Proceedings of the 1992 Winter Simulation Conference
ed. J. J. Swain, D. Goldsman, R. C. Crain, and J. R. Wilson

CONVERTING SIMULATION DATA TO COMPARATIVE INCOME STATEMENTS

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ABSTRACT

Differing concepts of simulation and modeling are one source of communication problems between accountants and engineers. To bridge the gap between the engineers and the accountants, simulationists must convert simulation data into financial terms such as comparative income statements. Simulation data can be used to predict the cost of goods sold and to assess the feasibility of revenue goals based on manufacturing system constraints. Cost drivers for an activity-based costing analysis can be modeled, measured in a simulation run, and the simulation data used to drive the analysis. This paper presents an example of the conversion of basic simulation data from a relatively simple model into comparative income statements. It discusses how simulation models fit into an activity-based costing analysis and examines the limitations of simulation-based information in financial analysis.

1 INTRODUCTION

Computer (discrete-event) simulation is widely used by engineers in the design and analysis of manufacturing systems but is rarely used or understood by accountants and business analysts. Accountants and business analysts perceive simulation models as data in a spreadsheet or database that is related by algebraic relationships. Prediction is based on statistical inferences drawn from the data. Simulation is performed by changing some of the data and observing the changes in the related data. Time is advanced by fiscal periods, not by state changes on the shop floor. Representation of shop floor constraints is limited.

Computer simulation, as engineers know it, can contribute information and insight into manufacturing systems that can be integrated into the accountants' financial analyses and simulation models. Other than direct experimentation which is usually too costly to be feasible, computer simulation is the most accurate source of such information.

This paper presents issues of simulation and financial analysis in the context of a capital investment decision. These issues arise in many other contexts, such as capacity planning, production planning, outsourcing decisions, and product mix decisions. In any context, accurate information on which to base the decision is needed. The decision maker has a variety of support tools available. Simulation is a potentially powerful tool in financial analysis when used properly and in concert with other analysis tools.

2 JUSTIFYING A CAPITAL INVESTMENT

A manufacturing concern's goal is to make money. A manufacturing system can be thought of as a money amplifier, where costs go in, revenues come out, and the difference is profit. If a manufacturer is not profitable for a period of time, it goes out of business. If its competitors can deliver products of higher quality or deliver them sooner or at lower cost to the customer, a manufacturer risks losing market share and, with it, potential profitability.

Investments in capital assets should improve the money amplification properties of the manufacturing system by reducing the input of costs or increasing the output of revenue. Equipment is purchased because it will reduce cost by improving efficiency or will increase revenues by improving throughput. Reducing cost may allow selling price reductions which increase revenues if demand is elastic. Improving flexibility can reduce work in process, increase the inventory turnover, reduce carrying cost, and improve cash flow.

Cash flow associated with a capital investment is calculated using a comparative income statement (Humbarger, 1987). The example in Table 1 compares the alternative of adding a new machine with the cash flow in the system before the machine was added. Multiple alternatives may be considered. Such

Table 1: Comparative Income Statements

	Before		After	
Revenue		$1,000,000		$1,000,000
Cost of Goods		600,000		585,000
Marginal Income		400,000		415,000
Depreciation	10,000		20,000	
Other Fixed Costs	300,000	310,000	300,000	320,000
Net Income		90,000		95,000
Taxes(.50)		45,000		47,500
Income after Tax		45,000		47,500
Add Back Depreciation		10,000		20,000
Cash Flow		55,000		67,500

alternatives need to account for both changes in cost of goods sold that directly result from the new equipment and changes in revenue resulting from improved customer service which is indirectly related to the new equipment.

Once cash flow for each alternative has been established, various measures of profitability are calculated for each alternative. Commonly used metrics for comparing capital investments are internal rate of return (IRR) and expected monetary value (EMV). All of these methods are based on predicted cost of goods sold and revenues.

The role of simulation in capital investment analysis is to predict the cost of goods sold and to assess the feasibility of revenue goals based on manufacturing system constraints. In the following subsections, the specific information provided by a simulation in this role is described. The limitations of simulation-based information are also discussed. The potential of activity-based costing analysis is examined.

2.1 Simulation-Based Information for Capital Investment Analysis

Revenue goals can be achieved only if throughput goals are reached. Profit goals require that cost of goods sold be held to an appropriate percentage of revenue. Simulation models predict throughput which can be converted to revenue. They also predict costs that vary with volume, machine time, queue time, and other performance measures represented in a model. Such costs contribute to the cost of goods sold. Thus, simulation data can be used to estimate profit as a function of throughput and cost of goods sold.

