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Galaxy Charts: The 1,000-Light-Year View of the Data

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This article presents a new kind of chart, called a Galaxy chart, which combines the strengths of other chart types. A Galaxy chart displays an entire Cost Element Structure on a single sheet of paper, showing all of the elements, their relationships, and their costs in a visually appealing way. Each child cost element is "in orbit" around its parent, with its children "in orbit" around their parent. The size of each cost element is directly proportional to its magnitude. Galaxy charts provide many insights. For instance, a single Galaxy chart displays the cost element structure hierarchy, the most significant cost elements, the least significant cost elements, the descending order of cost elements, and cost elements of equal value. This article will give an overview of the Galaxy chart concept, explain how to construct one, and explain a few of the insights that are available from the display insights that are typically difficult to gain without using a Galaxy chart.

Introduction

Graphical display authority, Edward Tufte, defines graphical excellence as "that which gives the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space" (Tufte, 2001). However, in practice, most cost estimators only show data in one of a few chart types that programs, such as Microsoft Excel, can automatically generate. Though these charts have their places and uses, there are a myriad of other ways to display data, tell a story, or make decisions.

As analysts, we should always be looking for new and different ways to comprehend a dataset or convey the analysis or estimate completed. We spend significant time poring over datasets in order to succinctly convey our estimates to decision makers. Additionally, we spend significant time discussing work breakdown structure (WBS) elements with small costs or small cost deltas at the expense of more important elements.

This article will attempt to help make analysts more efficient and effective by showing a new type of chart: the Galaxy chart, which builds upon and combines the strengths of other chart types. A Galaxy chart is not a default chart in any program, but can be drawn manually or coded to automate the process. Specifically designed to show data housed in a WBS, it allows an analyst or decision maker to put an entire WBS on a single sheet of paper, where significant cost elements quickly become clear. The article will first review several common visualization charts used for WBS data, then introduce the Galaxy chart and how to construct one, and finally review specific insights gained and applications for analysts. First, we will introduce some sample data used throughout the article.

Example Data

All of the charts in this article use the data from Table 1 that contains WBS cost data for a followship, Surface Combatant. The table was assembled using cost data from the Department of the Navy Fiscal Year (FY) 2012 Budget Estimates, Shipbuilding and Conversion, Navy (2011); all of the costs are normalized to fiscal year 2013 millions of dollars, expressed throughout the paper as FY13$M. In addition, we used expert opinion to allocate to some low-level elements. For display purposes, this table only shows the first three WBS levels, but a fourth level will be used throughout much of this article.

Throughout this article, we will refer to a WBS element's parent and children. A parent will refer to the element that is one level up in the structure (i.e., the parent of Plans Cost is Surface Combatant). A WBS element's children are the WBS elements that are one level down in the structure, who have the same parent. For example, Basic Construction/Conversion has the children of Labor, Material, FCCM, and Fee.

Review of Visualization Charts

Though a plethora of different visualization charts exist, the most commonly used charts are the ones that Microsoft Excel will display by default. Most other types require large amounts of time to create or modify. Despite the number of available charts, when trying to view where the "heavy hitters" or cost drivers in a WBS are, pie charts and column charts are two of the most viewed charts in practice. Often, these column charts come in the form of a Pareto chart. In addition, the cost estimating body of knowledge (CEBoK) created by the Society of Cost Estimating and Analysis (SCEA) identifies Comb charts as a useful way to view the data (Society of Cost Estimating and Analysis, 2010). Therefore, we will examine each of these chart types in depth.

Pie Charts

Pie charts are very basic; they are simply a circle with different colors for the various elements, as displayed in Figure 1. Each piece's area is equal to its proportionate percentage of the whole. For example, in Figure 1, Ordnance is 38% of the total cost, so its area is also 38% of the total pie. Pie charts can help an analyst see where to focus their efforts.

One of the limitations associated with basic Pie charts is that they only show the child-level data for a single parent-level WBS element. By connecting several Pie charts using lines, as shown in Figure 2, this limitation decreases. While this is useful for a few levels, it cannot tell the entire story. Analysts often only break out the largest pieces into their components, ignoring the smaller pieces and their sub-components. When we show many levels, the display is convoluted and complicated.

In practice, a single Pie chart can lead to tunnel vision and incorrect conclusions. For example, consider Figure 3. This Pie chart shows the sub-components of the Phalanx CIWS BLK 1B. When looking at this Pie chart, the analyst may decide to focus on Major Hardware when, in reality, this represents less than 0.01% of the total cost of the Surface Combatant. Even large fluctuations in this element will not have an impact on the overall cost. This type of tunnel vision can lead to poor conclusions and needless work. There are larger elements that exist in the overall cost where even a small movement may be more impactful. Conclusion: A Pie chart does not graphically capture the complexity of cost relationships that a WBS houses.

TABLE 1 Surface Combatant WBS and cost data

WBS level				
1	2	3	Name	Cost FY13$M
1.0			Surface Combatant	2,000
	1.1		Plan cost	85
	1.2		Basic Construction/Conversion	743
		1.2.1	Labor	379
		1.2.2	Material	253
		1.2.3	FCCM	15
		1.2.4	Fee	97
	1.3		Change orders	37
	1.4		Electronics	200
		1.4.1	SQQ 89 ASW	50
		1.4.2	SLQ-32 EW/MK 53 Nulka	10
		1.4.3	USQ 82 GEDMS	16
		1.4.4	EXCOMM	48
		1.4.5	Navigation system	2
		1.4.6	MK-12 IFF	5
		1.4.7	SLQ 25 NIXIE	2
		1.4.8	SLQ 4 LAMPS III	2
		1.4.9	SSEE	15
		1.4.10	MIDS	3
		1.4.11	CEC BLK II	7
		1.4.12	Misc. electronics	40
	1.5		HM&E	123
		1.5.1	STC 2 IVCS	7
		1.5.2	Main reduction gear	63
		1.5.3	Machinery control system	12
		1.5.4	Integrated bridge navigation system	9
		1.5.5	Misc. HM&E	32
	1.6		Other cost	63
	1.7		Ordnance	748
		1.7.1	AEGIS weapon system (MK-7)	343
		1.7.2	VLS MK 41	85
		1.7.3	MK 45 LWG	24
		1.7.4	MK 37 Tomahawk	39
		1.7.5	Phalanx CIWS BLK 1B	6
		1.7.6	MK 32 SVTT	2
		1.7.7	Electro-optical system	3
		1.7.8	MK 160 GFCS	9
		1.7.9	SPS 67 radar	13
		1.7.10	Misc. Ordnance	224

