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Combining Activity-Based Costing with the Simulation of a Cellular Manufacturing System

Paul Savory
University of Nebraska at Lincoln, psavory2@gmail.com

Robert Williams
University of Nebraska at Lincoln

Rodney Rassmuseun
University of Nebraska at Lincoln

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Rodney R. Rasmussen
Paul A. Savory
Robert E. Williams

Industrial and Management Systems Engineering
University of Nebraska - Lincoln
Lincoln, NE 68588-0518

ALL CORRESPONDENCE AND CORRECTIONS SHOULD BE ADDRESSED TO:

Mailing: Dr. Paul Savory
175 Nebraska Hall
Industrial Engineering
University of Nebraska
Lincoln, NE 68588-0518

Phone: (402) 472-0657
Fax: (402) 472-2410
E-Mail: psavory@unl.edu

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ABSTRACT

This paper presents an integrated simulation and activity-based management approach for determining the best sequencing scheme for processing a part family through a manufacturing cell. The integration is illustrated on a loop or U-shaped manufacturing cell and a part family consisting of four part types (A, B, C, and D). Production requirements for the cell demand that part batches be processed one type at a time. For example, all part A's are processed until weekly demand is met, then part B's, etc. The objective of this example is to determine the best part sequence (*e.g.*, ABCD, DCBA or CABD). In addition to traditional measures, the simulation model produces detailed activity-based costing estimates. Analysis of cost and performance parameters indicates part sequence CDBA provides the best overall choice. This sequence achieves a low per unit manufacturing cost, minimizes average time in the system and in-cell inventory cost, and maximizes unused production capacity. Although the scope of this effort was restricted to a small scale manufacturing cell, the costing concepts have general applicability to manufacturing operations at all levels.

KEYWORDS: activity-based management, activity-based costing, simulation, part scheduling

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“Integrating Simulation with Activity-Based Management To Evaluate Manufacturing Cell Part Sequencing”

1.0 INTRODUCTION

Discrete-event simulation traditionally focuses on using performance measures such as total time in the system for a part, work-in-process inventory, and machine utilization for making decisions. This paper proposes an enhanced alternative that embellishes a discrete-event simulation model to also determine activity-based costing (ABC) estimates. The costing information combined with the traditional simulation metrics will allow for a more complete evaluation of the system.

Since manufacturing costs directly impact profitability, it is reasonable to consider cost in addition to traditional manufacturing process performance metrics to evaluate the best sequencing scheme. Several authors [1, 2] discuss the importance of integrating estimated “operational costs” into the simulation model of a process. Such an approach provides a means for developing an economic evaluation of different policies and scheduling decisions.

This paper will demonstrate adding cost estimation into a simulation model for a loop or U-shaped manufacturing cell and a part family consisting of four part types (A, B, C, and D). The objective of the analysis is to determine the best sequence for processing a part family. Applying an activity-based management (ABM) approach, the optimal sequencing scheme will be judged based on a combined cost and performance perspective.

2.0 ACTIVITY-BASED COST MANAGEMENT

During the 1980’s, increasing world-wide competition forced industry to look for improved methods to determine the actual cost to produce a product. In 1987, Johnson and Kaplan [3] asserted that traditional management accounting information “is too late, too aggregated, and too distorted to be relevant for managers’ planning and control decisions.” This assertion helped motivate industry’s transition toward *activity-based cost* (ABC) accounting.

ABC is a procedure that often makes it possible to estimate product costs more accurately than traditional cost systems [4]. The purpose of an ABC system is to focus on the cause behind indirect costs. Activities, rather than traditional departments, are emphasized in order to isolate the cost drivers or factors most likely to cause or contribute to the incurrence of costs [5]. Malik and Sullivan [6] discuss that “the main difference between ABC and *traditional costing* is in the allocation of indirect resources to each product in a multi-product manufacturing environment. ABC traces the causal relationships between different cost-incurring activities and the final products, and thus attributes the cost of indirect activities to different products.” As a result, ABC systems improve the accuracy of cost allocation to manufactured parts through the use of appropriate cost drivers. In addition, the content of overhead assigned to a part through the definition of activities (such as material handling and setup) facilitates better decision making [6].

