.

Since its inception, the JSCM team has set in motion the procedures to reshape the market place by giving tangibility to the idea of what a commodity "should cost"; an objective view of the market. In doing so, the team's intent is to give credence to the idea that there is a better way of doing business for The Boeing Company. Ultimately, with successful cost reduction efforts, the value stream from production to Boeing's customer airlines will benefit. As they struggle in a razor thin margin operating environment, ensuring competitively priced Boeing products produces a more stable business model for the future.

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BIOGRAPHIES

Andrew Parker has been with The Boeing Company for eight years. Currently with the BCA CAS Inventory Analytics in Renton, Washington, he works as a Data Scientist doing inventory optimization. His background includes work with 787 Program Estimating and SM Finance. Andrew completed his Masters of Applied Statistics from Colorado State University and completed a BS in Mathematics and in Economics from the University of Puget Sound.

Steve Stranghoener has been with The Boeing Company for ten years. In his current assignment in the BDS Procurement Financial Analysis Home Office group in St. Louis, Missouri, Steve's roles include supplier affordability (Partnering for Success) and supply cost modeling. Steve's background predominantly consists of cost analysis and material estimating. Steve's work team was honored to be a recipient of a 2013 Enterprise Finance Functional Excellence award. Steve has a Master of Business Administration from Lindenwood University and a Bachelor of Science in Finance from the University of Missouri - Columbia.

Jesse Womack is a member of the BCA Core Estimating team located in Renton, Washington. He earned a bachelor's degree in Mechanical Engineering from the University of Missouri, Columbia. He joined the Boeing Company as part of Estimating in Integrated Defense Systems (now BDS) in 2001. Jesse's background consists of data-driven estimating, publishing the BDS Cost Estimating Relationship Catalog, and cost modeling for JSCM.