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## **AN INTEGRATED APPROACH TO SIMULATION AND ACTIVITY-BASED COSTING FOR EVALUATING ALTERNATIVE MANUFACTURING CELL DESIGNS**

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### **ABSTRACT**

One effective technique for improving manufacturing efficiency involves the application of group technology part families and manufacturing cells. Selection of the best or optimum configuration of the manufacturing cell relies on the experience and judgment of the cell designer. This paper describes how activity-based costing (ABC) concepts can be integrated into a discrete-event simulation model and be used to evaluate manufacturing cell configurations. The output of the combined ABC simulation model provides a detailed "Bill of Activity" which allows the cell designer to consider costs as a critical factor in the cell design problem. Alternative cell configurations studied in this paper include an in-line or linear cell, and a U-shaped or loop layout. Additional simulation models were created that tracked the non-allocated costs associated with operator idle time. The one operator cell was significantly better than the two operator model due to the reduced operator idle time and associated costs. The linear cell had slightly lower non-allocated costs for operator idle time as compared to the U-cell, but differences in other cost and throughput factors were insignificant.

### **INTRODUCTION**

Group technology is a manufacturing philosophy that takes advantage of the similarities in the

manufacturing and design attributes of production parts (Groover 1987). Similar parts are grouped together into part families. Manufacturing efficiency is improved by arranging the production equipment into cells to facilitate work flow. Common types of manufacturing cells include single machine cells and group machine cells with varying styles of material handling. Factors such as work volume, size and weight of the parts, and variations in the process routings are used to determine the best cell design.

Typical layouts for a group machine cell are an in-line layout with work flow in one direction, and a U-shaped or loop layout. If the process routings of the parts in the family are identical, a straight-line flow is recommended (Groover 1987). The U-shaped or loop layout would be preferred when there are significant variations in the routings. This distinction is sometimes very subjective. The purpose of this paper is to demonstrate integration of activity-based costing (ABC) concepts into the simulation model of a manufacturing cell. The intent is to support alternative configuration decisions using detailed cost data in conjunction with traditional parameters. It is assumed that no previous model exists and that one must be developed to evaluate manufacturing cell performance. It should be noted that, typically, activities within a manufacturing cell would not be viewed separately as part of an overall ABC system

because of the homogeneous nature of a cell (O'Guin 1991). In other words, a cell would be the lowest level of activity for cost assignment. The rationale is to prevent excessive detail within the ABC system. However, this does not preclude the application of ABC cost modeling within the cell for the purpose of evaluating cell performance under differing conditions.

Typical simulation studies of manufacturing processes use parameters such as resource utilization, inventory levels, cycle time, and throughput time to investigate system performance under varying conditions. Cost/benefit analyses associated with different configurations and process conditions have historically been accomplished through separate efforts. Since business decisions are based on cost and profitability, it is only natural that simulation studies also include cost considerations in the evaluation process (O'Loughlin et al. 1990). There are primarily two different approaches that can be used to collect cost parameters through simulation. One method collects data on-line as part of the simulation. The other is collection off-line using a post-simulation processing scheme that depends on data generated by the simulation (Moore 1990, Krishnamurthi et al. 1994). Krishnamurthi et al. (1994) base their research on a manufacturing process simulation that previously existed and implemented minor modifications to interface with the post-simulation cost model. This research assumes no prior model exists. Savory et al. (1996) introduces the incorporation of activity-based costing concepts into a discrete-event simulation model and compares it to the off-line approach. This present paper discusses the application of an integrated ABC simulation model to solve the manufacturing cell design and labor resource allocation problem. This paper will show how the inclusion of ABC will allow much more informed decisions regarding the appropriate cell configuration and the level of labor resources needed.

### DESCRIPTION OF ACTIVITY-BASED COSTING

The benefit of implementing an ABC system is to allow better decisions to be made due to improved cost data. The concept of ABC is the result of the realization that products require businesses to perform activities (work generating processes or procedures). Those activities in turn drive the organization to two types of associated costs: (1) costs directly tied to a product flow, and (2) those costs not tied to a product flow. Costs that are traceable to a product flow are ultimately assigned to the product. The non-product flow associated costs are assigned to the activities that make the costs necessary (Hicks 1992).

Since activities require resources to be consumed and products require activities to be performed, an ABC implementation is designed as a two stage process. The first stage uses *resource drivers* to

associate costs with resource consumption and support to activities, while the second stage allocates activity costs to products using *activity drivers*.