Decision making associated with cost and performance parameters is the function of *activity-based management* (ABM). The terms ABC and ABM are sometimes used interchangeably. Cokins [7] uses “ABC/ABM” throughout his text as opposed to differentiating between ABC and ABM. Strictly speaking, however, ABC refers only to the actual technique for determining the costs of activities and the outputs that those activities produce. The aim of ABC is to generate improved cost data for use in managing a company's activities. ABM is a much broader concept. It refers to the fundamental management philosophy that focuses on the planning, execution, and measurement of activities as the key to competitive advantage [8].

3.0 MANUFACTURING CELL AND PART FLOW DESCRIPTION

To demonstrate applying activity-based management with simulation, we will determine the best sequencing scheme for processing a part family through a manufacturing cell. This example highlights how the additional costing information aids the simulation analysis. The manufacturing system under study is a loop or U-shaped manufacturing cell with a single operator that performs all material handling, setup, loading, unloading, and quality control inspections within the cell. The cell is abstracted from a real manufacturing system and contains issues significant in most manufacturing systems (*e.g.*, breakdowns, part routings, preventive maintenance, batch processing). Specific details on the manufacturing cell are presented in Savory et al. [9] and Williams et al. [10].

Machines within the cell include two identical computer numerically controlled (CNC) lathes, one CNC milling machine, and a universal grinder. A depiction of the cell layout is provided in Figure 1.

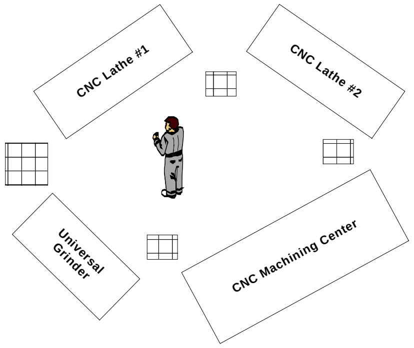

Figure 1. U-Shaped Cell Configuration

The part family consists of four part types (A, B, C, and D) each with different processing requirements within the cell. The sequence of machines visited by each part type during processing and the number of parts in each batch is presented in Table 1. Parts enter the cell as a homogeneous batch of one specific part type.

Table 1. Part Family Characteristics and Processing Sequence

		Processing Sequence			
Part Type	**Batch Size**	**CNC Lathe #1**	**CNC Lathe #2**	**CNC Machining**	**Universal Grinder**
A	4	1	2	3	4
B	3	1	2	N/A	3
C	6	1	2	3	N/A
D	2	1	2	N/A	N/A

Production requirements demand that parts be processed one type at a time. That is, parts flow through each machine one part type at a time, batch by batch, until a weekly quota has been satisfied. For example, all part A's are processed, then part B's, etc. Upon completion of the first part type's quota, the second, third and fourth part types are all processed in a similar manner until the week's requirements are met. The objective of this effort is to identify the best weekly sequencing scheme for the part types (*e.g.*, ABCD, DCBA, or CADB). Specifics concerning the production process, part arrival rates, production quotas, setup, processing, material handling, quality control and repair/preventive maintenance distributions/times are presented in Savory et al. [9] and Williams et al. [10].

4.0 ACTIVITY-BASED COSTING FOR THE MANUFACTURING CELL

ABC is a procedure that often makes it possible to estimate product costs more accurately than traditional cost systems. The concept results from the realization that products require businesses to perform activities (work generating processes or procedures). In turn, activities require resources to be consumed, which drives the business to incur costs. Therefore, an ABC implementation is designed as a two-stage process. The first stage transfers costs associated with resource consumption and support to activities, and the second stage allocates activity costs to products. These cost transfer mechanisms are appropriately referred to as *stage-one cost drivers* or *resource drivers* and *stage two-cost drivers* or *activity drivers*. Miller [11] provides a good coverage of how to identify activities and cost drivers.

