THE MERGER OF DISCRETE EVENT SIMULATION WITH ACTIVITY BASED COSTING FOR COST ESTIMATION IN MANUFACTURING ENVIRONMENTS

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ABSTRACT

Activity based costing (ABC) has revolutionized product costing, planning, and forecasting in the last decade. It is based on a philosophy of estimation that: "it is better to be approximately right, than precisely wrong." The philosophy of discrete-event simulation modeling follows a similar tack, where statistical inference and the stochastic nature of processes are used to replicate the behavior of a physical system. In this work, ABC and discrete-event simulation are linked to provide an improved costing, planning, and forecasting tool. Numerous point cost estimates are generated by the ABC model, using driver values obtained from a discrete-event simulation of the process. The various cost estimates can be used to produce confidence interval estimates of both the physical system and underlying cost structure. Rather than having a single point estimate of a product's cost, it is now possible to produce the range of costs to be expected as process conditions vary. This improved cost estimate will support more informed operational and strategic decisions.

1   INTRODUCTION

Traditional activity based costing models only produce point estimates of product cost. Various scenarios can be built manually and cost sensitivity can be estimated from results achieved from these scenarios. The problem with these manual scenarios is that they rely heavily on intuition and the interconnectivity of the cost drivers is generally not accounted for.

An example of when a combined activity based costing and discrete simulation model may be used is when the number of orders, the setup time per product, and the quantity of product produced are used as activity cost drivers.

In a simple ABC model one can change each one of these at will to produce different cost driver values and product cost estimates. A weakness of this approach is that any interaction effect between these three drivers is ignored. In reality, the inter-relationship of factors such as these may be quite complex and have a significant effect on actual product cost. For example, orders could be for different quantities of product and some products may not require a setup depending upon the sequence of jobs run. These interrelationships need to be accounted for if the cost model is to include the most accurate driver values for the number of orders, setup time, and quantity produced.

2   KEY CONCEPTS IN ACTIVITY BASED COSTING AND SIMULATION

To fully understand how ABC and discrete-event simulation can be combined, it is useful to review the main concepts of activity based costing and discuss how simulation can be applied to them.

2.1   Activity Based Costing and Simulation

Numerous authors have discussed the concept of activity based costing and how to go about building an activity based costing model, including Cokins (1996), Kaplan and Cooper (1998), Hicks (1992) and Ostrenga et al, (1992). The reader is referred to these works to refresh and expand on their knowledge of activity based costing.

It is assumed that the reader is familiar with the concepts of discrete-event simulation and is referred to a standard simulation textbook such as Banks, Carson and Nelson (1996) or Law and Kelton (2000).

According to Kaplan and Cooper (1998), ABC focuses on:

1. Identification of activities consuming an organization's resources.
2. Determination of an organization's key activities and business processes.
3. Estimation of the cost of the activities and business processes that are performed.

4. Determination of the amount of an activity required for an organization's products, services, and customers.

An ABC model is made up of resources, activities and cost objects. These are then linked by resource cost drivers and activity cost drivers respectively, as shown in Figure 1.
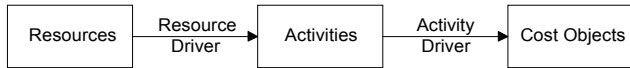

Figure 1: ABC Cost Flow

2.2 Resource Cost Drivers

Resource drivers can either be directly obtained from observation of the process or indirectly from surveys. It is clear that information about activities obtained from a staff survey will not be as accurate. Staff may assign more time to some activities than is actually required. However, very little can be done to correct for this introduction of error if a survey is the only source of such information. On the other hand, resources such as rent can be assigned very accurately by using square feet of floor space as the cost driver. The exact area taken up by each activity can be calculated and the cost of rent can be assigned accordingly.

Simulation can be utilized to determine the values of resource drivers to a limited extent. Simulation offers no advantage when definite resource drivers, such as floor space, are being used. The total floor space available is constant in the time period to be simulated, so simulating this resource would only complicate the model unnecessarily.

Resource drivers, such as, the percentage of an employee's time spent on each activity, can be more accurately estimated from a simulation run. However, using simulation to estimate these values increases the size of the simulation tremendously, as each employee and his stochastic behavior needs to be included in the simulation model.