The most important contribution of a simulation to an investment analysis is an assessment of whether the manufacturing system will constrain revenue goals. Product must be manufactured and distributed before it can contribute to revenue. The capacity of a simple manufacturing system is closely related to the time available at bottleneck resources. The calculation of capacity becomes difficult or impossible as the complexity of a system increases, as batching is introduced, as setup times become sequence dependent, and as more steps and more queues are introduced. Complex constraints, dynamic interactions, and random variation can be represented in a simulation model. An accurate prediction of whether or not the system will achieve throughput goals can be obtained by experimentation with the model.

Simulations provide information on costs that vary with manufacturing system activities that can be modeled and measured. Table 2 lists some of these costs and related system attributes that can be measured in a simulation (Garrison, 1982).

Table 2: Examples of Variable Manufacturing Costs

Classification	**Variable costs**	**Measured attribute**
Prime costs	Direct materials Direct labor	Volume Processing time
Variable overhead	Indirect materials Lubricants Tooling Supplies Utilities Setup Indirect labor	Volume Processing time Processing time Volume Processing time Setup time, number of setups Volume

Direct and indirect labor are step-variable rather than variable costs. A laborer's time is available only in blocks of several hours for regular time, although labor costs may behave like a true variable cost for overtime. Regular on-shift time and overtime can be modeled and measured in various ways in a simulation. Utilities and energy are also examples of costs that may have both a fixed and a variable component. Step-variable costs and costs with a fixed and a variable component may be deduced from simulation data with slightly more effort than true variable costs.

Simulation study data can be a basis for predicting capacity related costs other than capital investment. Laborers can be modeled as resources and their numbers changed as in hiring or layoff situations. Temporary inefficiencies can be introduced into the model to represent learning curves.

Most fixed costs are out of the scope of a simulation study. However, some fixed costs are step-variable over long periods of time. Simulation runs for a capital investment analysis can have time horizons of years. Over these time periods, fixed costs such as warehouse space become variable. If a capital investment in equipment improves inventory turnover to the point that off-site storage space is no longer needed, the cost of leasing the warehouse can be eliminated. Simulation studies predict the amount of work in process, and can be used to predict fixed costs such as leasing of warehouse space.

Carrying cost does not appear in the income statement but is relevant to inventory management decisions. Carrying cost of an item is related to the cost of capital invested in the manufacture of the item. Capital is required for the resources and material it consumes and the time it remains at a given stage of production. Carrying cost is directly related to the time items spend in queue and sometimes includes costs of deterioration, spoilage, pilferage, obsolescence, insurance, and taxes. Carrying cost is easier to track in a simulation study than in the real world because inventory does not have to be physically counted. A simulation can track carrying cost continuously. Time spent at each stage of production (in queue and in process) can be recorded and the resources and material expended to that point traced. When an item leaves the system, its value is deducted from the amount being carried. Data requirements for carrying cost computation can be huge if carrying cost is to be computed post-process. This is one of the few cases where it is desirable to integrate financial data into the simulation.

Paper flow and order preparation costs can be modeled, but should not be if they can be computed from volume. A relationship should be identified if it exists because these costs are not insignificant.

Transportation and lateness costs can certainly be captured by a simulation study. Distribution can be modeled just like a manufacturing system. Late orders can incur premium shipping costs or can drive customers away. Simulation studies can provide statistics on the number of late orders. These statistics can then be translated into premium shipping costs or used as part of an analysis to predict loss of market share.

2.2 Limitations of Simulation-Based Information

The main limitations of the information generated by a simulation are that:

(1) the costs generated are relative costs, and
(2) the information itself is limited by the detail level and the scope of the model.

The costs generated by a simulation are relative costs because the simulation generates data in terms of volume of product, number of setups, and time spent in activities such as processing, queueing, and setup at various stages of production. This data is translated, postprocess, into cost by applying unit costs inferred from historical data when it exists and from specifications of new equipment. Thus, costs generated by a simulation are relative in nature and should be compared with a baseline alternative when possible.

The information generated by a simulation is limited by the detail level and scope of the model. An example of detail is the following. If setup teams are a constraining resource, they must be modeled. Time in setup is not enough, because it is possible for two machines to be in setup at the same time. To remedy this, a setup team is modeled in such a way that a setup cannot be performed unless the setup team is available. An example of scope is the practice of modeling only part of a plant or a line. Alleviating a bottleneck in the modeled portion of the plant may shift the bottleneck to a portion of the plant not modeled. A simulation cannot provide information on interactions with parts of a plant outside the scope of the study.

