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SIMULTANEOUS COST AND PRODUCTION ANALYSIS OF MANUFACTURING SYSTEMS

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ABSTRACT

An outstanding opportunity for the participation of simulation modelers in the strategic planning of the firm is the development of integrated models for the evaluation of complex business scenarios. These models can be used to make the problem of investment in manufacturing technology more transparent to decision makers. The assumptions that a firm employs regarding the allocation of direct and indirect costs can be explored prior to the development of new policies. The interaction of multiple products and production technologies can be evaluated. A review of the research and professional literature pertaining to each of these issues is presented. An experimental model is then presented and described in detail, using the capabilities of a modern discrete-event simulation language. Data collected from multiple runs of this sample scenario are manipulated using spreadsheet procedures to produce a plot of cash flow for a sample set of assumptions. The applicability of this approach to a broader set of scenarios is discussed.

1. INTRODUCTION

The concept of integrating production, marketing, and financial plans is not a new one. In an early publication by Naylor[1971], the elements of the concept were developed, but the development of a truly sophisticated model was beyond the technology of the that period. Naylor focused on the description of econometric models of industries that employed very selective inputs that could be described as having originated from the functional areas of the firm. In an attempt to advance technology to match the complexity of his conceptual model, Naylor developed one of the early "financial planning" languages (SIMPLAN), and described many of its capabilities in a subsequent book [Naylor 1979].

Full integration of the complexity of production planning, market dynamics, and detailed data for cost analysis remained elusive. Financial planning languages did not include the capacity to incorporate complex queueing phenomena common to production systems. On the other hand, discrete-event simulation languages, particularly in the process mode, are clumsy in calculating financial formulae common to accounting, costing, and investment analysis. These calculations are iterative formula-based procedures with implicit DO-loop and conditional structures with implicitly indexed variables that can be used to data collection through time.

Financial planning languages also use deterministic time increment calendars where values of variables are updated only at those times. This format did not support sophisticated activity costing techniques that were beginning to permeate the theory of cost accounting. Thus, if finance and production costing are to be integrated with production process models, there must be a method that allows for the interconnection of financial and production processes in terms of both the widely disparate time units (e.g. seconds versus quarters), but also in terms of random aperiodicity of production with the periodicity of financial reporting.

While the most obvious innovation in simulation modeling languages in the eighties was the development of animation, recent releases of the leading products have included the ability to collect more data in more formats, transmit this data efficiently to spreadsheets, and perform replicate simulation runs of complex, long time horizon models very efficiently. Fortunately for simulation users, these capabilities coincide with an increasingly competitive economy where firms are questioning their traditional behavior regarding investment in technology and the allocation of costs to products.

2. RELEVANT LITERATURE IN ACCOUNTING

In a series of six detailed case studies of major US corporations for the Financial Executives Research Foundation, Keating and Jablonsky [1989, 1990] document a significant shift in the orientation of accounting and financial managers. Their model classifies firms as having one of the following dominant orientations: (1) Command and Control, (2) Conformance, or (3) Competitive Team. They contend that leading firms are becoming more market-oriented, and that the most effective financial and accounting practices are leading those functions to focus on the market as well, adopting a posture of financial leadership and customer service within the firm. By comparison, the traditional orientations of command and control, and conformance had more conservative orientations. In command and control, the accounting function was to guard the resources of the firm, require meeting tough performance measures regarding efficiency, and provide an "uninvolved" oversight function. A firm that was previously characterized by this orientation was the Ford Motor Company. The finance function did not engage in dynamic modeling of market and production interactions, nor did it pave the way for investment in product and process technology. Rather, it held the purse strings. Fortunately for Ford, this organization has undergone a significant rebirth, and now supports the firms aggressive market orientation through decentralized financial services in the individual business units of the firm.