It is important to remember that the amount of money a company pays for all its resources in a given year is assumed to remain constant throughout the simulation. Furthermore, most resources will remain the same in the next year, except those that vary directly with the number of products produced, such as utility costs and temporary labor costs. If these costs contribute significantly to the overall cost of resources, then they may have to be included in the simulation model. In most established manufacturing facilities these do not contribute a large amount and can be assumed to be constant over the simulation time.

Raw material costs may be assigned straight to the final product and should not be considered for simulation, as these costs can be added directly to the finished product.

2.3 Activity Cost Drivers

Activity drivers can be divided into 3 broad categories, namely transaction, duration and intensity drivers, Kaplan and Cooper (1998). These drivers differ in their ease of measurement and the time involved in obtaining the relevant driver values. Only transaction and duration drivers will be discussed, as they are the most pertinent to simulation.

Transaction drivers assume the same amount of a resource is used every time an activity is performed. Typical transaction drivers include number of setups, number of receipts and orders. Data are usually available for these drivers, thus they are easy and inexpensive to apply in an ABC and simulation model.

Duration drivers are slightly more expensive than transaction drivers to measure and record, but deliver more accurate results. Duration drivers are used when significant variation exists between the amount of an activity required for different cost objects. For example, some setups take 10-15 minutes, while others take 6 hours. Use of the number of setups (a transaction driver) would distort the costs, as a 15 minute setup would cost the same as a 6 hour setup. Setup time would be a better activity driver to use in this case. A few examples of both transaction and duration cost drivers are shown in Table 1.

Table 1: Examples of Activities and Activity Cost Drivers adapted from Kaplan and Cooper (1998)

Activity	Activity Cost Driver
Run Machines	Machine Hours
Set up Machines	Setups or Setup Hours
Schedule Production Jobs	Production Runs
Modify Product Specs	Engineering Change Notices
Maintain Machines	Maintenance Hours
Receive Materials	Material Receipts

Activity cost drivers are ideal for simulation and many of them are readily available as output from a typical simulation run. One can model complex interactions between cost drivers and the impact of changes on the production floor, such as those resulting from the introduction of new scheduling algorithms. Variation in cost drivers can be obtained by running repetitions of the simulation.

3 COMBINING THE CONCEPTS OF DISCRETE-EVENT SIMULATION AND ABC

The background presented previously discussed how activity drivers offer the best opportunity for modeling in a discrete-event simulation. The ideas of Cost Flow vs. Entity Flow and the possibility of the compounding of error will be discussed to further explore how simulation and ABC can be combined to produce better estimates of costs.

3.1 Cost Flow vs. Entity Flow

Both discrete-event simulation and ABC are based on the concept of entities flowing through the system. In a discrete-event simulation, physical items flow through the sequence of manufacturing operations. In ABC, costs flow through the model driven by defined activity drivers. In a simulation model, a billet of metal may flow through the system. The billet is loaded into a lathe, turned, drilled, tapped, packed in a box with 24 others and transported into finished goods storage. The focus is on the billet and the sequence of activities needed to produce the end product. In an ABC model, one follows the cost of a resource through the system. The monthly depreciation of the forklift is a cost, which is assigned to moving the finished product to the warehouse. If the driver for this activity is number of pallets, then one can work out how much each pallet costs to move and eventually arrive at a cost to move each billet from start to finish.

A closer examination of these two concepts reveals that they have a common intersection – the activity. Figure 2 graphically illustrates this intersection and sheds some light on how the two can be combined. Initially, the flow of product through the system and the flow of resources through a costing system may seem to be very far apart. A closer look reveals that they can be combined for the purpose of producing a better cost estimate.
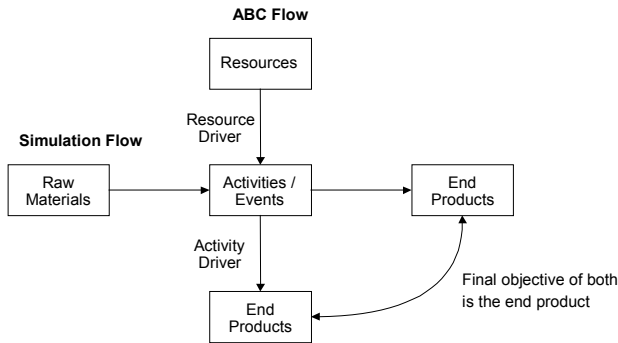
Figure 2: The intersection of ABC and Simulation Model Flow Adapted from Ostrenga et al. (1992)