Discrete event simulations model state changes over time for entities that flow through a system. Many aspects of financial analysis do not lend themselves to this type of modeling. However, if the limitations of simulation data are kept in perspective, it can be used to greatly improve the accuracy of financial analysis.

2.3 Activity-Based Costing and Simulation-Based Information

Activity-based costing uses a simple concept:

(1) activities consume resources, and
(2) products consume specific activities.

Activity-based costing traces costs directly when possible and allocates costs that cannot be traced based on the occurrence of an appropriate cost driver. A cost driver is something that causes products to be different, to have different routings and to absorb burden differently. Traditionally, labor has been the only cost driver used in cost accounting. As manufacturing processes have become automated, labor is less of a factor and its use as a cost driver can give misleading results. Activity-based costing expands the notion of cost driver to include such things as size, type, finish, lead time, processing time, queue time, surface area, weight, routing, complexity, and many more (Gilligan, 1990). The measured attributes listed in Table 2 are examples of cost drivers.

Activity-based costing is most powerful in analyses in which costs must be allocated to products. Total cost of a product mix, rather than cost of individual products, is of primary concern in capital investment analysis. In this case, an activity-based costing analysis is helpful in identifying activities that contribute to cost which must be modeled in a simulation study. Moreover, such an analysis identifies how costs should be allocated in the baseline model and how costs can be inferred from simulation data for proposed investments in plant and equipment. Combining activity-based costing and simulation could potentially multiply the effectiveness of both.

3 AN EXAMPLE

To illustrate the basic concepts of obtaining simulation-based financial information, comparative income statements were constructed from simulation data for a capital investment analysis. The simulation model of this example was built using SLAMSYSTEM, a Pritsker Corporation product. The simulation data was exported to a spreadsheet, Microsoft EXCEL, for collation and conversion to comparative income statements. Section 3.1 describes the facility being modeled and the rationale behind cost driver selection, model scope, and data collection. Section 3.2 describes the conversion of simulation data to comparative income statements.

3.1 The Simulation Model

The example model is of a facility that manufactures two variations of a product, A and B. Both variations of the product are assembled from four component types, parts 1, 2, 3, and 4. One each of parts 1, 2, and 3 are used in an assembly, but 14 of part 4 are required per assembly. The steps in the manufacture of parts 1 and 2 are cut to length (saw), drill, grind, heat treat, and finish. The steps for part 3 are punch and press. The steps for part 4 are cut to length (saw), grind, heat treat, and finish. Each workstation processes one lot at a time except for the furnace where lots are batched together. The facility and equipment are illustrated in Figure 1.

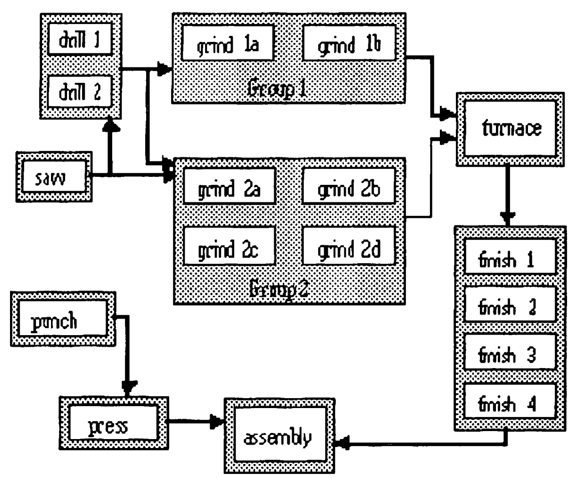

Figure 1: Facility and Equipment

The manufacturing system of this example operates under these assumptions:

(1) one operator per machine,
(2) same operator does both setup and processing,
(3) operator is available whenever machine is available,
(4) all machines in a machine class have the same setup characteristics,
(5) sequencing is FIFO,
(6) lot for lot bill of material explosion,
(7) make to order,
(8) capacity adjusted by overtime and hiring so large backlogs do not develop, and
(9) raw material is always available.