Pareto Charts

Pareto charts, named after 19th century economist, Vilfredo Pareto, attempt to display and
to emphasize the most important cost elements in a dataset. As shown in Figure 4, they usu-
ally consist of all of the WBS elements at a particular level and present them in descending
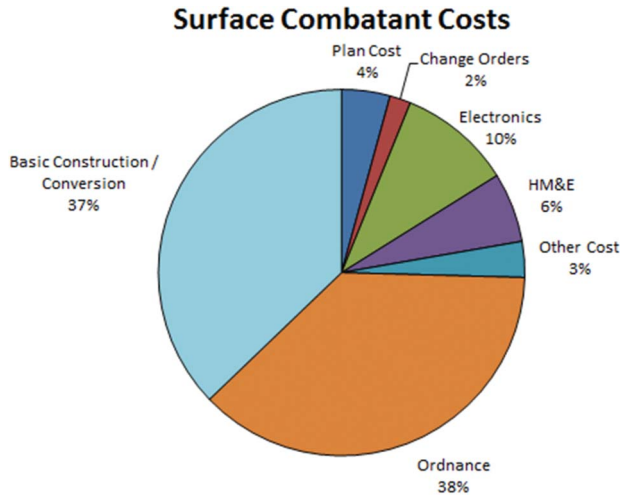
Surface Combatant Costs

FIGURE 1 Pie graph of Surface Combatant costs (color figure available online).
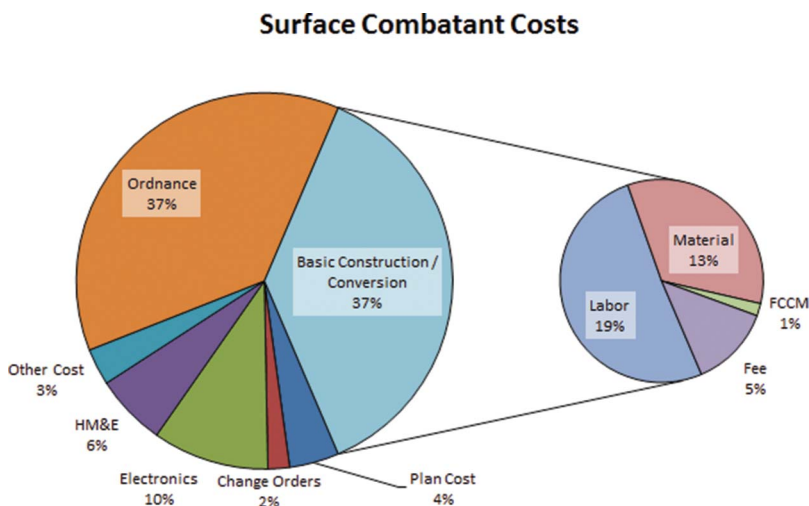
Surface Combatant Costs

FIGURE 2 Surface Combatant costs with basic breakout (color figure available online).

order from left to right on a column chart. Additionally, the cumulative percentage of each element is drawn and plotted on a second Y-axis. This quickly allows an analyst to see which cost elements are the most important.

Like Pie charts, Pareto charts work best when plotting the child-level data of a single parent-level WBS element. However, analysts often will plot all child-level WBS elements at the same time. For example, Figure 5 shows all of the Level 3 WBS elements from Table 1. This chart makes the larger cost elements obvious. A limitation of Pareto charts is the lack of comparable perspective with the data. Viewing one WBS level at a time fails to capture how all of the elements are related, i.e., parent-child relationships are lost. For instance, the fact that Labor and Material have the same parent is significant but not displayed. Pareto charts displaying Level 4 elements and below can completely disguise parent-child relationships.
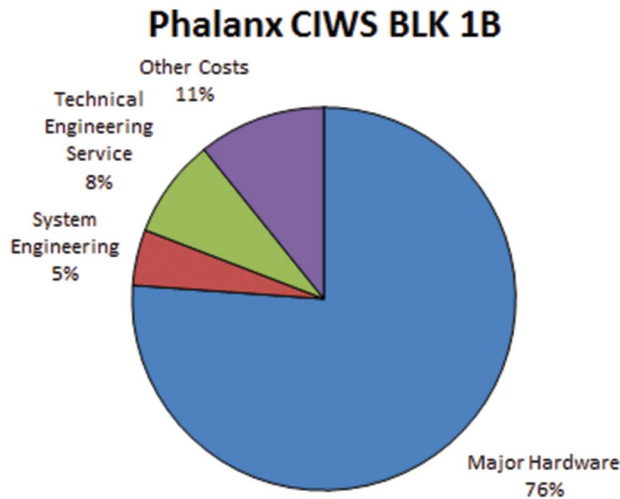
FIGURE 3 Pie chart breakout of Phalanx CIWS BLK 1B (color figure available online).
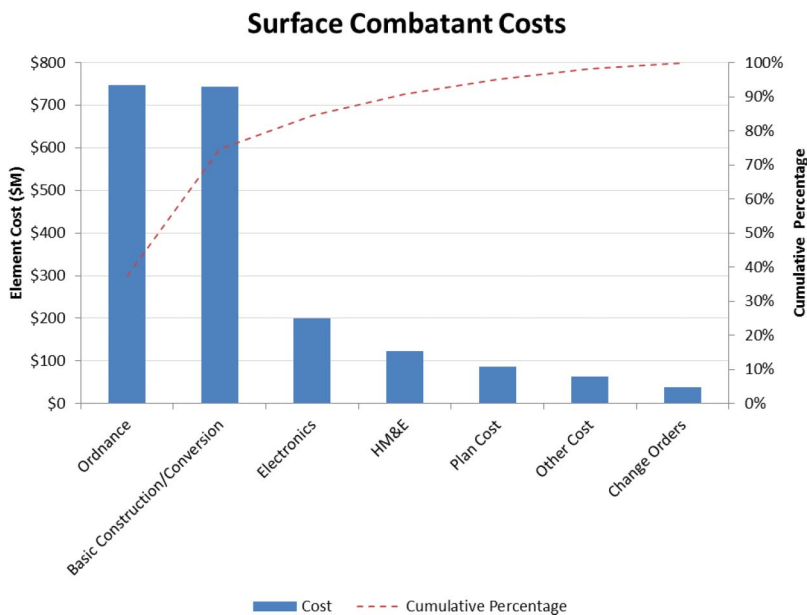

FIGURE 4 Pareto chart of Surface Combatant costs (color figure available online).