3.2 Compounding of Errors

A certain amount of error will always be introduced into any simulation that is built. Just as errors will also be introduced when building an activity based costing model. It may be argued that by using a simulation model with errors to predict driver values one may only be compounding the inherent errors of the ABC model because of the use of simulated driver values, as indicated in Figure 3.

This criticism may be true when only a single simulation is run. However, when the system is simulated multiple times, the average production cost and the production cost variance may be extracted. It was found that the simu-
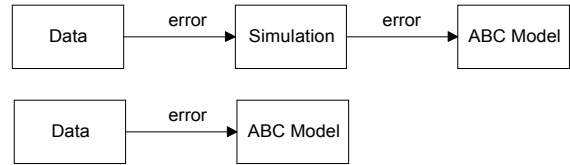
Figure 3: Compounding of Errors

lated average cost closely resembled the point estimate obtained from the ABC model without using simulation. Yet the simulation was also able to provide cost variance information which was previously not available.

4 STEPS IN COMBINING DISCRETE-EVENT SIMULATION WITH ABC

4.1 Modeling Outline

In this section, an overview of the steps to follow in combining ABC and discrete-event simulation will be presented. What we essentially have is an ABC model built in Excel or an ABC program and a model of the same system built in a simulation program. The ABC model contains the costs and activities of the system and the simulation is able to model the stochastic nature of these activities.

The steps that were followed in combining ABC costs with a simulation model of the process are listed below:

1. Develop an activity dictionary.
2. Build an ABC Model.
3. Decide on the most important activity drivers.
4. Gather performance data on the drivers and develop statistical distributions for the drivers.
5. Build a simulation model, making provision for the drivers identified above.
6. Run a static simulation to validate the simulation model and static ABC driver values obtained. In other words, the point estimate used in the first ABC model is obtained by the simulation with no stochastic variation.
7. Repeatedly run the model using the stochastic distributions for the cost drivers.
8. Produce confidence interval estimates of product costs using simulation data.

It is important to note that one run includes running the simulation, entering the driver values obtained from the simulation into the ABC model, and recording the resulting product costs.

4.2 Software Requirements

A few software requirements must be met in order to combine ABC software with simulation software. These

include the ability to import and export data, together with the ability to run simulation scenarios automatically.

4.2.1 Exporting Data

It is essential for the simulation program to export data. Each time the simulation is run, the relevant driver values need to be exported in a commonly recognizable format, such as *.txt, *.csv or *.dif. Many simulation programs, such as the one that was used for this experiment (Taylor ED®), are also able to write output directly into Excel.

4.2.2 Importing Data

The ABC software used must be able to import data. If Excel is being used to build the ABC model and the simulation program can write to Excel, then the import problem is solved. However, when building larger ABC models, use of dedicated ABC software is recommended. In this case it is imperative for the ABC software to be able to import data in a common format.

4.3 Scenario Building

This is possibly the most challenging issue in the modeling exercise. It is fairly simple to manually run the simulation model, export the data in a common format, and then import it again into the ABC software. The problem arises when running numerous production scenarios. It would take many hours to repeatedly run the same model manually and build new scenarios to get a cost distribution. The best solution to this problem is to have highly integrated ABC and simulation software. For the average user, a system such as this may not be available. A widely-available Windows Macros Program is one option that may be utilized. A macro mimicking the user's key and mouse strokes may be programmed and set to run a certain number of repetitions. The results from each scenario are saved and used for future analysis. A program such as this allows the computer to essentially build scenarios by itself.