The conformance orientation of financial management is characterized by bureaucratic organizational designs that stress external accountability and technical compliance to regulations. An example of a firm formerly in this mode is AT&T, when it operated in an industry that was subject to considerable government regulation. What international competition did to Ford, deregulation did to AT&T–and the accounting function responded to the new environment by adopting the competitive team orientation. Both of these firms are selected as outstanding examples of firms that made an effective transition to a new approach to operation, and in each case this necessitated an examination of internal cost accounting practices. New practices were evaluated from the vantage point of responsible member of a management team participating in the strategic planning process, rather than as an adversary that must be petitioned for operating capital.

The observations that Keating and Jablonsky have made in these case studies are not surprising, given the tension in accounting research and practice in the eighties. Of particular significance is the initial installment of what was to become a stream of research by Robert Kaplan, then Dean of the Graduate School of Industrial Administration at Carnegie-Mellon University [Kaplan 1983]. Kaplan recognized that traditional accounting practices were only measuring a subset of the performance criteria that were critical to successful competition in manufacturing. Furthermore, since managers were often evaluated on this limited set of performance measures, the effective management of production was being scuttled, at least in aprt, by accounting practice. This theme, and proposed solutions to the limitations of cost accounting, have been proposed [Brimson 1986; Mills 1988; Cooper and Kaplan 1987, 1988; Howell and Soucy 1987]. Kaplan argued for the coexistence of three different cost systems, based upon the unique demands of different manufacturing functions: inventory valuation, operational control and order tracking, and product cost measurement [Kaplan 1988].

The allocation of indirect costs continues to challenge managers. In a survey of the practice of allocation of these costs, it was determined that most firms allocated indirect costs to units of production despite all of the theory that indicates the futility of this effort [Fremgen and Liao 1981]. The theory of cost accounting prescribes that direct costs should be traceable to individual profit centers, and that any costs that involved multiple profit centers (or no profit centers) should be treated as indirect. However, to support cost-based pricing practices, these costs are distributed, often according to a rule that pertains to market conditions at one point in time, but fails to reflect the changing structure of the marketplace.

Raffi and Swamidass [1987] conducted a major survey of manufacturing overhead cost behavior in US firms. They report that these overhead costs are two and one-half times the direct labor cost in the average US manufacturing firm. Documentation of this fact further supports the reorientation that is needed in cost accounting, which traditionally went to considerable effort to tally labor costs, because they were measureable, and has not developed sophisticated analysis techniques for indirect costs. Simulation models can be configured to collect sophisticated data that is anchored in time, and should assist is this effort. For a tutorial on recent cost accounting concepts that could utilize this data, see Cooper [1987 a,b,c]. In the first of these articles, Cooper explains how the current cost accounting practices may distort management decision making because they do not accurately measure the profitability of different product lines. The second manuscript illustrates four methods of allocating costs to products, and uses a numerical example to illustrate the distortions than can arise with two of these common methods. Finally, a "two-stage" procedure is developed that recognizes that fixed costs cannot be allocated to individual units of production alone, but may be ascribed to machines, capacity utilized, and hours of production.

3. RELEVANT LITERATURE IN THE JUSTIFICATION OF INVESTMENT IN TECHNOLOGY

Concurrently with these developments in accounting was the recognition that financial measures in use in many firms were retarding the acquisition of advanced manufacturing technology. Gold [1982] noted that the benefits of this new technology could only be realized if the measurements applied to it exploited its ability to produce higher quality products, faster, and in greater variety. Each of these criteria was not incorporated into standard manufacturing performance measurement systems. Interest shifted from financial criteria to strategic analysis. Kulatilaka [1983], Carrie et al.[1984], Gustavsson [1984], Swamidass [1987], and Meredith and Hill [1987] each focus on non-financial criteria that must be considered in the new technology adoption process.