Associated with the first stage cost drivers are activity centers. An activity center is a collection of homogeneous processes like a manufacturing cell, machining or assembly functions, or a business process that a manager would like to effectively control (Dhavale 1992). The costs associated with resource consumption are first grouped into cost pools at each activity center. Cost pooling gives managers the data necessary for planning and controlling activities, and for measuring activity center performance (Dhavale 1993). An activity center can have one or more cost pools, but each cost pool requires homogeneity within the pool since only one cost driver is assigned for each cost pool. However, one must realize that some costs are triggered by unit, some by batches, and others by product.

### MANUFACTURING CELL AND PART FAMILY BACKGROUND

To demonstrate the integration of ABC and discrete-event simulation, consider the following hypothetical manufacturing cell and part family. The cell is comprised of four machines: two identical computer numerically controlled (CNC) lathes, one CNC machining center, and one universal grinder. The two manufacturing cell configurations that will be modeled are an in-line or linear arrangement (Figure 1) and a U-shaped or loop layout (Figure 2). The simulation modeling effort will also consider labor resource requirements. With two operators and the linear configuration, the first operator is responsible for all material handling, setup, loading/unloading, processing and quality control inspection for jobs on the two lathes. The second operator has the same responsibilities associated with the machining center and universal grinder. For cell configurations staffed by one operator, the operator must perform all material handling, machine servicing and quality control functions.

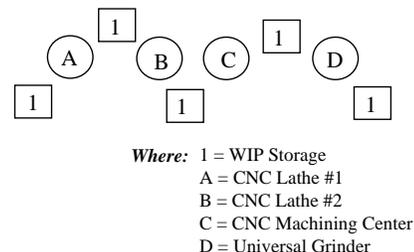


FIGURE 1: LINEAR CELL CONFIGURATION.

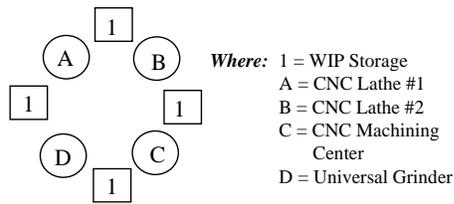


FIGURE 2: U-SHAPED CELL CONFIGURATION.

Direct and indirect labor rates were assumed to be \$12 per hour with a 30 percent benefit rate. Hourly preventative and repair maintenance rates (including parts and labor) were assumed to be \$50 and \$200, respectively. The purchase price, useful life, and other pertinent data on the four machines is as follows:

**CNC Lathe #1:** \$120,000 purchase price, 10 year life, 20 kilowatts power consumption, \$0.04/hour for utilities, and \$2.00/hour for consumables; **CNC Lathe #2:** \$120,000 purchase price, 10 year life, 20 kilowatts power consumption, \$0.04/hour for utilities, and \$2.00/hour for consumables; **CNC Machining Center:** \$100,000 purchase price 10 year life, 25 kilowatts power consumption, \$0.04/hour utilities, and \$2.50/hour for consumables; **Universal Grinder:** \$ 80,000 purchase price, 10 year life, 15 kilowatts power consumption, \$0.04/hour utilities, and \$1.75/hour for consumables.

The part family consists of four part types (A,B,C and D) each requiring different processing sequences. Part arrivals to the cell occur in homogeneous batches of a specific part type. Batch sizes for each part type are 4, 3, 6, and 2 for part types A, B, C, and D, respectively. The sequence for processing are:

- Part A: CNC Lathe #1 f CNC Lathe #2 f CNC Machining f Universal Grinder
- Part B: CNC Lathe #1 f CNC Lathe #2 f Universal Grinder
- Part C: CNC Lathe #1 f CNC Lathe #2 f CNC Machining
- Part D: CNC Lathe #1 f CNC Lathe #2

Batch arrivals occur based on an exponential distribution with a mean of four hours and forty minutes. Part type determination is based on production mix requirements of 30% type A, 20% type B, 40% type C, and 10% type D parts.

The cell operates for two consecutive eight hour shifts over a six day work week. Processing underway at the end of the second shift is completed before shutting down for the day. Production scheduling is based on completing all jobs within 51 weeks of annual operation. During that period of time, at least 1080 part type A's, 720 part type B's, 1440 part type C's, and 360 part type D's must be successfully manufactured. Quality control inspections are accomplished on every part after completing processing on each machine. It is assumed that

inspections result in a 2% part rejection at each stage of production.

