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Activity-Based Cost Analysis Through WITNESS 27 Discrete Event Simulation Modeling

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Abstract

The challenge for integration of simulation modeling and manufacturing financial cost analysis has been that while there are accounting standards and commonly accepted practices for the capture of direct labor and materials costs, application of other costs, often generally classified as overhead, are applied to products from a top-down perspective. Inaccurate apportioning to particular end-items and more specifically to individual parts may take place. This analysis explores the allocation of both direct factory costs and overhead costs in simulation modeling according to the Kaplan-Cooper model for frequency stratification and Time Activity-Based Cost modeling.

Keywords
Discrete Event Simulation, Activity-Based Cost Analysis, Factory Cost, Overhead Costs, WITNESS Horizon

1. Introduction
Historically, Discrete Event Simulation modeling has been an effective tool for modeling material flow, labor capacity and utilization, and machines and the effectiveness of their utilization. The capability for stochastic simulation of more complex activities beyond simple machine utilization such as set up, equipment malfunction, AGV battery recharging is generally well accepted.

On the other hand, simulation with the capture of cost information is a different matter. Capture of directly attributable factory costs such as direct factory labor and costs for the direct materials that are directly employed in manufacture or assembly of the product is possible with many of the DES software environments. The costs for these activities are usually readily apparent and easy to quantify. These two and the cost of scrap are normally classified as "Factory Cost". The costs accrue for each discrete part as it is produced or for hours of operational time consumed.

However, there have always been challenges in determining an effective means to allocate the non-direct Overhead costs. Some have employed a multiplier strategy based on direct labor, where total factory overhead costs are divided by total direct labor hours to produce a labor multiplier, factory floor space or number of components in the assembly. Especially with high levels of automation that one might encounter in a highly automated manufacturing operation, actual production may have very little direct labor content resulting in multipliers that are quite disproportionally large. This may lead to errors in attribution of those non-direct costs. It becomes a matter of focusing our attention on the behavior of the tail while ignoring the presence of the dog. Cooper and Kaplan have examined this topic of understanding costs in a way that is useful employing Activity Based Cost (ABC) analysis. As they have discussed in their writing, it is often the case that overhead costs are overapplied on some products and underapplied on others.

1.1 Objectives

Develop a discrete event simulation model which employs Activity Based Cost Analysis in the quantification of manufacturing costs.

2. Literature Review

Understanding production costs resulting from industrial manufacturing and assembly processes has its roots in the efforts of Fredrick Taylor in the early 1900's. The focus in that era was materials employed, the labor of the production workers, scrap from defective product and an application of those "overhead" factory costs not directly related to production resulting from energy and water utilities, facility, management and various engineering disciplines. Overhead costs were applied to products with minimal regard for actual consumption, often applied as a multiplier of direct labor costs, factory area employed or number of components in an assembly. Cooper and Kaplan (1991).

The foundational concepts that are now known as Activity Based Cost Analysis were first published in 1971 by George Staubus (1971). In the 1990's, Cooper and Kaplan (1991), explored the application of manufacturing and overhead costs to products in a way that could be more effective than that defined by traditional cost accounting methodologies. As they have discussed in their writing on activity-based costing, it is often the case that overhead costs are overapplied on some products and underapplied on others. As a result, enterprises could hypothetically increase their business in products that are not profitable and exit production of products that are quite profitable since they can't really differentiate between the two`.

Operations accounting may employ a variety of different strategies in applying these overhead costs to products. First, they may try to categorize the overhead by its relationship with manufacturing volume, ie, costs that are "Fixed Overhead" or "Variable Overhead" depending on their sensitivity to changes in manufacturing output. Historically, overhead could be assigned to production as related to floor space area, labor hours, or machine hours.

In their 1991 HBR paper, *Profit Priorities from Activity-Based Costing* (1991), Cooper and Kaplan's proposed solution to this issue was to treat costs based on their relationship with production functions. Direct materials and labor accrue with each part produced. Some costs such as set-up or logistics accumulate with each lot or batch of product produced. Still other costs such as production and quality engineering, in their definition are "Product Sustaining". Finally, those which vary least frequently were defined as "Facility Sustaining". The authors divide these various costs into four functional categories:

Unit Level Activities – direct materials, direct labor, scrap
Batch Level Activities – setup costs, plant internal logistic costs, purchase orders, inspection
Product Sustaining Activities – Process Engineering, Product Specifications, Engineering Change Notices
Facility Sustaining Activities – Plant management, building and grounds, building environmental costs

Cooper, R. and Kaplan, R., (1992) in Activity-Based Systems, discuss "Activity Availability" which they define as the sum of resource usage and unused capacity, which is essentially the same as the notion of allocated resource usage prorated against available capacity. They identify one of the errors of implementing Activity Based Cost Analysis is that in some instances, those implementing ABC try to fit this into the familiar structure of fixed and variable overhead.

Takakuwa, S (1997) makes the statement consistent with Cooper and Kaplan that, "..current methods of accounting in use in most factories do not always describe or allocate costs accurately." (1997). Takakuwa focuses on Flexible Manufacturing Systems in conjunction with simulation and ABC. One of the key points that he makes is that simulation is the ideal tool for cost estimation since it can provide a thorough summary of manufacturing activity. Takakuwa also employs Linear Programming in the analysis, defining an objective function and constraints based on the cost drivers that are associated with volume-unrelated costs.

Williams, R. E., Savory, P. A., and Rasmussen, R. R (1997) integrate group technologies, activity-based cost analysis and simulation as a means to more effectively allocate factory overhead costs. They employ two classes; resource drivers and activity drivers which correspond to Cooper and Kaplan's concepts of unit and batch level costs. These costs accrue on a per-part basis and costs which are assignable on a unit time basis.

Spedding, T. A., and Sun, G. Q. (1999) use the assembly of printed circuit boards as the basis for their analysis and model the system in WITNESS. In addition to Cooper and Kaplan's four activity levels, the authors discuss Transaction Drivers, Duration Drivers and Intensity Drivers as a means of increasing allocation accuracy of their models. They highlight the fact that while traditional accounting systems are volume based, many of the costs of manufacturing are independent of volume and more appropriately addressed on a batch basis. Accordingly, they describe the allocation of costs to "cost pools".