A WBS contains varying levels of detail. Basic Construction/Conversion has both children and grandchildren cost elements, whereas Plan Cost has none. Plan Cost, according to the NAVSEA 2005 Cost Estimating Handbook, "is the second major shipbuilding segment of the cost estimate . . . [and] includes the nonrecurring costs related to detailed construction plans and other associated engineering tasks for lead ships" (NAVSEA, 2005). As we dive deeper into the WBS, we soon have to eliminate the Plan Cost element since it is "unfair" to compare a Level 2 cost element with several Level 4 cost elements of Basic Construction/Conversion since they are broken out into such different levels of detail.
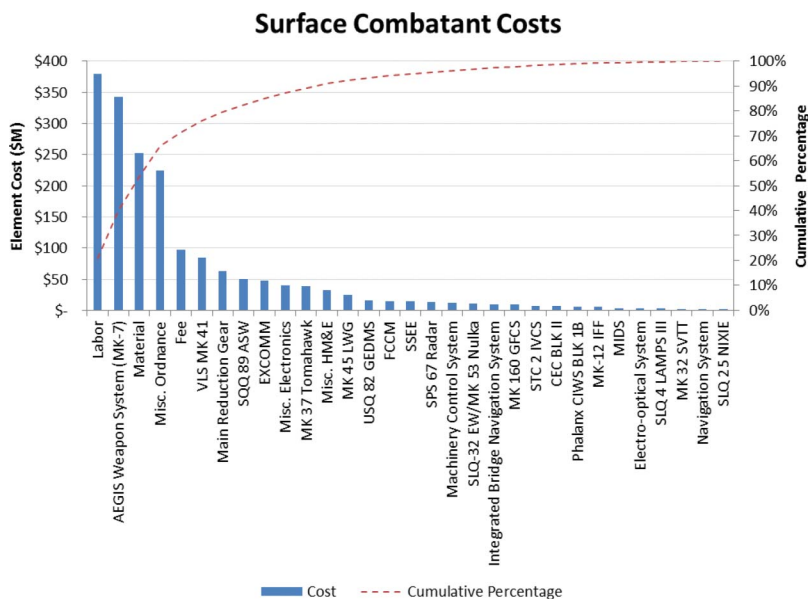
FIGURE 5 Pareto chart of all Level 3 WBS elements (color figure available online).

An alternative approach is to include only the lowest level cost elements in the Pareto chart, but parent-child relationships are lost.

If one only displays the children of one element, Pareto charts are susceptible to the same limitations as Pie charts. Various techniques attempt to scale the Y-axis to address this concern. However, this often ends up creating a chart that is difficult to read and provides little additional insight. Conclusion: A Pareto chart does not graphically capture the complexity of cost relationships that a WBS houses.

Comb Charts

Unlike a Pie chart or Pareto chart, a Comb chart can show all of the WBS levels as well as the relationships between them in a single chart. Figure 6 displays a typical Comb chart. The total cost is in the left-most section of the chart; movement to the right decomposes the total cost. Each WBS element includes the name, cost, and the percent of the total that it represents. The chart provides useful information that analysts require for comprehensive analysis and helps explain how the WBS is structured (Cooper & Plowden, 2010).

Since a Comb chart is hierarchal in nature, it helps an analyst focus their efforts, but they are not without weakness. Two issues exist with Comb charts. First, relative cost magnitudes are difficult to discern. While the table clearly shows parent-child relationships, only close examination of the entire Comb chart will identify the most significant and insignificant WBS elements. Second, if the WBS consists of many levels and elements, multiple separate pages are required to present the chart. Both of these practices devalue the entire presentation of the WBS data and cause confusion to viewers. Conclusion: Though Comb charts overcome some of the shortcomings of Pie charts and Pareto charts, they do not display the data in an easily readable graphical form.

	FY13$M			FY13$M	% of Total			FY13$M	% of Category
Surface Combatant	$2,000		Plan Cost	$85	4.3%				
			Basic Construction/Conversion	$743	37.2%	Labor		$ 379.16	51.0%
						Material		$ 252.77	34.0%
						FCCM		$ 14.87	2.0%
						Fee		$ 96.65	13.0%
			Change Orders	$37	1.9%				
			Electronics	$200	10.0%	SQQ 89 ASW		$ 50.34	25.2%
						SLQ-32 EW/MK 53 Nulka		$ 10.16	5.1%
						USQ 82 GEDMS		$ 15.62	7.8%
						EXCOMM		$ 47.58	23.8%
						Navigation System		$ 2.17	1.1%
						MK-12 IFF		$ 4.96	2.5%
						SLQ 25 NIXIE		$ 2.16	1.1%
						SLQ 4 LAMPS III		$ 2.45	1.2%
						SSEE		$ 14.67	7.3%
						MIDS		$ 3.40	1.7%
						CEC BLK II		$ 6.77	3.4%
						Misc. Electronics		$ 39.64	19.8%
			HM&E	$123	6.1%	STC 2 IVCS		$ 7.03	5.7%
						Main Reduction Gear		$ 63.05	51.3%
						Machinery Control System		$ 11.66	9.5%
						Integrated Bridge Navigation System		$ 9.35	7.6%
						Misc. HM&E		$ 31.79	25.9%
			Other Cost	$63	3.2%				
			Ordnance	$748	37.4%	AEGIS Weapon System (MK-7)		$ 342.62	45.8%
						VLS MK 41		$ 84.70	11.3%
						MK 45 LWG		$ 24.47	3.3%
						MK 37 Tomahawk		$ 38.85	5.2%
						Phalanx CIWS BLK 1B		$ 6.05	0.8%
						MK 32 SVTT		$ 2.35	0.3%
						Electro-optical System		$ 3.07	0.4%
						MK 160 GFCS		$ 8.89	1.2%
						SPS 67 Radar		$ 13.36	1.8%
						Misc. Ordnance		$ 223.71	29.9%

FIGURE 6 Surface Combatant Comb chart (first three WBS levels only).

Galaxy Charts

Introduction to Galaxy Charts

A Galaxy chart shows all WBS elements and their relationships on a single sheet of paper. Each WBS element is contained in its own circle and the circles connect with straight-line segments to show their relationships. As an example, examine Figure 7. The top-level, i.e., the total cost, we compare to the Sun, and each of its child-level costs to Planets. On the chart, each element has its own circle. The total cost, i.e., the Sun, is in the middle and its child-level costs, i.e., the Planets, "orbit" the Sun. Lines drawn between them illustrate this relationship. Though not shown in this example, the children's children, i.e., the moons, would be in orbit around their respective parents. This parent-child orbiting tactic would continue down through the entire WBS "Galaxy."

Throughout the WBS, each circle's area equals its cost and, at every level,

$$\text{Parent-level area} = \Sigma \text{ (Child-level areas).} \tag{1}$$

A more detailed discussion of this calculation occurs later in the article. This sizing technique means that top-level, larger cost elements are large circles and the low-level, smaller costs are smaller circles. In many cases, some circles become so small that they are almost unnoticeable; this is by design. This presentation helps analysts to focus on larger cost elements and to de-emphasize smaller, inconsequential cost elements.
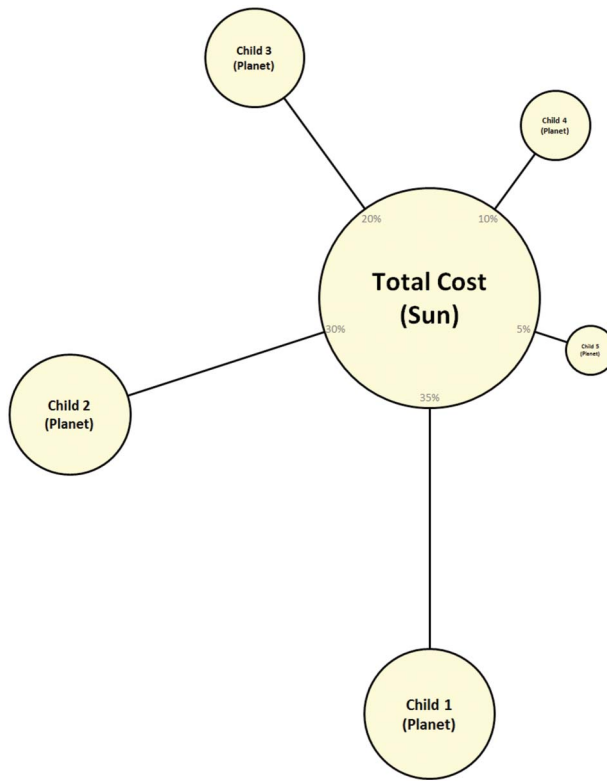
FIGURE 7 Galaxy Sun and Planets (color figure available online).