Graphically, the cost mechanisms for the manufacturing cell are shown in Figure 2. Resources are identified in the boxes on the left side of the figure and are connected to activities. The arrows connecting the resources to the activities are labeled with the resource drivers that transfer costs to the activities. The activities are connected to the product (part types A, B, C, and D) shown in a single box on the right-hand side of the figure. The arrows connecting the activities to the product are the activity drivers that transfer the cost to the product. While Figure 2 provides an overview of how costs are transferred, an ABC implementation requires specific cost transfer mechanisms to be defined in terms of mathematical equations. Specific acronym definitions and the equations used for this effort are presented in the Appendix. For example, Equation 5 describes the per unit inspection/quality control cost for each of the part types. It is composed of the labor rate for quality control inspectors, the time for a part to be processed on a machine, the inspection rate for a machine, and the number of units processed by the machine.

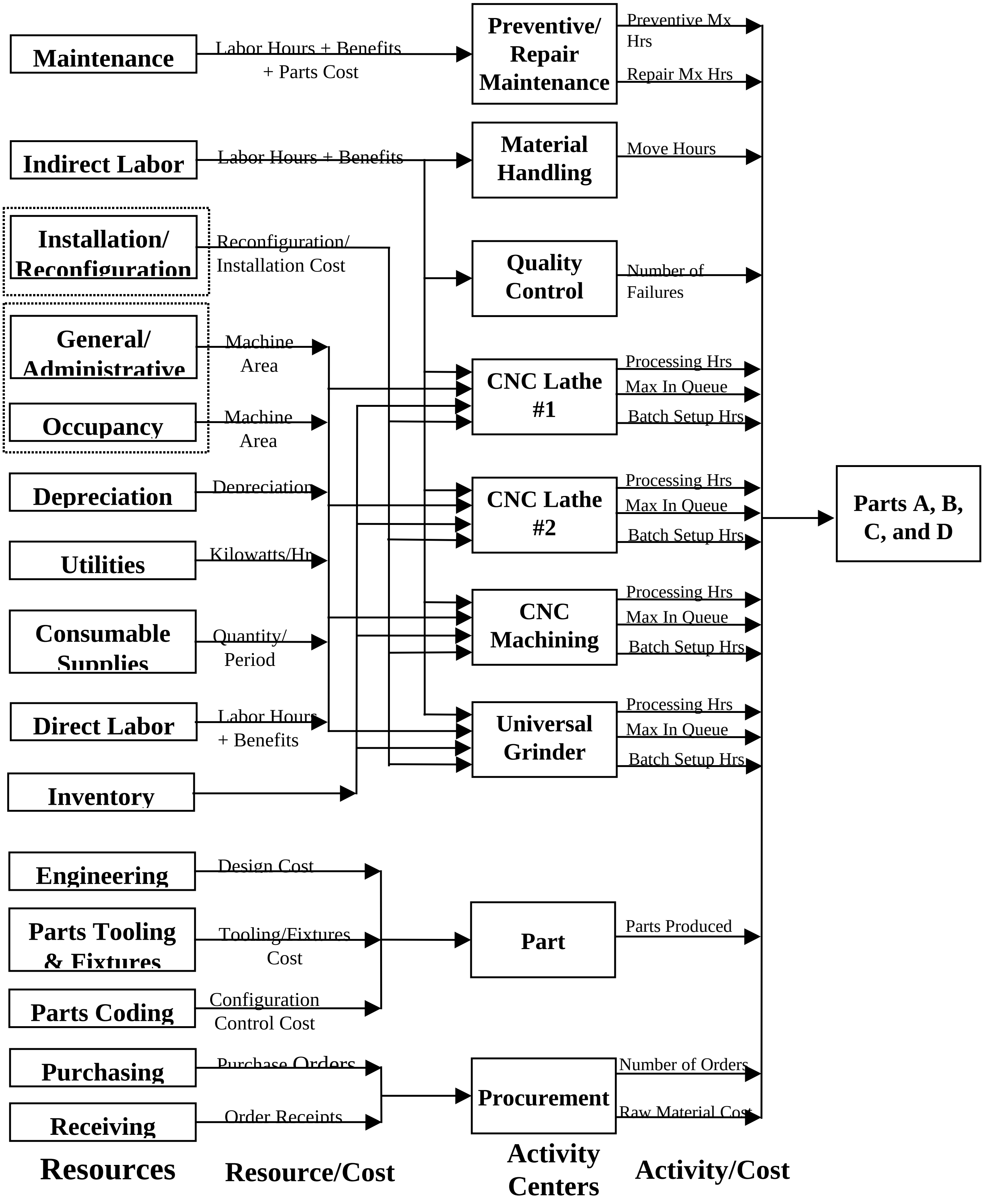

Figure 2. Activity-Based Costing Representation for the Manufacturing Cell

5.0 SIMULATION DESIGN

The SIMAN V simulation language was used to develop the simulation model of the manufacturing cell. To collect the processing time and cost components as outlined by Figure 2 and the equations in the Appendix, the simulation model primarily uses an attribute-based modeling approach. For instance, each part has an attribute that identifies it as a part type A, B, C, or D. Additionally, as the part proceeds through the cell, different attributes record the time delays associated with material handling, machine loading/unloading, processing, and inspection. When a part completes the manufacturing process, the processing time and costing data is collected. After the last replication of the simulation model, performance and costing estimates are developed and reported on a series of Bill of Activity’s that define the total cost and per unit cost associated with each activity center [9].