The first step in the modeling process is to define the problem. In this case, the problem was to determine the impact on the income statement of adding a machine at the bottleneck which occurred at the finishing cell. The bottleneck was found during preliminary runs of the simulation model. Preliminary runs are useful for finding bottlenecks in a facility that has not yet been built. Bottlenecks in existing facilities are usually known. The fifth finishing machine was assumed to have the same setup and operational characteristics as the other four machines. It was assumed to cost \$50,000, have a lifetime of 5 years, and have no residual value. Thus, it would depreciate at \$10,000 per year. Theoretically, the additional machine should have increased the capacity at the bottleneck by 25%. Two

Table 3: Volume, Setup, and Processing Time Data

		Baseline		Fifth Finishing Machine	
Machine Class	Volume (lots of 100)	Total Processing Time (min.)	Number of Setups	Total Processing Time (min.)	Number of Setups
saw	606	16,168	605	15,756	605
drill	404	110,010	371	110,361	371
grind 1	202	98,948	133	100,898	133
grind 2	404	616,024	337	603,600	337
furnace	202	97,202	0	97,331	0
finish	606	695,196	556	702,132	662
punch	202	198.04	183	207.98	183
press	202	400.36	183	408.04	183
assemble	202	11,299	113	10,763	113

alternative models were constructed, the baseline ("as is") alternative having four finishing machines and the alternative having five finishing machines. Product volume would be held constant for the two alternatives. Capacity differences would be adjusted by the addition of overtime.

The second step is to identify the performance measures that will provide sufficient information to solve the problem. In the case of this example, the performance measures were the variable costs and revenue generated. For purposes of simplicity, the variable costs were assumed to be the costs given in Table 2. Variable costs were assumed to be directly proportional to one of the following measurable attributes which are cost drivers:

(1) processing time for each machine,
(2) number of setups for each machine,
(3) product volume.

Raw material prices, labor rates, utility rates, and cost of capital were assumed to be constant over the simulation window.

In an actual application, the costs in Table 2 might not adequately capture the impact on the income statement of the investment in an additional machine. Other costs that could have considerable impact on the income statement might include rework, scrap, obsolescence due to engineering change orders, and interest expense on inventory and work in process. Moreover, the assumptions for variable costs listed above are not valid in every situation. For example, setup costs may include scrap. The key to a successful simulation study is to identify significant costs for the defined problem and to accurately model and measure their corresponding cost drivers.

The third step is to construct the model at a level of detail such that cost drivers can be accurately measured. This involves the usual validation and verification processes associated with simulation modeling. It may involve calculating and verifying unit variable costs based on a baseline model of the "as is" system if such a system exists. In the example model, volume of product, processing time, number of setups, and time on shift were measured. Output data for 10 runs of each alternative is summarized in Tables 3 and 4. Had interest expense, in the form of carrying cost, been identified as significant on the income statement, queue time would have been a cost driver that would have been measured. Had obsolescence due to engineering change orders been a significant cost, the effect of engineering change orders on availability of component parts would have to be modeled.

Table 4: On-Shift Time (in minutes)

Alternative	Total Time	Regular Shifts	Overtime Shifts
Basecase	249,600	120,000	129,600
Fifth Finishing Machine	208,800	120,000	88,800

The simulation window must be long enough to show a significant financial impact of an alternative. Unless the assumption that the system is empty and idle at the beginning and end of the simulation window is valid, inaccuracies due to timing of costs may be introduced. The simulation window for the example model was a full year to reduce the significance of the inaccuracies.

3.2 Converting Simulation Data to Comparative Income Statements

The conversion of simulation data to a comparative income statement was done in an electronic spreadsheet. The data from each simulation run was exported to the spreadsheet and averages taken in the spreadsheet. Tables 3 and 4 are copies of the spreadsheet tables in which the simulation data was averaged.

Converting simulation data in Tables 3 and 4 to comparative income statements has three stages:

(1) calculating unit variable costs from current financial data and from performance measures,
(2) inferring costs of the alternative from the unit costs computed in (1) and the performance measures from the simulation model of the alternative, and
(3) construction of comparative income statements.

A unit variable cost for a given time period is the total cost divided by the quantity of measured attribute as listed in Table 2. For example, unit lubricant cost over the last year would be the value of lubricant consumed in the last year divided by the amount of time the machines using the lubricant spent processing. In the example model, direct (raw) and indirect material costs were broken down by part. Lubricant, tooling, utility, and setup cost were broken down by machine.

Ideally, unit variable costs should be computed from actual financial data and actual performance data from the manufacturing system. Baseline model data should be used for validation and verification purposes only. Unfortunately, real world data is not always available in the form needed for generating unit costs. If data is not available from the real world system, unit cost may have to be estimated. Data from a properly verified baseline model may be helpful for estimating unit costs. For example, quantity and cost of lubricant consumed by a machine may be known, but the actual processing time for the machine may not be known. Actual processing time may be difficult to estimate if different routings exist and routing logic depends on the state of the system. In this case, the best estimate of processing time may come from a verified simulation model, using the same conditions and product mix that occurred during the time period for which lubricant cost is known.

The manufacturing system described in this section is a teaching example, which is a simplification of a real world system. Therefore, baseline simulation data was used to construct unit costs as described above.