5 APPLICATION EXAMPLE

An illustration of how simulation can improve cost estimates within ABC will be presented here. The case study that was used was developed by Kaplan and Cooper (1999). The case involves a pen factory that manufactures black, blue, red and purple pens. An ABC model of the factory is built in order to estimate the cost to produce each type of pen. In this paper, the analysis is extended to incorporate simulation and produce interval cost estimates for different production scenarios.

5.1 Problem Outline

The stochastic element that was modeled was an empirical distribution for the amount of orders received for each type of pen: 33.3% for blue, 33.3% for black, 25.4% for red and 8% for purple. Simulation runtime was constant for each scenario. Activities such as setup time (which was different for each type of pen) and assembly time were assumed to be constant. It should be noted that the effect of changes in these factors on production cost could have been studied by introducing stochastic setup times and processing times. That was not the purpose of this effort however. Thus in the simulation, only the number of orders was monitored. All other driver values such as number produced, machine hours and setup time could be computed (as they were all a constant multiplied by the number of orders processed for each pen color.). The simulation ran the factory for a period of one year. The layout of the simulation in Taylor ED®, is shown in Figure 4 and the structure of the ABC model cost flow is shown in Figure 5.
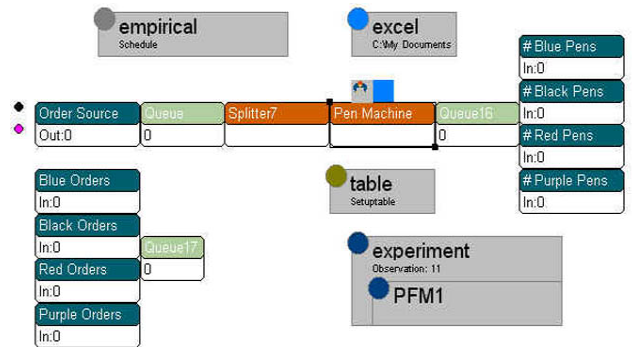

Figure 4: Pen Model Simulation in Taylor ED®

5.2 Using the Software

Four software programs were used. EasyABC® was used for building the ABC model, the simulation model was built in Taylor ED®, Excel was used as the bridge between EasyABC® and Taylor ED® and finally Macro Express 2000® was the software used to administer the overall effort.

The good features of EasyABC® are that an ABC can be built in a clear and straight forward manner and that it is able to both import and export driver data in common file formats. The export and import file format that was used for this particular application was *.csv. However, the one drawback was that the data was placed in an outline and thus the simulation program had to replace only certain values in the outline. The software could not just accept a stream of data.

The import problem in this particular case was overcome by using Excel as the link between Taylor ED® and EasyABC®. The activity driver outline from
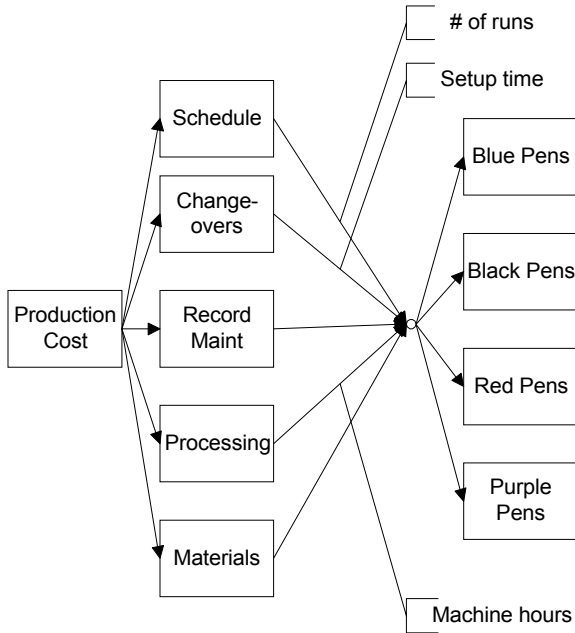
Figure 5: Flow of ABC Costs

```
EasyABC
VERSION                 4.1
ACTIVITY
DRIVER_QUANTITIES_ACTUAL
BASE_CURRENC English (United States)
PERIOD      Scenario1
SHARED_DRIVER_QUANTITIES
# of runs
         1 Blue        COST_OBJECT          50
         2 Black       COST_OBJECT          50
         3 Red         COST_OBJECT          38
         4 Purple      COST_OBJECT          12
Machine Hrs.
         1 Blue        COST_OBJECT        5000
         2 Black       COST_OBJECT        4000
         3 Red         COST_OBJECT        9000
         4 Purple      COST_OBJECT        1000
Setup Time
         1 Blue        COST_OBJECT         200
         2 Black       COST_OBJECT          50
         3 Red         COST_OBJECT         228
         4 Purple      COST_OBJECT          48

UNIQUE_DRIVER_QUANTITIES
```