Beck and Nowak (2000) summarize the thinking of Kaplan and Cooper regarding cost capture as; Identification of activities consuming an organization's resources, Determination of an organization's key activities and business processes and finally estimation of the cost of the activities and business processes that are performed. They summarize a threshold when activity-based cost analysis might be useful when the following conditions are extant, the number of orders, the product setup time and quantity of product/batch size can be employed as cost drivers. The authors begin their paper with the useful observation that, "it is better to be approximately right than precisely wrong" Beck (2000) which is easily associated with the thought that there is little difference between a wrong answer and a right answer provided too late to be useful. The authors also relate resources with resource drivers which are then related to activities through activity drivers into cost objects. There are three aspects to activity drivers: transaction, duration and intensity. The authors provide a useful outline for development of ABC DES simulation models.

Robert Kaplan and Steven Anderson considered the disadvantages inherent in Activity-Based Costing and proposed an alternative in *Time Driven Activity Based Costing*. (2007) Their unique contribution to the topic was the concept that all costs should be considered from one common dimension, that being time. In effect, working with a common denominator. Based on this, they propose the concept of a time dependent equation to manage costs with each having a time multiplier or coefficient.

To summarize the findings, whilst there is a considerable amount of literature specific to Activity -Based Cost Analysis and even mentions of simulation, generally there is minimal actual translation of theory into demonstrated examples.

3. Methods

We will begin by characterizing the costs in terms associated with Cooper and Kaplan's hierarchy: Unit Costs, Batch Level Costs, Product Sustaining Costs and finally Facility Sustaining Costs.
If Total Activity Based Costs are considered from the perspective of an equation:

Total Activity-Based Cost = Unit Costs + Batch Sustaining + Product Sustaining Costs + Facility Sustaining Costs.

Each of these costs in the equation could have multipliers for duration, resources consumed, difficulty etc. If one considers these activities, they have certain characteristics:

Type of Activity – Unit/Batch/Product/Facility	Activity frequency of occurrence
What triggers the activity	Activity duration (probably stochastic)
Task effort (fatigue derating)	Number of personnel

This is the type of variable information that equations can be built around. Given that these are all stochastic in nature, we can build simulation models that would help in understanding the effect of such activities as Kaizen SMED set-up reduction impact on Batch Costs as we strive for optimization and waste reduction

Unit Costs:
Unit costs are simply the direct labor costs, direct material costs and parts scraped that are commonly applied on a per-unit basis. These costs are relatively easy to identify, characterize and incorporate into simulation models.

Batche Level Costs:
When setup costs are discussed, other than from a generic cost perspective, it is often as part of a Lean Manufacturing evaluation either to be eliminated altogether or to translate internal setup time to external setup time. These setup costs are the costs that accrue from the end of one part's production until the start of the next, assuming that the cell or production line is capable of producing more than one product. Batch level costs also include production resource scheduling activities in ERP. Traditionally tools such as Economic Order Quantity (EOQ) analysis are often employed to minimize the cost of set-up by balancing fixed and variable expenses. This approach often leads to thinking that setup costs become inconsequential if only the batch can be made large enough. On the other hand, waste reduction in Lean Manufacturing analysis strives toward the reduction or elimination of setup altogether.

It should be acknowledged that setup for any specific machine or process may vary from one event instance to the next. Setup time for product changeover often depends upon conditions of prior setup and production. For example, if a plastic injection molding process is being changed from molding a red colored plastic to a natural-colored plastic, then the time spent purging and cleaning will be significantly different than if it is merely changing from one black colored material to another. Or the change may be from one part to another that involves time-consuming replacement of one injection mold for another.

Product Sustaining
Apportionment of these costs is most effectively addressed based on the number of discrete end items. Product sustaining costs often follow a curve similar to the reliability bathtub curve. Initially products require extensive support during product launch and at the end of life, materials and components for the product are no longer available and need to be replaced, thus incurring added engineering and production control resource support. Depending on where a product is on that lifecycle curve, it may have very different Product Sustaining costs than others in the portfolio.

Facility Sustaining
Imagine that there is a Mass Production Cookie Corporation. For the purpose of discussion, imagine that the Plant Manager has a ninety-inch UHD flat panel display and the alligator filled moat surrounding the factory. Simply enough, these costs are independent of the types of products produced and their quantities. Think about it for a moment. Is there any reason to infer that the number of alligators is directly correlated to the volume of production, or type of product produced? Are the alligators at all interested in where the various products are in the product life-cycle progression? Simply enough: not even slightly. The situation is the same for the more mundane aspects of maintaining the facility.

In both the Product Sustaining and Facility Sustaining costs, we will apportion these costs based on number of batches of SKU's in the annual production plan.

This case study model is designed to explore and illustrate several aspects of simulation modeling, bringing together external spreadsheet data sets linked to Witness Data Tables and activity-based costs. With the current focus in the literature and popular media on artificial intelligence and smart manufacturing we have decided to explore discrete event simulation for the manufacturing of a uniquely and potentially highly popular product, the Toastmaster 9000, which is an AI enabled toaster. You might ask yourself, why on earth would I, or anyone for that matter, want a toaster having artificial intelligence? Isn't it enough that I put bread or English muffin in, push some sort of button and warm toasty toast pops up minutes later? Hardly the case.

3.1 Toastmaster 900, AI Enabled Toaster Manufacture

3.1.1 Model Flowchart

Since we are planning a Really Quite Smartly Agile Factory 4.99, it only makes good sense to begin with a flowchart of the planned assembly process as shown in Figure 1. We will employ an additive 3D printing manufacturing process, which will print stainless steel. These armatures will be printed on demand, in order to produce the complex structure and minimize inventory.