We considered sizing the circles by radius. Doing so meant that if one circle represented twice as much cost as another circle, the radius would be twice as large (instead of the area). However, this leads to disproportionate circle sizes and to distorted views of parent-child relationships, which makes WBS comparisons very difficult.

In a Galaxy chart, the parent's child elements circle the parent in a clockwise manner, at an ever-decreasing distance. For the total cost circle (the Sun), the largest element is immediately below the parent, but for all other circles, the largest circle begins 180° from where the parent line connects. In both cases, the remaining elements are evenly spaced around their parent circle in a decreasing order relative to their size, as is displayed in Figure 8. The distance between the parent and child also decreases clockwise around the circle. The combination of decreasing circle size and decreasing circle distance creates a Pareto-like effect, making it very clear to an analyst how the circles are ordered.

All circles contain an element label and dollar amount, and, if the WBS component has children, it contains percentages. The element label represents the name of the WBS element, and the dollar amount is the cost represented by the circle, usually expressed in $K or $M. The percentages inside a circle relate to their respective children. At the beginning of the line connecting a parent to its child, a percentage displays that child's percentage of the total program or project cost, i.e., the Sun's cost. The percentage text is relatively small when compared to the main circle text and is gray in color so as not to detract visually from the rest of the text. In the smaller circles, the text is often unreadable when printed, but it is important to consider the possibility of an analyst zooming in while it is in electronic form.

All circle borders and lines within the Galaxy chart are black in color, and the main text within each circle is black. Each circle is a very light shade of yellow; this color enhances
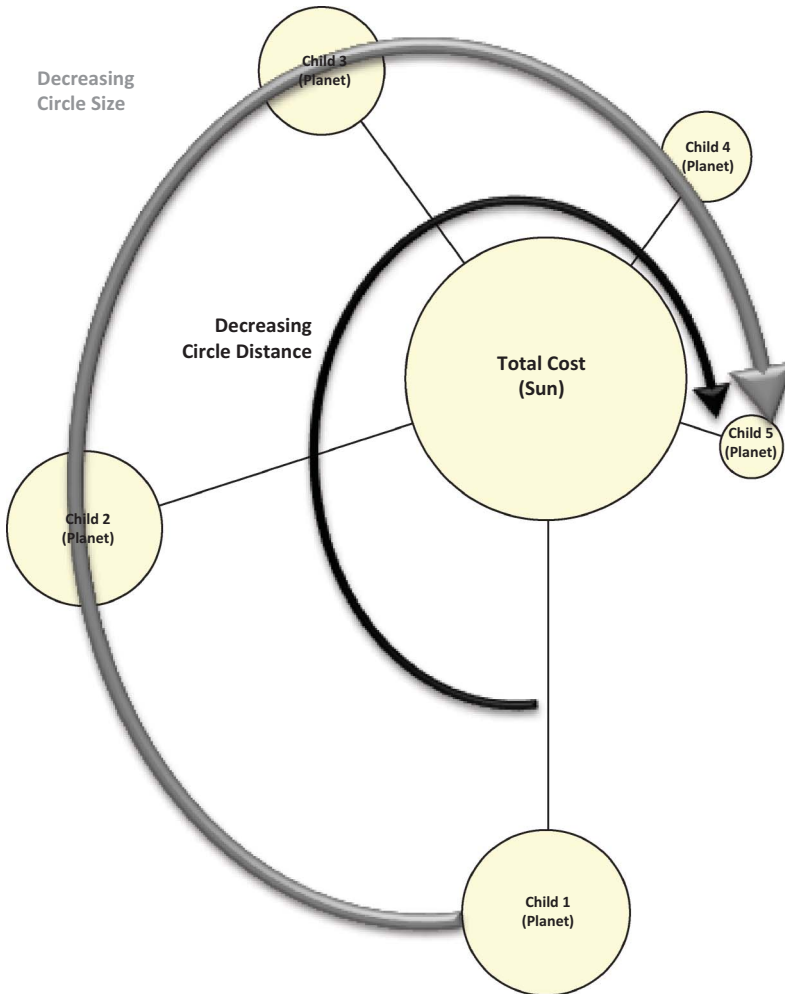
FIGURE 8 Decreasing circle sizes and distances (color figure available online).

readability, helps emphasize the text, and enables copying without loss of clarity. We considered using many different color shades, but graphical display authorities, such as Edward Tufte, argue against this practice since it creates "color-clutter" (Tufte, 1990). We believe the overuse of different circle colors distracts from the information content conveyed by circle sizes, scaled straight-line segments, and carefully chosen font coloring.

A Galaxy chart combines the strengths of Pie charts, Pareto charts, and Comb charts into a single technique for displaying data. From Pie charts, it borrows the concept of sizing costs relative to the total cost by scaling the area. From Pareto charts, it borrows the idea of arranging child-level costs in descending order, making it clear where the most costs are located. Lastly, from the Comb chart, it borrows the interrelated structure of showing every WBS element, sub-element, and the relationships that exist among them.

Returning to the Surface Combatant dataset previously discussed, a complete and very detailed Galaxy chart is constructed and displayed in Figure 9. This Galaxy chart contains 94 WBS elements on a single page. Many of the smaller Moons are important, but this type of display should help an analyst keep in mind how small these WBS elements are relative

FIGURE 9 Surface Combatant Galaxy chart (color figure available online).

to the total. We will examine the insights gained from this chart in a later section, but first we will explore in detail how to construct a Galaxy chart.

Constructing a Galaxy Chart

In this section, we will construct a Galaxy chart using the Surface Combatant example data provided in Table 1. This process can be automated using code, making the construction of

these charts a quick, neat, and repeatable process. One can write this code in Excel VBA or a more advanced programming language. All of the charts in this article were drawn using a proprietary code developed by Technomics. Though the software is patent pending, it is available online at http://www.galaxycharts.com. Anyone can securely upload data and generate their galaxy chart for free on this site.

Step 1. We first start with the top-most WBS element, the Sun. In this example, we represent it by a large circle, with an area of 2.0 square inches (in.^{2}), as shown in Figure 10. Inside this circle we put the element name and the total cost in FY13$M. We color the circle with a light yellow color to make it distinctive on the white page.