Set-ups are accomplished for each batch with setup time dependent on whether the previous batch was of the same part type or not. If the previous batch was the same part type as the current batch, then a short setup is accomplished, otherwise a long setup is performed. For CNC Lathe #1, CNC Lathe #2, and CNC Machining Center, the Short set-up time distribution is (in minutes) Triangular(30,60,90)/4 and the Long set-up time distribution is Triangular(30,60,90). For the Universal grinder, the short and long set-up times are Triangular(20,40,60)/4 and Triangular(20,40,60), respectively. All these probability distributions are commonly used in simulation for describing these types of event (Pegden et al. 1990).

All other times within the cell are based on actions involving individual parts rather than batches. After the batch setup is done, an individual part is selected, moved to the machine, loaded, processed, unloaded, moved, and inspected. This cycle is accomplished at each station until all parts within the batch are complete. Distributions representing part loading, unloading and inspection times were common to all four stations and the distributions are (in minutes): Normal(3.0,0.5) for Part Loading, Normal(2.0,0.25) for Part Unloading, and Uniform(1.5,2.0) for Part Inspection. Material handling or move times are not presented but are based on distances between the various stations and the time for the respective operator to travel from one point to another. Part processing time distributions for each part type at each station are: Triangular(10,15,20) for CNC Lathe #1 and CNC Lathe #2, Triangular(10,20,30) for CNC Machining Center, and Triangular(10,20,30) for the Universal Grinder.

Both preventive and repair (corrective action) maintenance are considered within the cell. Preventive maintenance (PM) is accomplished on a 30 day schedule or in conjunction with a maintenance repair action. Machine failures are based on an increasing failure rate Weibull distribution with a mean of approximately 90 days. PM in conjunction with machine repair occurs after repair actions are complete and with duration dependent on the time since the last PM event. If PM was performed within the 15 days, a partial PM is performed, otherwise a full PM action is taken. Full PM times (in minutes) were assumed to follow a Uniform(50,70) distribution, while the repair actions followed a Triangular distribution with parameters (30,60,90). Partial PM actions required approximately half as much time as a full PM effort.

## DEVELOPMENT OF COST DRIVERS AND ACTIVITY CENTERS

Figure 3 provides a generalized activity-based costing depiction of the alternative manufacturing cells evaluated in this paper. Resources and activity

centers shown are not meant to be all inclusive but simply representative for the project objectives. Areas highlighted by a dotted box were not addressed as part of this simulation modeling project. If the effort had been based on an existing manufacturing facility, this information would have been available and could have been included. Since the purpose of this research is to demonstrate the integration of ABC concepts into the manufacturing cell simulation, exclusion of these areas does not significantly impact the intent.

As shown in Figure 3, when parts are produced it requires activities to be accomplished and resources

to be consumed. The costs associated with the activities are passed on to the parts through the second stage cost drivers or activity drivers. When activities are performed they require resources which pass on the cost for the resource consumption through first stage cost drivers or resource drivers. The production of parts, for example, requires raw materials, batch setups, material handling and processing. Each of these require resources in terms of purchasing and receiving actions, indirect labor, direct labor, machine usage with associated depreciation costs, consumable supplies, and electrical power.