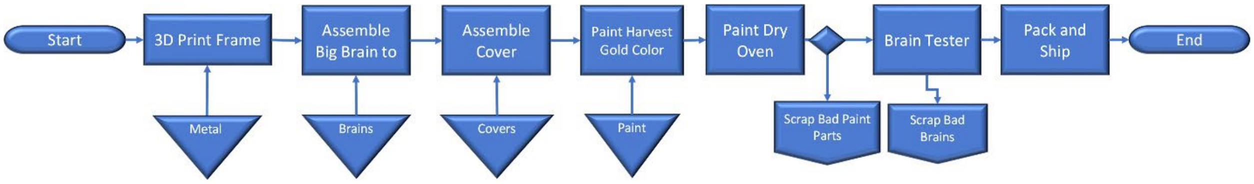

Figure 1 Process Flowchart

The Big Brain is assembled to the armature in the next assembly process closely followed by snap-fit assembly of the stainless-steel cover. The whole assembly is then coated with paint followed by a trip through the paint drying oven. Any units with blemished paint are rejected. Finally, the product is functionally tested prior to shipment to our highly valued customers. To be fair, it's just a quiz really, on the intersection of Malthusian economics and string-theory and not a full test. Those units that pass the quiz are then packed and shipped.

3.1.2 Model Excel-Based Source Data Set

The powerful advantage of using Data Tables linked to an external MS Excel workbook dataset is the great flexibility that it gives us. The spreadsheet can be employed as a simple interface between the analog factory-based world and the digital model as shown in Figure 2. In the following table, we have three different toaster models. But we might have twenty other toaster variants that are produced on this same production line. Rather than changing cycle time or breakdown data manually throughout the model, we can simply have our Witness model select data from among the three different toaster models listed individually in the model. This is similar to a Python dataframe.

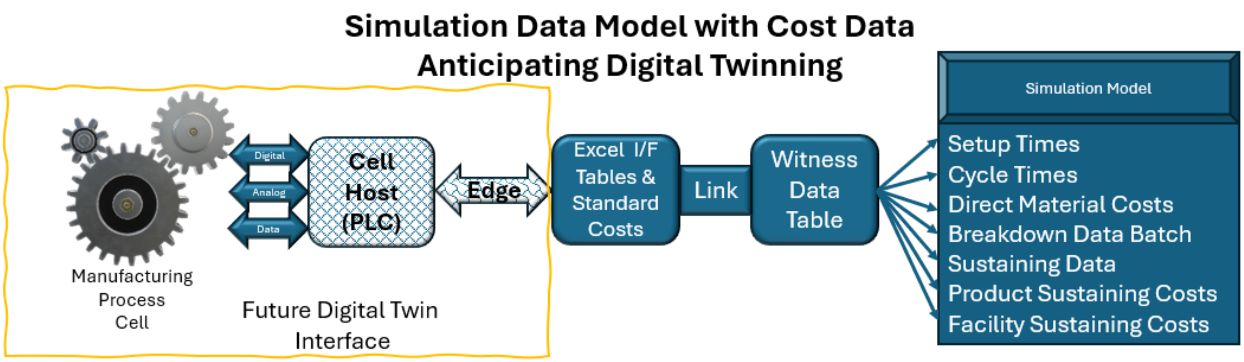

Figure 2. Model Data Flow

For this model, an Excel workbook with three data tables was created. These tables include our process data table, Direct Material cost data and sustaining costs table. As an example, Table 1 shows the process data flow. The source for these spreadsheet data could be sourced from historical information, Methods-Time-Measurement Standard Data (MTM) or even live data periodically updated from the factory MES for Digital Twinning purposes as highlighted in the yellow outline box.

You might notice in Table 1 that breakdown for each process has a minimum and maximum cycles to failure. This is consistent with VDA and AIAG PFMEA specifications for frequency. Repair time is defined by a normal distribution for illustration purposes, but one might just as easily recognize that an exponential or Erlang distribution would be a more representative distribution, depending on the nature of the empirical data.

Table 1. Source Data Excel Table

Toastmaster 9000 AI Enabled Toaster Even Bigger Data Model - Process

	Model A		Model B		Model T		Common Setup Time								
Resource	Cycle Time (Minutes)	Cycle Time SD	Cycle Time (Minutes)	Cycle Time SD	Cycle Time (Minutes)	Cycle Time SD	Setup Mean	Setup σ	Capacity	Break Down Max	Break Down Min	Repair Time (minutes)	Repair Time SD	Machine Cost	Cost per Minute
Metal Buffer							0.00		10	300	250	12.00	3.00	$15,000	0.009
3D Metal Frame Print	4.33	1.11	3.75	0.98	5.25	1.33	15.00	3.00		75	45	4.00	0.50	$350,000	0.228
iBuffer							0.00		5	225	125	6.00	1.10	$15,000	0.009
Assemble Big Brain	2.77	0.78	3.35	0.99	4.74	1.11	11.00	2.75		195	155	8.00	1.75	$500,000	0.326
Conv							0.00		3	350	325	4.50	0.50	$12,000	0.007
Cover Buffer							0.00		12	444	333	3.30	0.98	$12,000	0.007
Assemble Cover	1.74	0.40	2.30	0.12	2.78	0.47	8.00	1.78		450	350	12.00	2.46	$250,000	0.163
Big U Conv							0.00		3	700	200	5.00	1.00	$25,000	0.016
Paint Buffer							0.00		500	232	133	8.00	2.00	$12,000	0.007
Paint Harvest Gold	3.38	0.64	2.75	0.68	4.33	0.63	18.00	5.00		124	55	13.00	3.30	$225,000	0.147
Paint Conv							0.00		2	900	800	23.00	7.00	$13,000	0.008
UV Paint Dryer	2.48	0.75	1.00	0.20	4.12	1.20	12.00	2.00		500	450	15.00	1.75	$75,000	0.049
Painting Insp. scrap	7.87%		11.00%		3.40%										0.000
Tester Buffer							0.00		2	750	650	2.00	0.10	$15,000	0.009
Brain Tester	4.00	1.24	3.00	0.75	4.25	1.05	5.00	0.98		230	127	32.00	9.90	$175,000	0.114
Bad Brain Scrap	3.30%		5.40%		8.75%										0.000
Pack & Ship	4.90	0.17	4.10	0.78	6.20	1.93	5.00	0.76		1200	900	3.00	0.98	$8,000	0.005
Repair Technicians									2						
Operator									1						
Batch Size	1500.00		875.00		750.00										

Table 2, the Data Table from Witness shows the format of the machine element data as it is imported from the Excel file. This includes cycle time, break-down frequency and repair time and capital costs all with variability. This is analogous to the Python dataframe.