Step 2. Now we add the Sun's child-level WBS elements, the Planets. We order them from largest to smallest. Next, by dividing the child-level cost by the total cost, we determine the percentage each child-level element is of the total cost. In order to determine the area of the circle of the element, we multiply this percentage by the area of the Sun's circle area (2.0 in.^{2}). Lastly, since we are drawing circles, we determine each circle's radius from:

$$\text{Radius} = \sqrt{\frac{\text{Area of the Child-Level Element}}{\pi}}. \qquad (2)$$

As is summarized in Table 2, all of the data needed to draw the next set of circles on the Galaxy chart is available. Each circle displays the WBS label name and the cost. In some cases, the font size may need adjusting to make everything readable. As shown in Figure 11, we place the most significant child-level WBS element, i.e., Ordnance, immediately below the total cost and move clockwise with each subsequent WBS element. In order to determine the number of degrees to separate the elements, we use the formula:

$$\text{Degrees to Separate WBS Elements} = \frac{360^{\text{o}}}{\text{Number of Child-level Elements}}. \qquad (3)$$

In this case, we separate each element by 51°, since there are seven child-level elements. A scaled straight-line segment connects each child-level cost with the parent in proportion to its contribution to the whole. As the child-level circles get smaller, the line segments decrease so that the circles are closer and closer to the parent circle. This descending order and shorter distance to the parent creates a Pareto effect by visually identifying the contribution of each child-level element to the total cost. Lastly, to the parent-level circle, just

FIGURE 10 Total Surface Combatant cost circle (color figure available online).

TABLE 2 WBS Level 2 circle calculations

Number	Name	Cost	Percent of total	Area (in.^{2})	Radius (in.)
1.7	Ordnance	$748	37.4	0.75	0.49
1.2	Basic Construction/Conversion	$743	37.2	0.74	0.48
1.4	Electronics	$200	10.0	0.20	0.25
1.5	HM&E	$123	6.1	0.12	0.20
1.1	Plan cost	$85	4.3	0.09	0.16
1.6	Other cost	$63	3.2	0.06	0.14
1.3	Change orders	$37	1.9	0.04	0.11
	Total cost	$2,000	100	2.0	
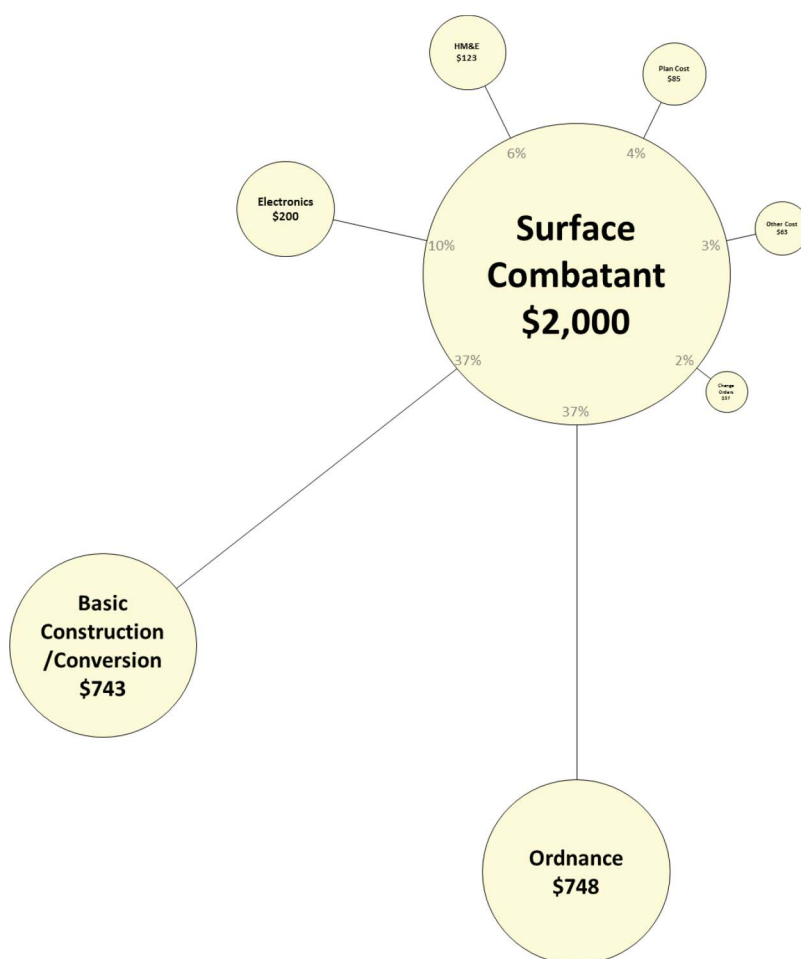
FIGURE 11 Surface Combatant Galaxy chart (Levels 1 and 2 only) (color figure available online).

inside the parent circle at the base of each child, we add the child's percentage contribution to the total cost.

Step 3. Since the first two WBS levels are complete, we move on to the next WBS level. Here, we follow the same process and calculations for each circle as is summarized in Step 2. In this case, we place the most significant child-level WBS element at 180° from the parent-level cost and move clockwise with each subsequent WBS element. This pattern allows a viewer to trace the largest WBS elements throughout the chart; the most significant cost elements for any parent-level WBS are located on the same vector. Once we calculate the characteristics of every circle, insert, and connect them, the chart is complete. In order to minimize clutter, we discourage Galaxy charts below WBS Level 4.

Galaxy Chart Insights

We gain many insights from Galaxy charts. To illustrate their advantages, we will examine Galaxy charts at various events throughout the acquisition process:

1. Initial Estimate;
2. Analysis of Alternatives (AoA);
3. Independent Cost Estimate (ICE) vs. Initial Estimate reconciliation;
4. Earned Value Management (EVM).

Initial Estimate Insights

When looking at an Initial Estimate displayed on a Galaxy chart, there are many insights quickly available. Due to the nature of the sizing, perhaps the most apparent insight is the identification of the largest cost elements. Since the size of a circle relates directly to its cost, the larger circles are the ones upon which an analyst should focus. The smaller circles, particularly those whose text is difficult to read, are not as important in the entirety of the Initial Estimate. For example, in Figure 12, the Surface Combatant's circle includes a black circle indicative of the MK 32 SVTT's cost. It appears almost as a dot, or a small "sunspot." Even if the MK 32's cost doubled, the cost of the Surface Combatant would not substantially change. A carefully constructed Galaxy chart graphically emphasizes the cost difference; in Figure 12, we overlaid the two circles to emphasize the point.

FIGURE 12 MK 32 SVTT (black) and Surface Combatant circles (yellow) (color figure available online).

It is worth noting that though a circle is small, it should not be ignored, because it could be significantly smaller than what it should be due to an incorrect estimate. In such cases, Galaxy charts provide an unintended benefit . . . cost element that should be large will be conspicuous by their absence.

As we can see in Figure 9, sometimes the level of detail available in a WBS is significant and the resulting Galaxy chart is "cluttered," and, perhaps, confusing. We diminish the clutter by removing and consolidating many of the smaller circles. For example, in Figure 13, we removed all circles representing less than 1% of the total cost and consolidated them into fewer "Other Cost" circles. This reduces the number of circles by nearly 50%, creating a much clearer picture of the most significant costs.