The simulation program also determines non-allocated costs. Examples would include operator idle-time costs and unused or excess capacity costs. Operator idle-time costs reflect the amount of time that the operator is not busy moving parts, loading or unloading the machines, performing setups, or inspecting parts. Unused capacity costs are based on machine depreciation and the difference between actual and scheduled production time. In a perfect scheduling environment there would be no unused capacity costs. However, anytime production is finished prior to the scheduled completion, there is a portion of the depreciation costs that are unallocated. This can be viewed as an opportunity since excess capacity can be used for processing other products.

Figure 3 provides an overview of the simulation model development process. Note that in addition to collecting data on system performance, a modeler must also collect costing data on the system. Examples would include: labor rates, machine cost, depreciation rate, supply costs, preventive maintenance costs. Using both performance and cost data, a modeler develops a simulation model that represents the system under study that also incorporates procedures for collecting all the necessary part timing components. Williams et al. [10] provides details on the model development process. While we demonstrate this approach for a specific manufacturing cell, the costing techniques are applicable to any type of system under study. In addition, the impact on simulation runtime should be minimal since the costing routines are not time intensive.

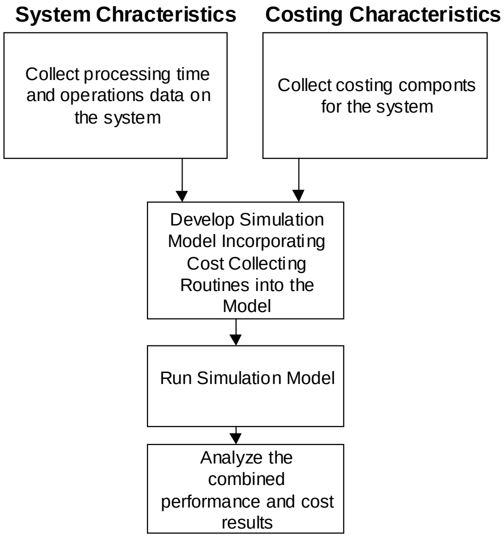

Figure 3. Overview of linking simulation and activity-based management.