Table 2. Witness Data Table Linked to Excel

EBData

Resource	Mod_A_...	Mod_A_SD	Mod_B_CT	Mod_B_SD	Mod_T_CT	Mod_T_SD	S/U_Average	S/U_SD	Capac...	BD_Max	BD_Min	Rep_T_Average	Rep_T_SD	Machine_Cost	M_C/Min
Metal Buffer	0	0	0	0	0	0	0	0	10	300	250	12	3	15000	0.009
3D Metal Frame Print	4.33	1.11	3.75	0.98	5.25	1.33	15	3	0	75	45	4	0.5	350000	0.228
iBuffer	0	0	0	0	0	0	0	0	5	225	125	6	1.1	15000	0.009
Assemble Big Brain	2.77	0.78	3.35	0.99	4.74	1.11	11	2.75	0	195	155	8	1.75	500000	0.326
Conv	0	0	0	0	0	0	0	0	3	350	325	4.5	0.5	12000	0.007
Cover Buffer	0	0	0	0	0	0	0	0	12	444	333	3.3	0.98	12000	0.007
Assemble Cover	1.74	0.4	2.3	0.123	2.78	0.47	8	1.78	0	450	350	12	2.46	250000	0.163
Big U Conv	0	0	0	0	0	0	0	0	3	700	200	5	1	25000	0.016
Paint Buffer	0	0	0	0	0	0	0	0	500	232	133	8	2	12000	0.007
Paint Harvest Gold	3.38	0.64	2.75	0.68	4.33	0.63	18	5	0	124	55	13	3.3	225000	0.147
Paint Conv	0	0	0	0	0	0	0	0	2	900	800	23	7	13000	0.008
UV Paint Dryer	2.48	0.75	1	0.2	4.12	1.2	12	2	0	500	450	15	1.75	75000	0.049
Painting Insp. scrap	0.0787	0	0.11	0	0.034	0	0	0	0	0	0	0	0	0	0
Tester Buffer	0	0	0	0	0	0	0	0	2	750	650	2	0.1	15000	0.009
Brain Tester	4	1.24	3	0.75	4.25	1.05	5	0.98	0	230	127	32	9.9	175000	0.114
Bad Brain Scrap	0.033	0	0.054	0	0.0875	0	0	0	0	0	0	0	0	0	0
Pack & Ship	4.9	0.17	4.1	0.78	6.2	1.93	5	0.76	0	1200	900	3	0.98	8000	0.005
Repair Technicians	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Operator	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
Batch Size	1500	0	875	0	750	0	0	0	0	0	0	0	0	0	0

The tables for Direct Material Costs and Sustaining Costs are similar to those shown here for the machine elements. Having said all that, there are alternatives in how you might structure your data in Excel. You might structure process data in one Excel tab, setup times in another, breakdowns in a third tab and sustaining costs in a further tab.

3.1.3 Model Layout

So much data in hand, what should we do with it? Figure 3 shows our complete model of the AI Toaster assembly line. Initially this was a linear line, but then, we are all Lean Six Sigma here, so we decided, why not make it a "U" shaped cell?

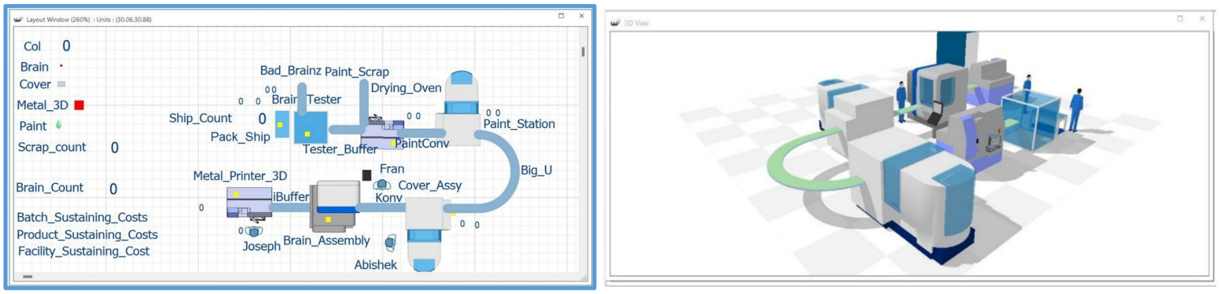

Figure 3. 2D and 3D Witness Model Layout

3.1.5 Machine Element Detail

When this model first starts, a cell setup is performed for the first product to be manufactured. The variable "Col", which is the column number, initializes with the value of 2 – indicating the first data column in our EBData table. We will track the build quantity against the batch quantity. When the batch has been completed and there isn't any WIP in the cell we will perform the setup for the next model of toaster.

The mean cycle time and cycle time standard deviation are drawn from our EBData Table. Of course, alternatively, these fields could be parameters for a exponential, Erlang or Lognormal Distribution. The Row number is specific to each resource element. For example, Row 2 holds the process data for the 3D Metal Printer and row 4 holds the Brain Assembly process data. This is in the following form: Normal(EBData[4,col],EBData[4,(col+1)],107) where the first field is the mean cycle time, second field (col+1) is the standard deviation and the final number, in this case 107 is the random seed number.

3.1.6 Machine Element Setup

When we first start out in simulation modeling, many of us ignore set up time. Setup time is that time which is necessary to prepare the various machines, people and other resources for production specific to some part or product. Internal vs external setup can be implemented, but for this study, all setup was treated as internal time.