Figure 6: EasyABC® Activity Driver File

EasyABC® was exported and opened in Excel. This provided the structure for the data to be imported. Taylor ED then updated only the driver cells in Excel. The outline that was to be updated is shown in Figure 6. The cells that were updated by the simulation program are shaded in gray. The updated cost drivers were saved in a *.csv format from Excel and imported into the model. Once in the model, all the cost allocations were recalculated and the resulting product cost saved in a scenario.

Macro Express 2000® performed a variety of tasks that would otherwise have to be performed manually by the user. It reset and started the simulation, opened Excel, and saved the resulting cost driver file. Finally it opened the ABC software, imported all the data, recalculated the cost allocations and saved the scenario under a unique name. The cycle was repeated another 9 times for this illustration.

5.3 Results

A summary of the results obtained is shown in Table 2. It is clear that the blue and black pens (products produced in large batches of 1000 and 800 each - high volumes) experienced the smallest variation in their costs. Red and Purple pens (products produced in batches of 240 and 85 respectively - low volumes) experienced a large variation in their production costs.

The range of costs incurred by each color of pen were:

Blue Pen $1.15 to $1.24
Black Pen $1.15 to $1.21
Purple Pen $1.61 to $2.33
Red Pen $3.30 to $5.50

The Blue, Red, and Purple pens each had setup times of 4 hours and over, while the Black pens only required a 1 hour setup. This can greatly influence the amount of orders that could be processed in the fixed time available. Furthermore, record maintenance was divided equally among the four pen types, thus this cost varies significantly for the pens that are produced in lower volumes.

5.4 Conclusions from the Experiment

While the case used to validate the concept of merging ABC with simulation was kept to a reasonable level of complexity, the results achieved show that the combined activity based costing with discrete event simulation analysis gives a far greater insight into the dynamic nature of product costing system behavior. It reveals the sensitivity of certain products to stochastic variations in just one activity driver and the robustness of others. This information can prove to be extremely valuable in deciding pricing policies for these product lines and aid in deciding upon future improvement projects.

6   CONCLUSION

Point estimation in simple ABC models does not provide information on the sensitivity of product costs to process variation. In this paper it was shown that by combining ABC concepts with a discrete-event simulation model the range of expected product costs may be obtained. Activity cost driver values and their interactions can be successfully integrated and then used to repeatedly estimate true product cost. Engineers and accountants can use this output to make a more informed decision about operational procedures and corporate strategy.