6.0 SIMULATION RESULTS AND ANALYSIS

A total of 24 different variations of the basic simulation model were used to represent the 24 different part sequencing schemes (e.g., ABCD to DCBA). Thirty simulation replications, each representing 52 weeks of operations, were run for each of these 24 different part sequencing schemes. Each set of 30 replication took approximately 60 minutes to run on a Pentium 90 MHz computer with the majority of this time attributed to running the actual simulation scenario and little to the cost collecting mechanisms. Data obtained for the comparison includes the average time in the system (TIS), per part in-cell inventory costs, per part manufacturing cost, operator idle time cost, and unused/excess capacity costs.

The key system performance statistic is the total time a part is in the manufacturing cell. Table 2 details the average TIS results for each of the 24 different sequencing schemes. An initial evaluation of the information indicates that due to their small times, the two best sequences are ADBC and CDBA (highlighted in Table 2). However, such a simple evaluation overlooks the variability within the data. Further analysis of the results using 90% confidence intervals around each TIS indicate that ACBD, ACDB, BACD, BCAD, CABD, DABC, and CDAB are significantly different from ADBC and CDBA and thus can be eliminated.

Table 2. Average Time in the System For Each Part Sequence

Sequence (Sequence Number)	**ABCD** (1)	**ABDC** (2)	**ACBD** (3)	**ACDB** (4)	**ADBC** (5)	**ADCB** (6)	**BACD** (7)	**BADC** (8)
Ave TIS for Part Family	674.64	590.84	770.19	719.04	576.32	642.35	713.12	588.84

Sequence (Sequence Number)	**BCAD** (9)	**BCDA** (10)	**BDAC** (11)	**BDCA** (12)	**CABD** (13)	**CADB** (14)	**CBAD** (15)	**CBDA** (16)
Ave TIS for Part Family	722.22	604.24	625.56	623.45	757.95	697.15	672.83	610.99

Sequence (Sequence Number)	**CDAB** (17)	**CDBA** (18)	**DABC** (19)	**DACB** (20)	**DBAC** (21)	**DBCA** (22)	**DCAB** (23)	**DCBA** (24)
Ave TIS for Part Family	647.24	577.96	651.44	724.43	662.46	656.25	730.61	656.25

Per unit in-cell inventory costs are considered next. These costs are based on the maximum number of parts that are found waiting in a machine queue and the corresponding size of the holding area. In an idealized just-in-time environment, one would strive to make this number zero. Realistically, because of variability in production scheduling, material handling, processing, machine failures, and operator actions, it will never be zero without impacting the efficiency of the production process by starving machines. Table 3 presents the average per unit inventory cost information. It is observed that sequences CBDA and CDBA (highlighted in Table 3) are the most desirable since they provide the smallest inventory cost.

Table 3. Inventory and Per Unit Manufacturing Costs for Each Part Sequence

Sequence (Sequence Number)	**ABCD** (1)	**ABDC** (2)	**ACBD** (3)	**ACDB** (4)	**ADBC** (5)	**ADCB** (6)	**BACD** (7)	**BADC** (8)
Inventory Overhead Cost	$0.28	$0.24	$0.29	$0.27	$0.25	$0.25	$0.27	$0.25
Per Unit Manufacturing Cost	$32.78	$32.77	$32.86	$32.80	$32.72	$32.70	$32.77	$32.72
Sequence (Sequence Number)	**BCAD** (9)	**BCDA** (10)	**BDAC** (11)	**BDCA** (12)	**CABD** (13)	**CADB** (14)	**CBAD** (15)	**CBDA** (16)
Inventory Overhead Cost	$0.26	$0.23	$0.26	$0.25	$0.28	$0.25	$0.24	$0.22
Per Unit Manufacturing Cost	$32.76	$32.70	$32.86	$32.78	$32.87	$32.76	$32.76	$32.68
Sequence (Sequence Number)	**CDAB** (17)	**CDBA** (18)	**DABC** (19)	**DACB** (20)	**DBAC** (21)	**DBCA** (22)	**DCAB** (23)	**DCBA** (24)
Inventory Overhead Cost	$0.24	$0.22	$0.29	$0.28	$0.28	$0.26	$0.27	$0.25
Per Unit Manufacturing Cost	$32.77	$32.72	$32.81	$32.85	$32.85	$32.77	$32.92	$32.77