4. Data Collection – Modeling and Capturing Costs

Witness can differentiate costs by Type, by Group and by Individual so costs can be analyzed in different groupings and perspectives. At an individual machine designer elements costs and revenue can be accumulated as a Fixed Cost, by time-based use or by physical quantity. It is these three characterizations that enable us to incorporate our Unit Costs, Batch Costs, Product Costs etc.

Direct Material

Once again, with manufacturing process cycle times, we will use a paired Excel spreadsheet and data table to bring the cost data into the model. To simplify the metal, we have cost per unit of metal, a unit being the quantity sufficient to form one armature. We could cost it per gram and then math it out with weight of material in an armature, but I suggest using the simplest approach possible. Use the same approach for the cost of paint. The metal cover and AI brain are consumed from inventory on a whole unit, integer basis, so that cost is easy to define (Figure 4).

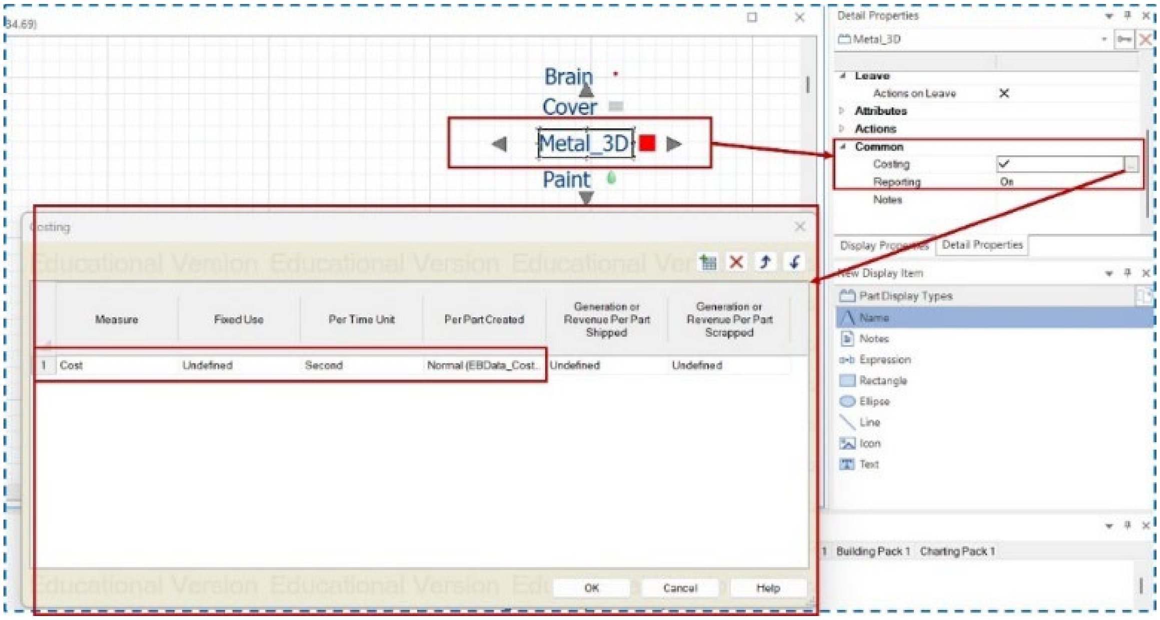

Figure 4. Simulation Model Direct Material Cost Field

Notice that with Witness 27, to access the cost fields for elements, we need to scroll down in our Detail Properties window to the **Common** field. Clicking on the three dots to the right of the field launches the Costing window.

Direct Labor

Our model has three workers, at least in the initial stage of development. I leave it to the reader to decide whether they should be classified as operators, technicians or some type of hybrid position. In our example, we have a labor rate specified that is drawn from our EBData Table. Simulation will show us their utilization levels (Figure 5).

One of the interesting capabilities with labor costing in Witness is that we can have a labor rate for the time when the

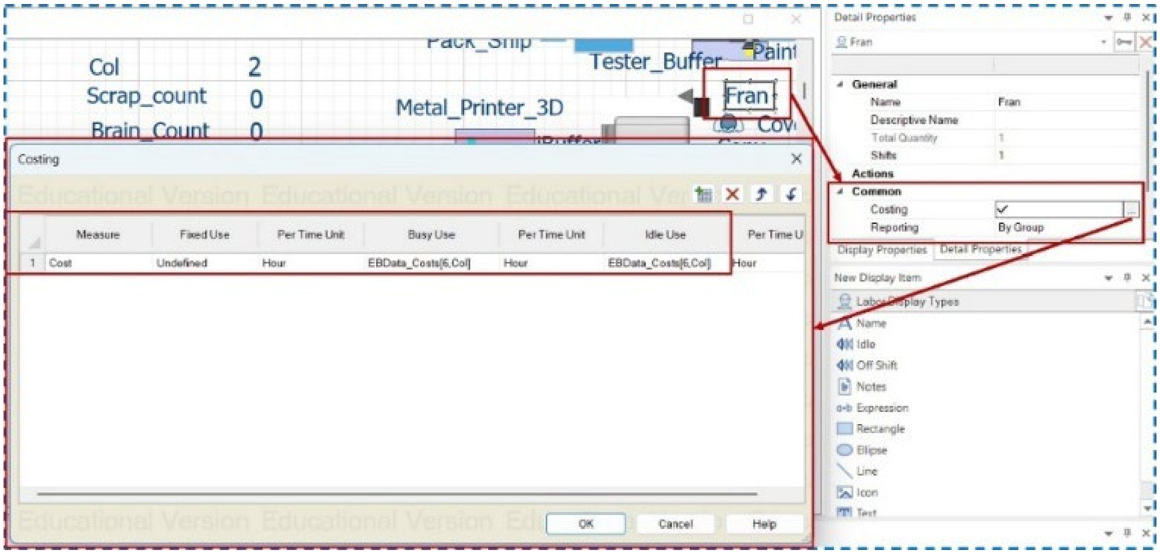

Figure 6. Witness Model Direct Labor Cost Field

person is busy and potentially a different labor rate for when they are idle. While this is an intriguing notion for those of the Industrial Engineering persuasion, there are no readily available examples to cite where this might be used.