Obviously, circle removal and consolidation at any percentage level is possible. However, an important characteristic of Galaxy charts is the emphasis of significant cost elements via visual cues. Therefore, since large circles will always be more noticeable and eye-catching than small circles, removal and consolidation will likely be an unnecessary activity.

Galaxy charts allow comparisons between dissimilar WBS elements. For example, as shown in Figure 14, the Propulsion (Material) and VLS MK 41 circle sizes, and costs, are similar. Many other comparisons are immediately visible, too. Yet, before the Galaxy chart was drawn, we might overlook an insight such as this.

A well-created Pareto chart might also allow similar comparisons. However, in this example, Propulsion (Material) is a Level 4 WBS element without any child-level elements, whereas the VLS MK41 is a Level 3 WBS element with two children-level elements. Very few Pareto charts would have put these two elements on the same chart.

Analysis of Alternatives Insights

So far, all of our observations and comparisons are from a single Galaxy chart for an Initial Estimate. Now, we consider multiple, side-by-side, Galaxy charts that enable detailed comparisons. For this example, suppose that the Surface Combatant of Figure 9 is one of the two alternatives for an AoA study. The other alternative is an Amphibious Ship (Amphib). As shown in Figure 15, using data from the AoA, we now have two Galaxy charts, one for each alternative, and we can make the following observations:

1. Though the child-level cost elements of the total cost are similar between the two ships, the order is different. In Figure 15, Ordnance is the largest child-level cost element of the total cost for the Surface Combatant, but the third largest for the Amphib. When one considers the missions of the two ships, it makes sense for Ordnance, i.e., the combat system, to be a very large part of a Surface Combatant's total cost. Basic Construction/Conversion is the largest child-level cost element for the Amphib, but not for the Surface Combatant. Again, this discovery closely aligns with the mission of an Amphib.

2. Since the same scale sizes all of the circles in Figure 15, relative circle sizes provide useful comparisons. Aside from the obvious fact that the Amphib is more expensive than the Surface Combatant, it is noteworthy that the Basic Construction/Conversion of the Amphib is approximately equal to the End Cost of the Surface Combatant. Further, we easily observe that Basic Construction/Conversion is significantly greater for the Amphib than for the Surface Combatant. At the lower levels of the WBS, other comparisons and contrasts exist. One example is that the Labor cost for Integration/Engineering of the Amphib is almost as much as *all* of the Material cost for the Surface Combatant.

FIGURE 13 Surface Combatant, only showing elements greater than 1% (color figure available online).

3. Viewing two Galaxy charts side-by-side enables numerous comparisons and insights. Suppose our example AoA included only one concept and variations on the concept. Then by aligning multiple, side-by-side Galaxy charts the cost differences among the variants will be easily recognizable.

4. The previously described use of Galaxy charts leads to one final AoA-related idea. Aligning two or more galaxy charts side-by-side, *linked to a cost model,* creates

FIGURE 14 VLS MK41 and Material Propulsion circle sizes (color figure available online).
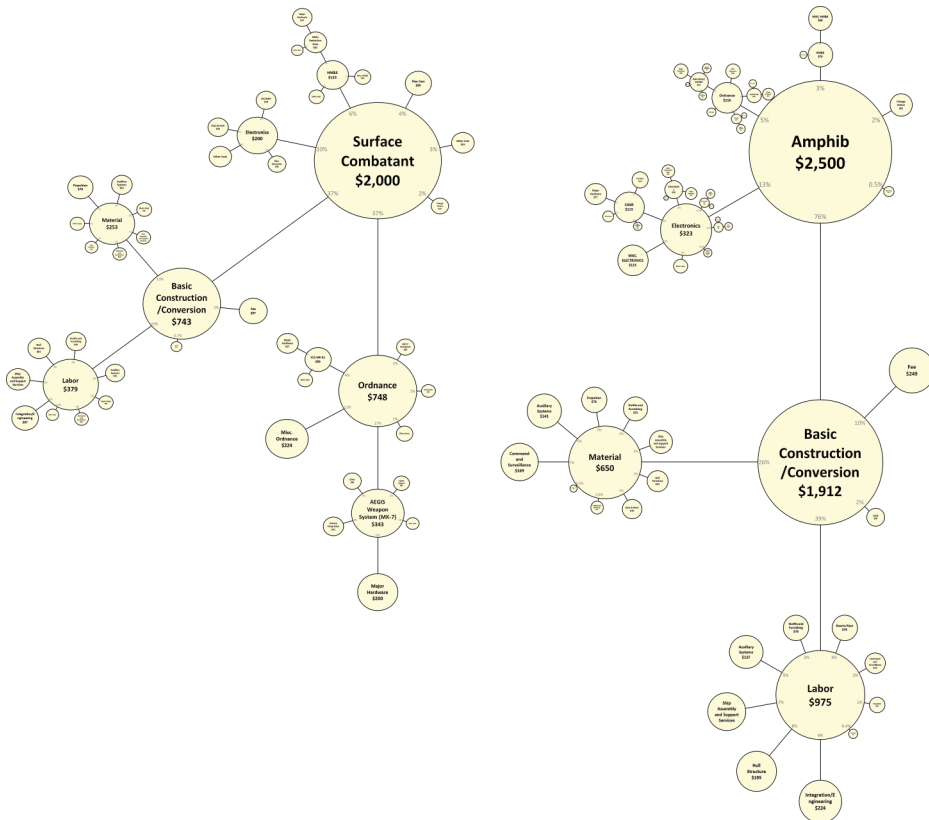

FIGURE 15 Surface Combatant and Amphib Galaxy charts (color figure available online).

a dynamic graphical display. This approach allows visual and quantitative sensitivity analysis. Changes in cost model assumptions will cause changes in (1) line segments lengths between child-level and parent-level cost elements, (2) child-level and parent-level circle sizes, and (3) numeric text included in the circles. Therefore, increases and decreases in cost elements due to changes in cost model assumptions will be immediately observable.

Reconciliation Insights

Suppose that the Initial Estimate for the Surface Combatant is complete, an Independent Cost Estimate is also complete, and reconciliation needs to take place. While we could compare the estimates side-by-side, we require a closer look at the differences. If they did

not use the same WBS, we would have no other option, but since they use the same WBS, we can lay the ICE on top of the Initial Estimate. As displayed in Figure 16, the Initial Estimate Galaxy chart remains unchanged from that shown in Figure 13. Now, we add a dashed line representing the ICE. Constructed in the exact same way as the estimate, the ICE circles are sized by area and centered on the Initial Estimate circle. In this display, the Galaxy charts' visual cues indicate where all of the cost discrepancies exist, but more importantly, where the *significant* differences exist.

Again, large circles are indicative of important cost elements and are evident during visual inspection. Basic Construction/Conversion is a significant cost driver, but the ICE and the Initial Estimate are approximately equal, suggesting that a rigorous review of this cost element is unnecessary. Ordnance is also a significant cost driver. In this case, the ICE's estimate is considerably larger than the Initial Estimate. Why? Very quickly, an analyst can see that the AEGIS System's Major Hardware and Misc. Ordnance are two cost elements that need close review. Insights such as these can quickly focus an analyst's energy on cost elements with meaningful payback.