Also shown in Table 3 are the per unit manufacturing costs. Note that there is not a one-to-one correspondence between the sequences with the highest TIS values (which were eliminated) and the sequences with the highest costs. This indicates that costs are influenced by additional factors. However, by normalizing the TIS, per unit inventory cost, and per unit manufacturing cost data, it becomes apparent that, in general, their behaviors have similar trends. Normalized data for TIS and per unit manufacturing cost are shown in Figure 4.

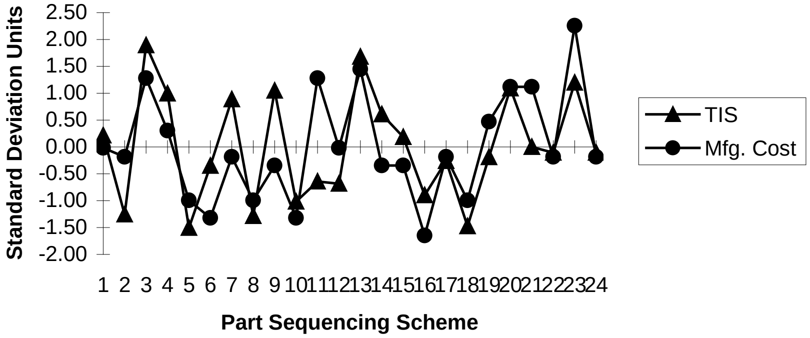

Figure 4. Trend Comparison of Standardized TIS and Manufacturing Costs

Non-allocated costs collected by the simulation include operator idle-time and unused capacity costs. The results are presented in Table 4. To minimize the operator idle-time costs, sequence CABD would be selected. However, CABD corresponds to the second highest TIS value and was previously identified for elimination. In addition, CABD has the second highest per unit part cost. This observation reinforces the hypothesis that minimizing operator idle time within a cellular manufacturing environment may not have the desired outcome of reducing TIS or cost. Considering unused capacity costs, it can be seen that sequence CDBA provides the highest value. In general, this high unused capacity costs reflects improved processing efficiency.

Table 4. Operator Idle Time and Unused Capacity Costs for Each Part Sequence

Sequence (Sequence Number)	**ABCD** (1)	**ABDC** (2)	**ACBD** (3)	**ACDB** (4)	**ADBC** (5)	**ADCB** (6)	**BACD** (7)	**BADC** (8)
Operator Idle Time Cost	$43,087.64	$46,337.60	$42,699.84	$43,136.76	$47,066.29	$44,235.08	$43,988.95	$46,318.68
Unused Capacity Cost	$26,812.99	$27,021.42	$26,669.05	$26,867.63	$27,073.01	$26,940.44	$26,676.87	$27,101.91
Sequence (Sequence Number)	**BCAD** (9)	**BCDA** (10)	**BDAC** (11)	**BDCA** (12)	**CABD** (13)	**CADB** (14)	**CBAD** (15)	**CBDA** (16)
Operator Idle Time Cost	$43,732.65	$45,765.16	$49,199.28	$47,500.96	$41,702.65	$43,255.81	$42,461.39	$45,736.32
Unused Capacity Cost	$26,766.26	$27,191.28	$27,044.76	$27,152.55	$26,547.26	$26,782.94	$26,749.61	$27,110.79
Sequence (Sequence Number)	**CDAB** (17)	**CDBA** (18)	**DABC** (19)	**DACB** (20)	**DBAC** (21)	**DBCA** (22)	**DCAB** (23)	**DCBA** (24)
Operator Idle Time Cost	$43,275.76	$45,687.94	$47,339.92	$44,923.96	$48,809.93	$47,683.23	$45,940.25	$47,338.89
Unused Capacity Cost	$26,808.86	$27,212.35	$26,979.64	$26,851.26	$27,042.13	$27,135.52	$26,641.30	$27,064.44