Table 5: Variable Definitions

Variable	Definition
V	Total volume manufactured over simulation window for the alternative
V_p	Volume of product p manufactured over simulation window for the alternative
W_m	Total processing time over simulation window for machine m for the alternative
P	Set of all parts
M	Set of all machines
R_p	Raw material unit price for part p
L	Labor rate
H_r	Regular hours for the alternative
H_o	Overtime hours for the alternative
I_p	Unit cost of indirect material for part p
U_m	Unit cost of lubricant for machine m
T_m	Unit cost of tooling for machine m
S	Unit cost of supplies
E_m	Energy consumption rate for machine m
F	Fixed base utility rate
C_m	Cost per setup for machine m
N_m	Number of setups for machine m
K	Unit cost of indirect labor

Table 6: Formulas for Calculating Variable Costs

Variable Cost Category	Formula
Raw material cost	$\sum_{P} R_p V_p$
Direct labor cost	$L(H_r + 1.5H_o)$
Indirect material cost	$\sum_{P} I_p V_p$
Lubricant cost	$\sum_{M} U_m W_m$
Tooling cost	$\sum_{M} T_m W_m$
Supplies	SV
Utilities	$F + \sum_{M} E_m W_m$
Setup cost	$\sum_{M} C_m W_m$
Indirect labor cost	KV

Costs for alternatives other than the baseline are computed as summarized in Tables 5 and 6. Most of these costs are computed by summing a unit cost multiplied by a measured attribute (processing time, volume, or number of setups) over the set of machines (*M*) or the set of parts (*P*). Supplies and indirect labor are based on total volume. Direct labor is based on a sum of regular and overtime hours where overtime is valued at 1.5 times regular time. Costs for the example model are summarized in Table 7.

Table 7: Cost of Goods Sold by Category

Variable costs	Basecase	Fifth Finishing Machine
Direct materials	393,900	393,900
Direct labor	712,640	573,920
Indirect materials	11,900	11,900
Lubricants	13,850	13,644
Tooling	12,200	12,132
Supplies	1,050	1,050
Utilities	117,488	117,535
Setup	37,276	39,946
Indirect labor	98,000	98,000
Total	1,398,304	1,262,027

Finally, the comparative income statements may be constructed. Revenue is computed as the product of volume and selling price. For this example, the selling price is $39 and it is assumed that all items produced are sold. Cost of goods sold is the total obtained in Table 7. An extra $10,000 of depreciation is added to the fifth finishing machine alternative. Other costs must be obtained from current financial data. Comparative income statements for the baseline model and the fifth finishing machine alternative are given in Table 8.

4 CONCLUSIONS AND FUTURE DIRECTIONS

Differing viewpoints and priorities have historically caused communication problems between accountants and engineers. Translation of engineering data into financial terms as demonstrated by this paper is part of the solution to bridging the gap. The other part of the solution is the development of common models to be used by both engineers and accountants.

The model presented in this paper is the first step toward building such a common model. The authors intend to refine the model to provide laboratory experiences for business students at the University of Indianapolis. Planned refinements include the explicit modeling of shifts, laborers, setup teams, paper flow, constraining raw material, constraining work in process space, engineering change orders, scrap, and rework. Improvements will be made to batching and sequencing logic. Setup and processing characteristics may vary within a machine group. Drivers for lateness costs and carrying costs will be modeled and measured. Orders for products will be generated based on performance with respect to due dates. Students will be able to experiment with potential capital investments, capacity management strategies, and operating philosophies such as JIT and synchronous manufacturing.

Integration of the engineering technique of simulation with business education will ultimately produce cost accountants and managers with a complete view of a manufacturing system. Students will understand both the operational and the financial aspects of the manufacturing concern. They will be able to communicate with engineers because they will share a common model.

Table 8: Comparative Income Statements for Basecase and Fifth Finishing Machine

	Basecase		Fifth Machine	
Revenue		$2,363,400		$2,363,400
Cost of Goods		1,398,304		1,262,027
Marginal Income		965,096		1,101,373
Depreciation	210,000		220,000	
Other Fixed Costs	595,475	805,475	595,475	815,475
Net Income		159,621		285,898
Taxes(.50)		79,811		142,949
Income After Tax		79,810		142,949
Add Back Depreciation		210,000		220,000
Cash Flow		289,810		362,949

ACKNOWLEDGMENTS

The authors gratefully acknowledge Jenny Mishler of Pritsker Corporation and Steve Spicklemire of the Department of Mathematics and Physics at the University of Indianapolis for their support in this project.

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