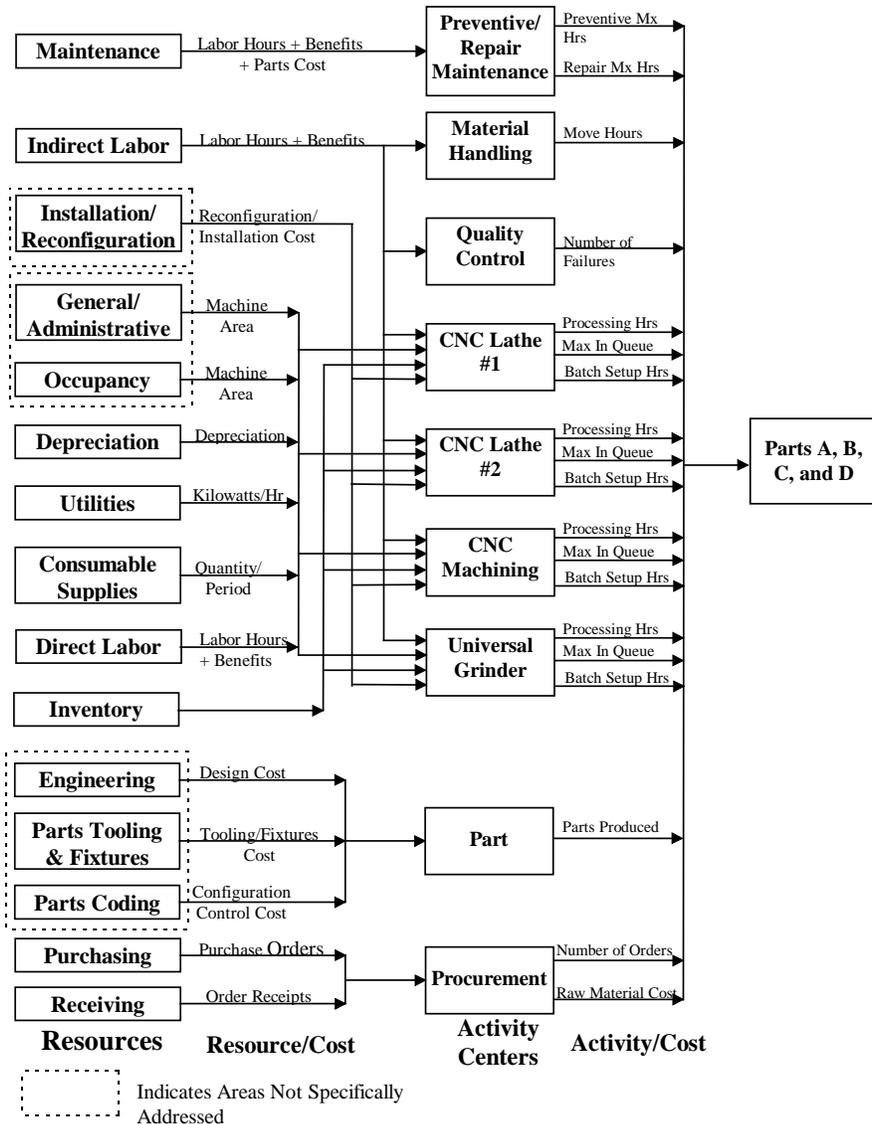


FIGURE 3: ACTIVITY-BASED COSTING REPRESENTATION FOR THE MANUFACTURING CELL.

## MODEL DEVELOPMENT

Model development was accomplished using the SIMAN simulation language (Pegden et al. 1990). The model primarily uses an entity-attribute based design to identify characteristics such as part type and processing times for various activities. These activities include batch setup, part loading, processing, unloading, inspection, and part movement between stations. The rationale was to provide for the greatest degree of flexibility to evaluate different situations involving part routing. Specific details about the model development are found in Savory et al. (1996). The simulation models were used to generate the respective Bill's of Activity and Detailed Bill's of Activity for each part type.

## RESULTS AND ANALYSIS

Three cell configurations were evaluated. The first was the linear cell with two operators. Figure 4 shows the simulation output in the form of the Part Family Bill of Activity. The results are the average of 30 simulation replications. Total and per unit costs are presented for each activity center considered in this study. Figure 5 is a Part Type A Bill of Activity.

Part Family Bill of Activity		
Product: Part Family		
Start Process Quantity: 3851		
Completion Quantity: 3613		
Activity Center	Cost	Cost Per Unit
Procurement	\$ 38509.00	\$ 10.00
Material Handling	\$ 434.64	\$ 0.11
Quality Control	\$ 7870.38	\$ 2.04
Preventive/Repair Maintenance	\$ 4704.96	\$ 1.22
CNC Lathe 1	\$ 45942.64	\$ 11.93
CNC Lathe 2	\$ 44509.62	\$ 11.56
CNC Machining Center	\$ 31371.88	\$ 8.15
Universal Grinder	\$ 20797.22	\$ 5.40
Manufacturing Cost Per Unit:		\$ 49.19

FIGURE 4: PART FAMILY BILL OF ACTIVITY - LINEAR CELL, TWO OPERATORS.

Based on relatively low operator 1 and 2 utilization, it was decided to model the next configuration: the linear cell with one operator. A comparison with the two operator configuration reveals that the manufacturing cost per unit is nearly the same. Similar results are found in comparing each part type's Bill of Activity. However, a review of the average number parts in-process (WIP) and total part time-in-system (TIS) indicates significantly higher numbers for the single operator configuration. These differences represent a parts flow slowdown which can be attributed to increased operator activity in the single operator cell. Investigation into why the manufacturing cost per unit are so similar when the WIP and TIS results are so different highlighted a common cost accounting problem in a manufacturing cell environment. The problem is associated with the

time/cost allocation for an operator performing multiple tasks concurrently. A traditional approach would typically attach a labor charge to the total time the machine is being utilized. However, during the machine process time the operator may be performing part inspections, setup or loading/unloading of other machines, or be completely idle. If it is determined that the operator's presence is not necessary during processing, these individual simultaneous operations can be accounted for and operator idle time can be separated out as a non-allocated cost.