Based on the performance and cost criteria, the best part production sequence is CDBA. This sequence has the second best TIS (very close to the smallest TIS), the smallest in-cell inventory cost, one of the smaller per unit manufacturing costs, and the highest unused capacity cost. Additionally, the operator idle-time cost falls in the middle of the range of values indicating reasonable operator utilization.

7.0 CONCLUSIONS

Decisions made solely on traditional performance parameters or only on cost parameters may fail to find the best system performance at the minimum cost. The objective of this paper is to demonstrate generating activity-based costing estimates using a discrete-event simulation model and to then use the costing information to embellish the system analysis. The integration of cost and performance parameters as part of the decision making process is a vital function of activity-based management (ABM) philosophy. The addition of costing information can allow better decisions to be made at two critical stages: (1) during the system design phase, and (2) during a continuing process improvement or “corporate re-engineering” phase. Although the scope of our effort was restricted to a single group technology manufacturing cell, the concept has general applicability to most types of manufacturing and production systems including job shop, batch production and flexible manufacturing systems.

ACKNOWLEDGMENTS

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APPENDIX Nomenclature And Cost Equations

Time:

$\mathbf{T}lp_{ij}$ - Total labor time for production (load and unload) of part types i processed on machine j
$\mathbf{T}p_{ij}$ - Total machine time for production (load, process, and unload) of part types i processed on machine j
$\mathbf{T}su_{ij}$ - Total time for batch setup (change over) for part types i processed on machine j
$\mathbf{T}qc_{ij}$ - Total time for quality control inspection for part types i completing processing on machine j
$\mathbf{T}mh_{ij}$ - Total move time for part types i processed on machine j
$\mathbf{T}pm_{j}$ - Total time for preventive maintenance on machine j
$\mathbf{T}rm_{j}$ - Total time for repair maintenance on machine j

Rates:

$\mathbf{R}dp_{j}$ - Depreciation/production hour for machine j
$\mathbf{R}dsu_{j}$ - Depreciation/setup hour for machine j
$\mathbf{R}lp$ - Labor rate for production activities (loading and unloading parts)
$\mathbf{R}lsu$ - Labor rate for batch setup activities
$\mathbf{R}lqc$ - Labor rate for quality control inspections
$\mathbf{R}lmh$ - Labor rate for material handling
$\mathbf{R}cs_{j}$ - Consumable supplies rate for machine j
$\mathbf{R}ga_{j}$ - General/Administrative cost/hour for machine j (based on scheduled hours)
$\mathbf{R}oc_{j}$ - Occupancy cost/hour for machine j (based on scheduled hours)
$\mathbf{R}ir_{j}$ - Installation/Reconfiguration cost for machine j
$\mathbf{R}p_{j}$ - Operating cost/hour for machine j
$\mathbf{R}qc$ - Inspection cost/inspection following machine j
$\mathbf{R}pm$ - Preventive maintenance cost/hour
$\mathbf{R}rm$ - Repair maintenance cost/hour
$\mathbf{R}op$ - Order processing cost/per order
$\mathbf{R}m_{i}$ - Raw material cost per batch for part type i
$\mathbf{R}I$ - Inventory overhead rate per part

Quantities:

$\mathbf{N}\mathrm{q}_{ij}$ - Number of batches of part i processed on machine j
$\mathbf{N}\mathrm{p}_{ij}$ - Number of units of part i processed on machine j
$\mathbf{N}\mathrm{a}_{i}$ - Number of part type i to enter processing
$\mathbf{N}\mathrm{o}_{i}$ - Number of orders for part i
$\mathbf{N}\mathrm{lt}_{i}$ - Estimated number of part type i to be produced over product life cycle
$\mathbf{N}\mathrm{I}_{j}$ - Maximum number of parts waiting in the machine j queue