Lastly, we return to the two estimates for Basic Construction/Conversion. Though they are very similar at the total level, when one examines the child-level cost elements, differences are observed. Relative to the Initial Estimate, the ICE is smaller for Labor cost and larger for Material cost. Further, cost differences exist among all of the Labor and Material child-level cost elements. All of these visually identifiable cost differences cancel each other so that similar parent-level cost totals exist for Basic Construction/Conversion. Is further analysis required? If the answer is "Yes," then the visual cues from the Galaxy chart can guide the analysis.

Earned Value Management (EVM) Insights

Moving forward in the life cycle, we examine the Surface Combatant while it is under construction. We assume that the cost values found in the Initial Estimate are the shipbuilder's Budget at Complete (BAC), so our starting point is Figure 13. In order to show multiple costs on a single Galaxy chart, we removed our preferred yellow shading from the BAC cost elements. In Figure 17, we add two additional sets of values: the shipbuilder's Latest Revised Estimate (LRE) and the Actual Cost of Work Performed (ACWP). The result is Figure 17. Please note that EVM Galaxy charts have a temporal nature, so for each update of EVM data, we update the Galaxy chart of Figure 17 also.

As for the ICE example, we add a dashed line representing the LRE. Constructed in the exact same way as the BAC, we calculate each LRE circle area as a percentage of the total LRE circle area and we center each circle over its corresponding BAC circle. In this display, the Galaxy charts' visual cues indicate that for every cost element the LRE is greater than the BAC. As with the ICE example, an analyst can also see where the most significant cost differences exist.

The ACWP is a gray shaded circle within each BAC circle. We chose gray instead of our preferred yellow color so that it will show up when copied. We calculate each ACWP circle area as a percentage of the total ACWP circle area and we center each circle over its corresponding BAC circle. While BAC and LRE might be relatively stable over time, every update of EVM data results in a new total ACWP. With time, each ACWP circle increases in diameter until the construction effort is complete.

The confluence of BAC, LRE, and ACWP circles provides at least two useful insights to EVM performance. First, work sequencing is visible. Those WBS elements with whose ACWP shading is a higher percentage of the corresponding BAC or the LRE circles are the most complete WBS elements. For instance, the ratio of ACWP
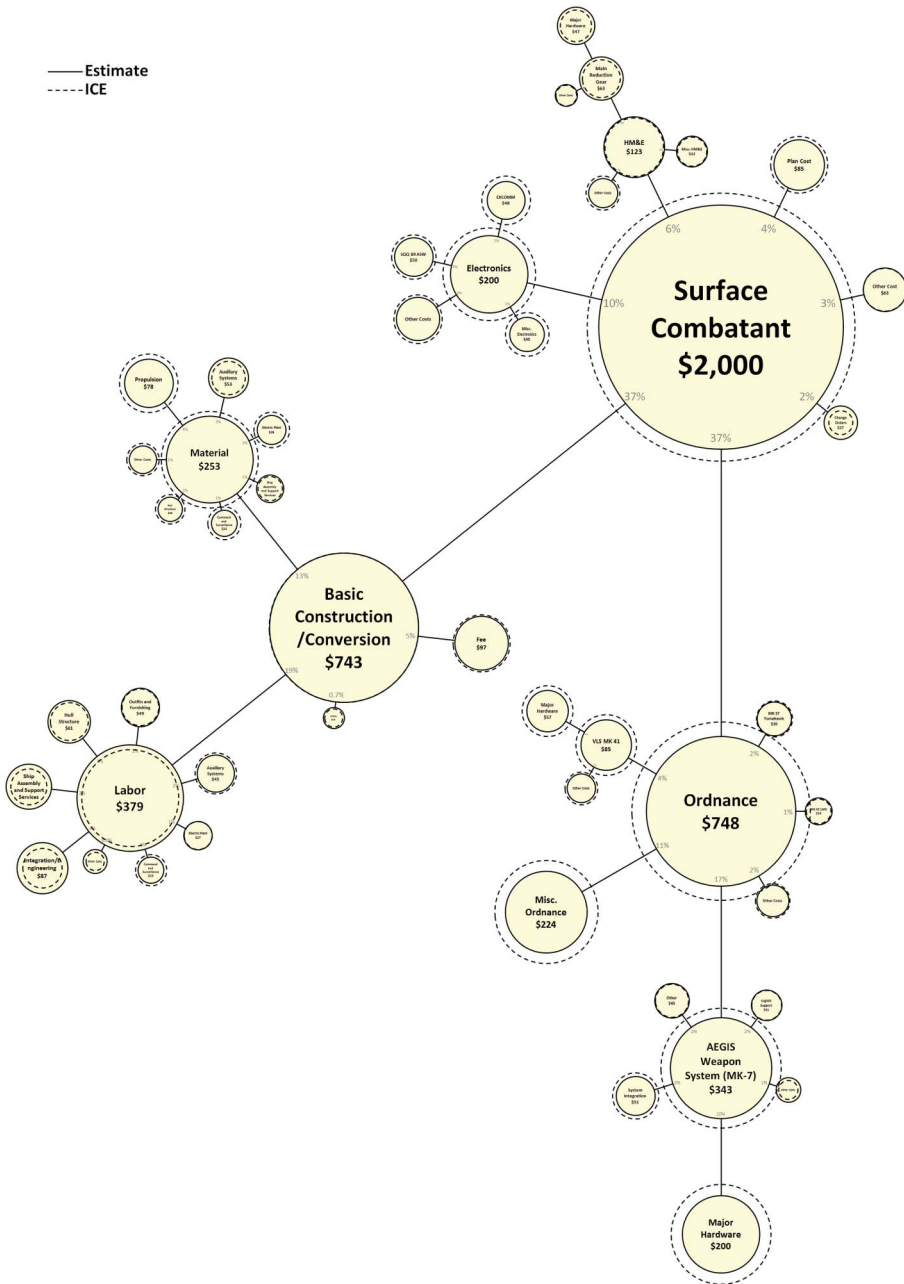
FIGURE 16 Galaxy chart showing both the Initial Estimate and ICE (color figure available online).

shading to BAC for the Ordnance-related effort exceeds the same ratio for the Basic Construction/Conversion-related effort; the Galaxy chart suggests that Ordnance effort precedes Basic Construction/Conversion effort.