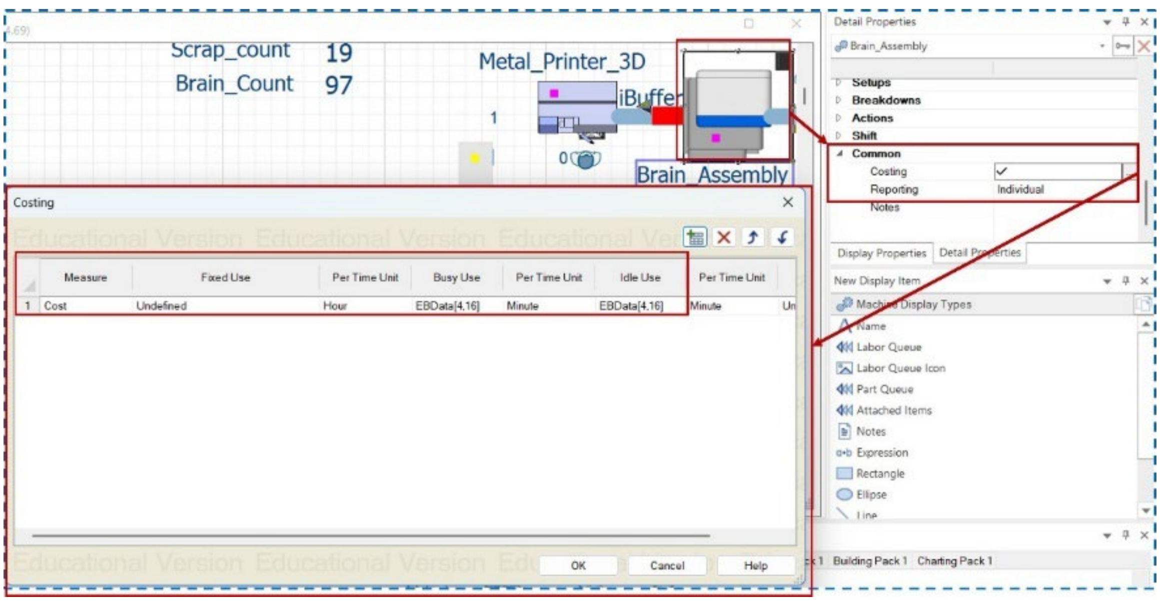

Figure 5. Witness Model Sustaining Costs Field

Figure 6 takes data from our spreadsheet/data table and accrues it on an hourly basis against the actual production. Think of this as an allocation of fixed manufacturing overhead to our production.

Scrap Costs

Finally in our ***Big Three*** of factory costs: Direct Labor, Direct Material and scrap, we come to the topic of scrap. Sure, continuous improvement helps us to eliminate scrape and other types of waste, but until that time, we will have some scrap. Witness keeps track of our scrap for us as we push defects to scrap. We can assign costs for scrap in terms of revenue generated from the salvage value of the materials.

Machine Costs in Factory Overhead

How do we calculate costing for machines? Do we simply take the cost of the equipment, ancillary equipment and installation costs, divide this by the estimated number of usable hours in the project lifespan and then apply to part cost on parts per hour basis? From our Engineering Finance class, we all remember depreciation, with some level of dread. Right then, let's carry on. This can be a complicated discussion since we might employ any one of several different depreciation strategies to determine an annualized cost. Think of depreciation as an accounting mechanism for capturing the declining value of a capital asset. As an asset grows older, it declines in value until at some point you sell it off for salvage or it has zero capital value. At the same time, the total of depreciation increases until that amount plus the salvage value equals the original capital asset acquisition. This could be a ten-year, five-year, etc period as agreed by various government and accounting agencies. Consult with your accounting department to determine which strategy they employ for determining depreciation. The more common methods are straight-line depreciation, MACRS, or declining balance. We can use that annual depreciation, or change in asset value in conjunction with the actual hours that the capital asset is operated in our factory or based on the daily batch scenario.

Sustaining Costs

Earlier, we discussed the notion of Activity Based Cost allocation and we have now reached the point where we will attempt to actually implement such a strategy. Remember, in Cooper/Kaplan terms we have Unit Costs, Batch Sustaining Costs, Product Sustaining Costs and Facility Sustaining costs. We will examine Batch Sustaining costs and then a similar method is applied to the other two. In our model with Witness 27, since we can capture setup costs, our Batch Sustaining Costs will include all batch costs except for setup (Figure 7).