Costs:

$\mathbf{C}\mathrm{pc}_{i}$ - Per unit cost for part type i
$\mathbf{C}\mathrm{m}_{i}$ - Per unit procurement cost for part type i
$\mathbf{C}\mathrm{p}_{ij}$ - Per unit production cost for part type i on machine j
$\mathbf{C}\mathrm{mh}_{i}$ - Per unit material handling cost for part type i
$\mathbf{C}\mathrm{mx}$ - Per unit maintenance cost
$\mathbf{C}\mathrm{dv}_{i}$ - Per unit development cost for part type i
$\mathbf{C}\mathrm{qc}_{i}$ - Per unit development cost for part type i
$\mathbf{C}\mathrm{e}_{i}$ - Total cost for part family engineering development
$\mathbf{C}\mathrm{c}_{i}$ - Total cost for part family codification
$\mathbf{C}\mathrm{t}_{i}$ - Total cost for part family tooling and fixtures
$\mathbf{C}\mathrm{I}_{j}$ - Per unit inventory overhead cost for machine j

- Equation 1: the accumulation of all costs to provide the per unit cost for part type i (A, B, C, or D).

$$\mathbf{C}pc_i = \mathbf{C}dv_i + \mathbf{C}m_i + \mathbf{C}mh_i + \mathbf{C}qc_i + \mathbf{C}mx + \sum_j \left(\mathbf{C}p_{ij} + \mathbf{C}I_j\right)$$

- Equation 2: the per unit development cost for part type i.

$$\mathbf{C}dv_i = \frac{1}{\sum_i \mathbf{N}lt_i}\left(\mathbf{C}e_i + \mathbf{C}c_i + \mathbf{C}t_i\right)$$

- Equation 3: the per unit procurement cost for part type i.

$$\mathbf{C}m_i = \frac{\mathbf{R}op * \mathbf{N}o_i + \mathbf{R}m_i * \mathbf{N}q_i}{\mathbf{N}a_i}$$

- Equation 4: the within-cell per unit material handling costs for part type i.

$$\mathbf{C}mh_i = \frac{1}{\mathbf{N}a_i}\sum_j \mathbf{R}lmh * \mathbf{T}mh_{ij}$$

- Equation 5: the per unit inspection/quality control cost for part type i.

$$\mathbf{C}qc_i = \frac{1}{\mathbf{N}a_i}\sum_j \left(\mathbf{R}lqc * \mathbf{T}qc_{ij} + \mathbf{R}qc * \mathbf{N}p_{ij}\right)$$

- Equation 6: the per unit maintenance cost based on part family.

$$\mathbf{C}mx = \frac{1}{\sum_i \mathbf{N}a_i}\sum_j \left(\mathbf{R}pm * \mathbf{T}pm_j + \mathbf{R}rm * \mathbf{T}rm_j\right)$$

- Equation 7: the per unit production cost for part type i on machine j (CNC Lathe #1, CNC Lathe #2, CNC Milling Machine, Universal Grinder).

$$\mathbf{C}p_{ij} = \frac{1}{\mathbf{N}a_i}\sum_j\left[\left(\mathbf{R}ga_j + \mathbf{R}oc_j + \mathbf{R}ir_j + \mathbf{R}dp_j + \mathbf{R}p_j + \mathbf{R}cs_j\right) * \mathbf{T}p_{ij} + \mathbf{R}lp * \mathbf{T}lp_{ij} + \left(\mathbf{R}dsu_j + \mathbf{R}lsu + \mathbf{R}cs_j\right) * \mathbf{T}su_{ij}\right]$$

- Equation 8: the per unit inventory costs for machine j.

$$\mathbf{C}I_j = \frac{\mathbf{N}I_j * \mathbf{R}I}{\sum_i \mathbf{N}a_i}$$

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