The second insight is that the ACWP circles indicate actual and potential overruns and underruns. For example, Figure 17 indicates that a significant overrun occurred for the Plan
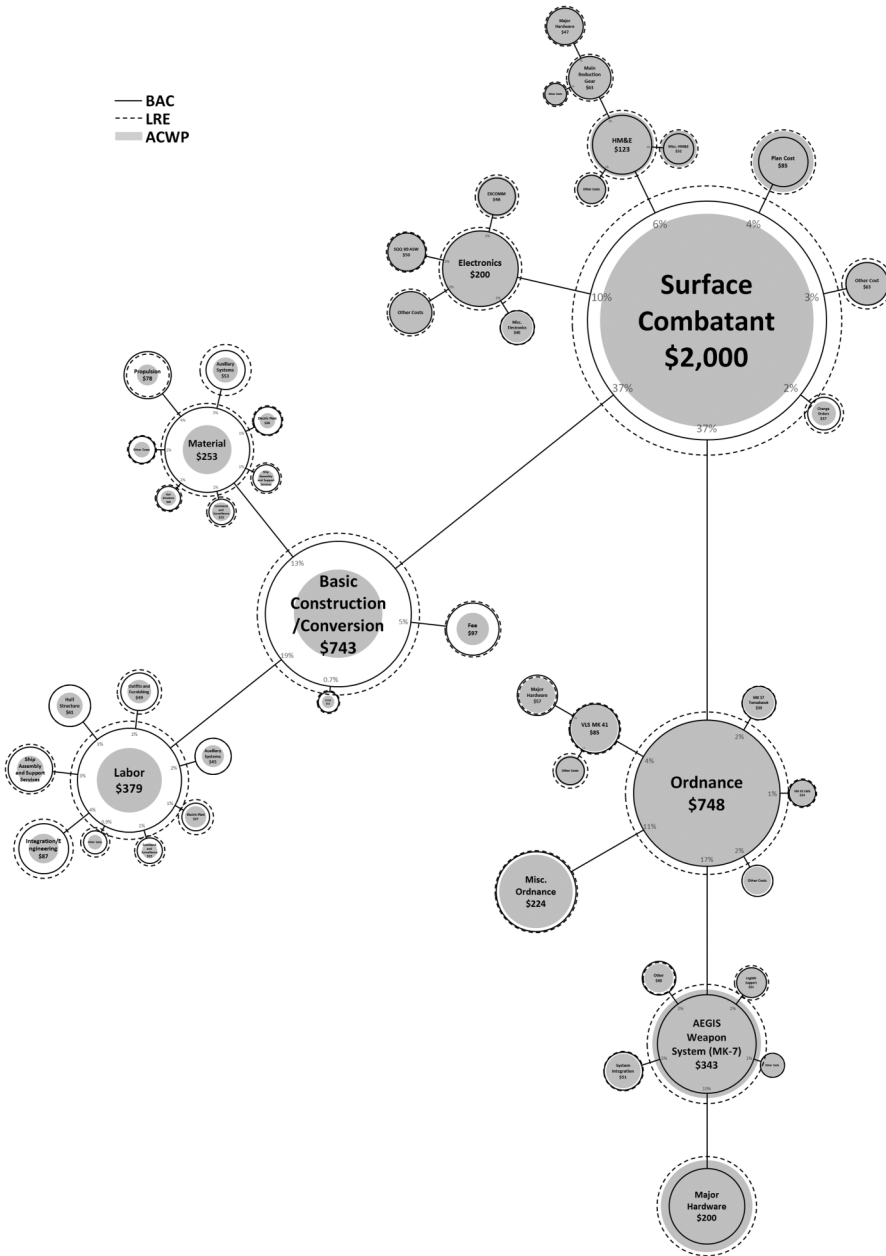
FIGURE 17 Surface Combatant with EVM data.

Cost element, i.e., its current ACWP is greater than its BAC. However, the parent-level for Plan Cost is the Surface Combatant total cost for which the ACWP is currently less than BAC. If Basic Construction/Conversion, the second most significant child of the Surface Combatant total cost, can remain within its BAC and not increase to its forecasted LRE, then it is possible that ACWP for the total cost element will remain less than its BAC and LRE.

Applying Galaxy charts to EVM analysis is intriguing, and other EVM metrics beyond those discussed here might be displayed using Galaxy charts. For instance, we can show the Budgeted Cost of Work Scheduled (BCWS) and the Budgeted Cost of Work Performed (BCWP), or the Cost Variance, Variance at Completion, and Percent Complete in the same way. Though Galaxy charts will not show trends over time, like a line graph, they give an analyst visual and quantitative insight into the current state of each individual WBS element and of the total program.

With the ability to show multiple EVM metrics on the same chart, an analyst can quickly make comparisons, discern what is important, and determine where to focus their efforts. As previously observed, a significant overrun occurred for the Plan Cost element, but it is nearly complete, so little, if any, improvement in its performance can be made. The current forecast for the Basic Construction/Conversion element is an overrun too, but time remains for improving its EVM metrics. Galaxy charts allow an analyst to make insights such as these, to understand the inter-relationships that exist among the WBS elements, and to make recommendations.

It is also possible to add a time dimension to this Galaxy chart. Multiple Galaxy charts created chronologically throughout the construction process can create a "flipbook" of the program showing the temporal behavior of the BAC, LRE, and ACWP. The flipbook might also help analysts observe budget shifting among the cost elements and compare ACWP progress at different stages of the construction process.

Further Research and Enhancements

This article only scratches the possibility horizon for the concept of Galaxy charts. Here, we only applied Galaxy chart concepts to the cost-related WBS of Department of Defense (DoD) sea systems. Our next steps will investigate applying Galaxy charts to WBSs of non-DoD systems, to schedule analysis, and to any other data that is hierarchal in nature. We believe that all analysts can benefit from the ability to see their data displayed in a Galaxy chart.

We also have ideas for additional research and enhancements to Galaxy charts. One idea is experimenting with the circle's distances from each other. The current version of the Galaxy chart stipulates that the length of the line segment between a parent and its children will decrease in a clockwise manner as the size of the children's circles get smaller. We chose this approach because it creates an easily recognizable, repeatable scheme that emphasizes the significance of a child's contribution to the parent. However, the approach also uses two graphical concepts, i.e., line segment length and circle size, to convey a single concept–magnitude. We are investigating alternative approaches where the line segment length allows the visual display of another dimension, such as schedule, duration, start dates, end dates, or some other time-related phenomenon.

Conclusions

A Galaxy chart is an intuitive chart that an analyst or decision maker can use to gain an accurate and comprehensive view of the costs within a WBS. The key takeaway is that Galaxy charts allow an analyst to gain understanding not available with current visualization techniques. Constructed manually or by automation using code, they help an analyst discern what costs are important, how cost elements are related, and where analysis time enjoys the greatest potential payback.

We hope the readers of this article will construct Galaxy charts of their own. Galaxy charts have many different possibilities and uses within the cost analysis arena and beyond.

We described several uses that demonstrate the power and utility of Galaxy charts. Our hope is that Galaxy charts will "*assist the thinking of producer and consumer alike*" (Tufte, 2006) by allowing the creator and viewer to think in deeper and more thoughtful ways about the data in order to make more robust and rigorous analysis.

Acronymns

$M	Millions of dollars
ACWP	Actual Cost of Work Performed
AoA	Analysis of Alternatives
BAC	Budget at Complete
BCWP	Budgeted Cost of Work Performed
BCWS	Budgeted Cost of Work Scheduled
CEBoK	Cost Estimating Body of Knowledge
DoD	Department of Defense
EVM	Earned Value Management
FY	Fiscal Year
ICE	Independent Cost Estimate
LRE	Latest Revised Estimate
SCEA	Society of Cost Estimating and Analysis
WBS	Work Breakdown Structure

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