Bill of Activity		
Product: Part Type A		
Start Process Quantity: 1172		
Completion Quantity: 1083		
Activity Center	Cost	Cost Per Unit
Procurement	\$ 11720.00	\$ 10.00
Material Handling	\$ 130.17	\$ 0.11
Quality Control	\$ 2960.39	\$ 2.53
Preventive/Repair Maintenance	\$ 1431.93	\$ 1.22
CNC Lathe 1	\$ 13900.04	\$ 11.86
CNC Lathe 2	\$ 13640.85	\$ 11.64
CNC Machining Center	\$ 13965.02	\$ 11.92
Universal Grinder	\$ 12169.50	\$ 10.38
Manufacturing Cost Per Unit:		\$ 59.66

Figure 5: PART TYPE A, BILL OF ACTIVITY - LINEAR CELL, TWO OPERATORS.

As a result of the comparison between the two linear cell configurations, the SIMAN simulation code was changed. The modification allowed labor allocation costs during machine processing to be based on actual labor requirements and operator idle time to be captured and reported as a non-allocated cost. The modification objective was to clearly reveal the cost differences between cell configurations with varying labor resources and activities. For this system, the manufacturing cost per unit is \$13.71 less. The difference is due to a de-coupling of labor and machine costs during machine processing and removal of non-allocated costs due to operator idle time.

For the one operator linear cell model, the manufacturing cost per unit is slightly less than for the two operator configuration. The revised models now report the non-allocated costs for operator idle time. It shows that the non-allocated costs for operator 1 idle time of \$ 42,048 and \$42,298 for operator 2 for a combined \$84,346 total. The one operator linear cell shows a significant reduction in operator idle time non-allocated cost (\$16,872). When viewing the manufacturing part costs, non-allocated costs, and part throughput information, the data suggests the one operator configuration is preferred over the linear cell with two operators.

The final configuration modeled was the U-shaped or loop layout. The total manufacturing cost per unit was slightly lower (\$0.03) than for the one operator linear cell. As one would expect, the U-cell resulted in

a slight reduction of \$0.01 per part in material handling due to shorter move distances. Other costs for the activity centers were fairly similar. Non-allocated cost for operator idle time (\$17,394) was approximately \$500 more than was observed for the one operator linear cell, but differences in Average WIP and TIS were insignificant. Given the statistical nature of simulation and the relatively small differences observed, it is not reasonable to recommend selection of a U-cell configuration over a linear cell with one operator based on this information alone. Using the information provided by the modeling effort, a cell designer could present upper management with alternatives based on cost and performance. The final decision concerning cell configuration could then be made based on part family manufacturing priorities, facility layout for material handling, and cell configuration cost and performance factors.

## CONCLUSIONS

The application of group technology part families and manufacturing cells is an effective method for improving manufacturing operations and reducing manufacturing costs. A critical step in the application of group technology is the design of the manufacturing cell. This paper presents an approach that integrates activity-based costing (ABC) and discrete-event simulation to aid decisions concerning cell design and operation. The combined cell simulation and ABC model provides a "Bill of Activity" which breaks down part manufacturing costs for each activity performed within the cell during the manufacture of a hypothetical part family. Different models addressing the various cell configurations were created and the simulation results provided traditional performance parameters as well as ABC based costs for use in the decision making process. Three possible cell configurations were modeled as part of this research effort: the linear cell with both one and two operator scenarios; and the U-shaped cell with one operator. Results of this research led to the following conclusions: (1) The Part Family and Detailed Bill's of Activity are useful metrics for evaluating alternative cell designs; (2) Using the traditional approach of attaching a labor charge to the total time a machine is being utilized can make it difficult to distinguish between competing cell designs. This paper presented a method for capturing the non-allocated costs associated with operator idle time which makes it easier to evaluate competing cell designs; (3) The linear cell with one operator was significantly better than the two operator design due to the reduced operator idle time and associated costs; (4) Lower non-allocated costs for operator idle time were found with the one operator linear cell as compared to the one operator U-cell, but differences in the other costs and simulation outputs were insignificant; and (5) The integration of ABC with a discrete-event simulation model can provide a cell

designer with very useful cost information for the determination of the best cell configuration with the appropriate labor resource level.

## ACKNOWLEDGMENTS

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