Table 2: Pen Factory Simulated ABC Costing Results

Period:	1	2	3	4	5	6	7	8	9	10	Min	Max	STD
	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost	Cost			
Blue	$1.18	$1.20	$1.16	$1.18	$1.17	$1.17	$1.15	$1.24	$1.20	$1.19	$1.15	$1.24	0.025
Scheduling & Handling	$0.15	$0.15	$0.14	$0.15	$0.14	$0.15	$0.14	$0.17	$0.16	$0.15	$0.14	$0.17	0.009
Changeovers	$0.09	$0.10	$0.08	$0.09	$0.08	$0.08	$0.08	$0.10	$0.10	$0.09	$0.08	$0.10	0.009
Record Maintenance	$0.02	$0.03	$0.03	$0.02	$0.02	$0.02	$0.02	$0.03	$0.02	$0.03	$0.02	$0.03	0.005
Processing	$0.42	$0.42	$0.41	$0.41	$0.42	$0.42	$0.41	$0.45	$0.42	$0.42	$0.41	$0.45	0.012
Blue Materials	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	0
Total Cost	$1.18	$1.20	$1.16	$1.18	$1.17	$1.17	$1.15	$1.24	$1.20	$1.19	$1.15	$1.24	0.025
Total Bill of Costs	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	0
Total Assigned Cost	$0.68	$0.70	$0.66	$0.68	$0.67	$0.67	$0.65	$0.74	$0.70	$0.69	$0.65	$0.74	0.025
Black	$1.15	$1.16	$1.15	$1.17	$1.15	$1.15	$1.16	$1.21	$1.16	$1.15	$1.15	$1.21	0.019
Scheduling & Handling	$0.18	$0.19	$0.17	$0.19	$0.18	$0.18	$0.18	$0.21	$0.19	$0.18	$0.17	$0.21	0.011
Changeovers	$0.03	$0.03	$0.03	$0.03	$0.02	$0.03	$0.02	$0.03	$0.03	$0.03	$0.02	$0.03	0.004
Record Maintenance	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	$0.03	0
Processing	$0.41	$0.41	$0.42	$0.42	$0.41	$0.41	$0.42	$0.44	$0.41	$0.41	$0.41	$0.44	0.01
Black Materials	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	0
Total Cost	$1.15	$1.16	$1.15	$1.17	$1.15	$1.15	$1.16	$1.21	$1.16	$1.15	$1.15	$1.21	0.019
Total Bill of Costs	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	$0.50	0
Total Assigned Cost	$0.65	$0.66	$0.65	$0.67	$0.65	$0.65	$0.66	$0.71	$0.66	$0.65	$0.65	$0.71	0.019
Red	$2.20	$2.31	$2.13	$2.29	$2.13	$2.19	$2.09	$1.61	$2.33	$2.23	$1.61	$2.33	0.207
Scheduling & Handling	$0.60	$0.63	$0.57	$0.63	$0.59	$0.62	$0.58	$0.38	$0.64	$0.62	$0.38	$0.64	0.076
Changeovers	$0.53	$0.59	$0.51	$0.58	$0.49	$0.52	$0.47	$0.36	$0.59	$0.55	$0.36	$0.59	0.07
Record Maintenance	$0.14	$0.17	$0.12	$0.15	$0.12	$0.13	$0.10	$0.10	$0.17	$0.13	$0.10	$0.17	0.025
Processing	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	$0.25	$0.41	$0.41	$0.25	$0.41	0.051
Red Materials	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	0
Total Cost	$2.20	$2.31	$2.13	$2.29	$2.13	$2.19	$2.09	$1.61	$2.33	$2.23	$1.61	$2.33	0.207
Total Bill of Costs	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	$0.52	0
Total Assigned Cost	$1.68	$1.79	$1.61	$1.77	$1.61	$1.67	$1.57	$1.09	$1.81	$1.71	$1.09	$1.81	0.207
Purple	$4.66	$5.13	$4.41	$5.39	$4.63	$5.44	$4.66	$3.30	$5.45	$5.50	$3.30	$5.50	0.684
Scheduling & Handling	$1.70	$1.77	$1.61	$1.77	$1.67	$1.74	$1.63	$1.01	$1.80	$1.74	$1.01	$1.80	0.231
Changeovers	$0.99	$1.11	$0.96	$1.09	$0.91	$0.97	$0.89	$0.63	$1.12	$1.03	$0.63	$1.12	0.144
Record Maintenance	$1.01	$1.28	$0.88	$1.57	$1.09	$1.76	$1.18	$0.88	$1.57	$1.76	$0.88	$1.76	0.344
Processing	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	$0.41	$0.23	$0.41	$0.41	$0.23	$0.41	0.057
Purple Materials	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	0
Total Cost	$4.66	$5.13	$4.41	$5.39	$4.63	$5.44	$4.66	$3.30	$5.45	$5.50	$3.30	$5.50	0.684
Total Bill of Costs	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	$0.55	0
Total Assigned Cost	$4.11	$4.58	$3.86	$4.84	$4.08	$4.89	$4.11	$2.75	$4.90	$4.95	$2.75	$4.95	0.684

ACKNOWLEDGMENTS

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