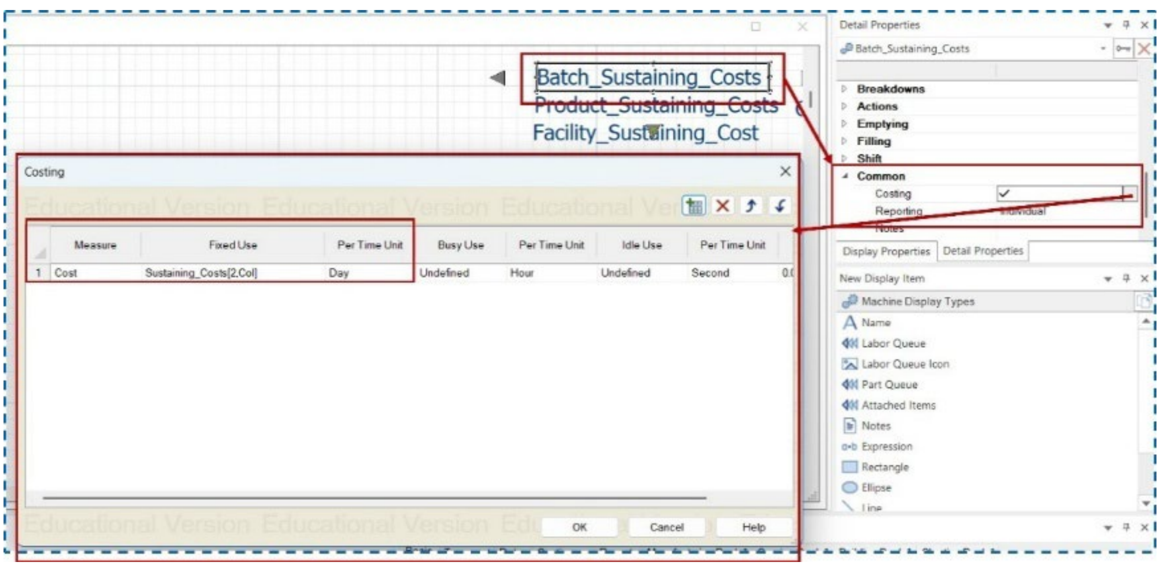

Figure 7. Batch Sustaining Costs

In Witness, Product Sustaining and Facility Sustaining Costs are in effect treated as machine elements that are cost accumulators on a batch basis. For this model, the model is configured for cost allocation to be accrued on a daily basis of one per day. Batches are schedule leveled on an annual basis with equal size periodic batches. For the purposes of this model, SG&A costs, that is Sales Governance and Administration, will be considered as part of the Facility Sustaining costs, although it is apparent that we could add a fourth ABC cost category to include SG&A, corporate allocation costs, etc. that are common to multinational corporations and where these costs have minimal relationship to manufacturing operations.

Revenue

As you have noticed, costs are accrued as they occur, for example, paint cost is added during painting, the cost of the metal cover is added during cover assembly, etc. Remember, from our costs and revenue summary report example that we will also generate revenue. We will accrue revenue on the final part rather than attaching revenue at every point or change (Figure 8).

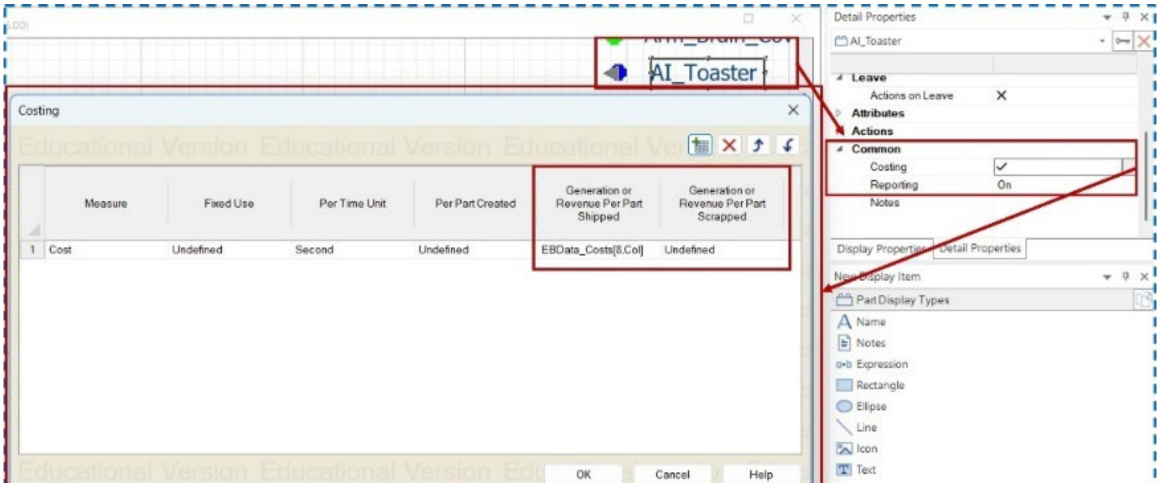

Figure 8. Witness Model Revenue Field

This is the same Costing window that you have already encountered but in this case all that we are adding is the revenue generated by the sale of each AI Toaster model.

5. Results and Discussion

These reports provide a summary of costs for a particular run/batch Cost per individual part can be exported by writing to a data Table 3 that is linked to an external Excel spreadsheet.

5.1 Numerical Results – Cost, Revenue and Sustainability

Direct Material and Direct Labor, the foundation of Factory cost are highlighted with red boxes in the next image. These data were produced from a simulation run for the Model A variant. Note that scrap cost is not individually reported here. For emphasis, the Cooper/Kaplan Batch, Product, and Facility sustaining costs are highlighted. The costs not highlighted in red boxes are various factory overhead costs. The By Use category indicates that these are variable factory overhead costs.

Direct labor is based on all applied hours, in this case including time spent during machine setup and time devoted to toaster production. Finally at the bottom of these cost and revenue reports we have the total profit. This is really total factory profit. Sales Governance and Administration costs (SG&A), taxes and corporate allocated costs are not included in this calculation. The machine element costs in this case reflect capital asset depreciation costs and variable utilities. As previously discussed, these process utilities such as carbon costs, water, process gases, cleaning solvents, etc could be defined separately, but for simplicity they have been bundled here (Figure 9).

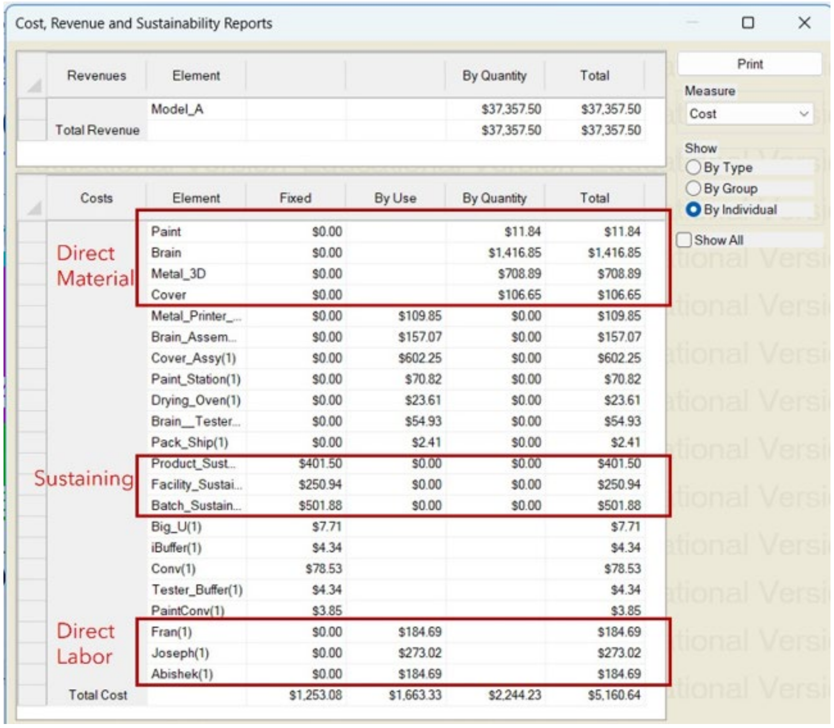

Figure 9. Cost, Revenue and Sustainability Report

Table 3. Product Cost and Revenue Summary Table

Variant	Time/Unit	Quantity	Direct Labor	Direct Material	Sustaining Costs	Machine VOH	Total Profit
Model A	15.55	31	20.72	72.39	37.24	32.93	1038.61
Model B	15.5	31	20.75	67.84	25.40	32.98	1048.91
Model T	16.6	29	22.19	113.29	26.58	31.47	2099.35

5.2 Graphical Results

Next, consider visualization of the output data. Witness has a series of Chart Designer Elements. The image on the in Figure 10 shows some of the charts available – just scroll up and down to view all of the options. There are several different standard charts available to us that will be employed in this model. Use of these standard charts saves lots of time in creating data visualization elements (Figure 10).

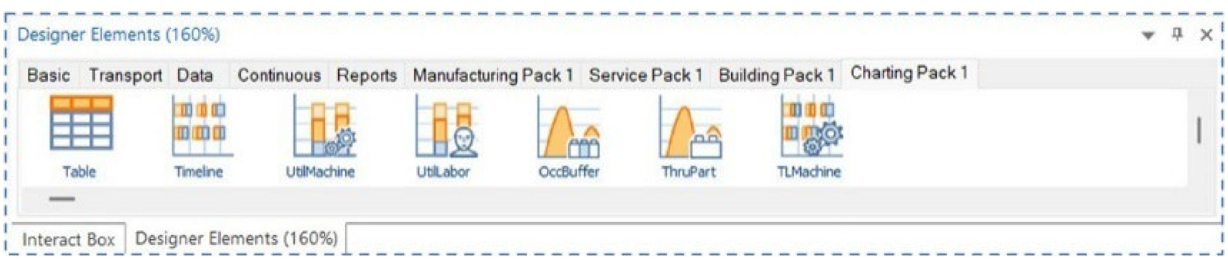

Figure 10. Witness Charts Designer Elements

First, let's create a chart to display machine utilization using the **UtilMachine** chart. Drag the **UtilMachine** chart element into the workspace. The first window to pop up will be the prompt to specify the number of machine elements that you want to monitor. This could include all your machine elements or just a select few that are most important.

Utilization is a key metric for manufacturing cell performance. The following two graphs provide easily understandable view of both labor and individual cell performance. As we can see from the Labor utilization graph, there are probably too many labor resources for conventional economic cell operation. Frequently, Machine Utilization charts can visually cue us to the balance of the cell flow and potential bottlenecks

5.3 Proposed Improvements

Future investigations will focus on incorporating model features to enhance analysis of product changeover and also to periodically refresh the data tables from the Excel source data. The Excel spreadsheet then becomes data bridge interface between operations factory data, standard factory data and the model to support digital twinning (Figure 11).

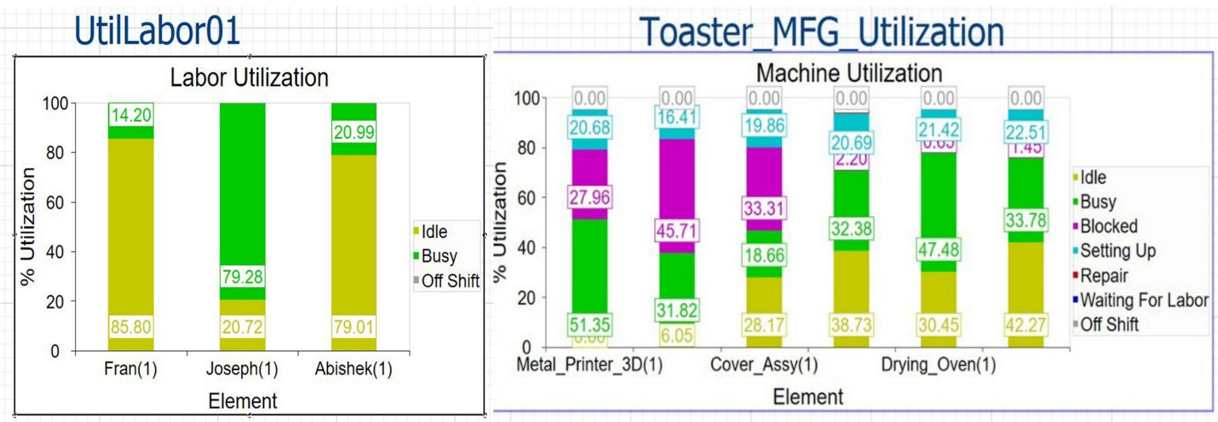

Figure 9. Utilization Charts

6. Conclusion

We have invested effort in adding cost information in each of our design elements. And we ensured that we also accrued revenue with each completed part. Frequently, engineers neglect to include cost data in their models for a variety of reasons. There are time constraints, lack of management interest, lack of familiarity with the cost elements, etc. Additionally, our accounting and finance compatriots, when they are performing a financial analysis, are capturing an inflexible snapshot of the costs at fixed period of time in a deterministic fashion. This is one of the reasons that cost estimates are fraught with risk. Simulation costing, since our models are fully stochastic, presents a more dynamic view of costs over time.

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