Strategic arguments were useful to an extent, but the question of the effect of an investment in technology and the performance of that technology under various assumptions of machine reliability, workforce learning, and market conditions was left unanswered. Several authors returned to the task of mathematically modeling the performance of these systems. Adler [1987] developed revised productivity measures. Singhal et al. [1987] discuss models that include start-up conditions, layout of the physical system, structure of the information and planning system, and production control. Monahan and Smunt [1987] described a decision support system that evaluates the shift from batch processes to automated flexible processes, incorporating cost functions and some simulation components that determine the percent utilization of capacity. Their objectives were not inconsistent with our own, but the approach taken addressed a more specific problem. The simulation model of Monahan and Smunt employed the XCELL language, and could include a reasonable degree of detail regarding a production process. It represented an improvement on the analysis reported by Hutchinson and Holland [1982] which attempted to place an economic value on the flexibility of advanced technology, but did not include a detailed production simulation.

Two analytical approaches to the costing problem merit mention. Miltenburg and Krinsky [1987] evaluate flexible manufacturing system using a sophisticated financial model, but their sophisticated analytic model of the FMS is not flexible enough to evaluate specific production scenarios. Karmarkar and Rummel [1986] develop analytic descriptions of product cost allocation, focusing on the opportunity costs implicit in a particular manufacturing configuration.

4. CONCEPTUAL FOUNDATION OF THE PROTOTYPE

If costing is to be mated with production processes, it must be made an integral part of the logic of the process itself. Thus, the calculation of costs must be linked to the actual sites and activities involved. In the prototype model presented here, this is accomplished by using the "station" as the location of costing. Each station is the receiver of resources, such as material, labor skill and labor hours, setup by maintenance, and process technology. An allocation of these costs can be made to units as they advance through the logic of the production process, from station to station. Other costs that could be reasonably ascribed to the unit produced would be a float cost, reflecting the opportunity cost incurred (interest in alternative investments lost) for the expenses incurred for producing the unit at a particular point in time–on a designated production path and technology.

The prototype example presented here is an extension of Kilgore and Kleindorfer [1988] and is related to the approach taken by Kilgore [forthcoming]. In this model we postulate a scenario where a particular manufacturing configuration, a job shop, is in place. The machines could be reconfigured into manufacturing cells at some cost, they could form a dedicated flow line with some loss of product mix flexibility, or they could be replaced by a multi-function machine center. Each of these changes might well be considered in the execution of a particular manufacturing strategy. Each change could have related machine reliability problems, workforce learning assumptions, routing–scheduling–set-up differences, and importantly–cost allocation implications.

Suppose that the manufacturing facility has several products that it is capable of producing. How does it evaluate the effect of introducing a new product at various times? How do assumptions regarding the market penetration of the product effect decision making? When should mature products be phased from production? These are the kinds of questions that can be addressed with a simulation model that simultaneously performs manufacturing, market, and financial analysis and produces output from multiple runs in a form that facilitates analysis. The "station" structure in SIMAN [Pegden, 1985] is employed to collect activity based costing data, and the costs that are attributable to each unit of production are also collected. Capital investments made while new technologies are put in place are recorded (as could salvage values for retired equipment), and costs associated with new product introduction are realized in the financial quarter when they occur. The output from this system is sufficient to permit a wide variety of accounting methods for cost allocation, pre- and post-taxation consideration, and comparison of alternative scenarios.

5. PROTOTYPE MODEL COMPONENTS

The SIMAN modeling language employed here is structured to separate the definition and values of input variables, specification of output measures and their file location, and related experimental conditions such as run length and replications in a file distinct from the simulation model. Table 1 is a sample experiment file for an implementation of this prototype model. Note that the job shop machines are active at the beginning of this simulation, and the machining center, a new technology that will be acquired within this scenario (machine (1) in Line 3) is inactive. Line 6 indicates that quarterly output measures will be collected in a Lotus 123 file; Line 7 indicates the station sequence for the different products that are manufactured. Line 8 defines variables, indexes them where appropriate, and declares starting values. Line 9 triggers the introduction of new products. In this experiment, three products are manufactured at the start of the simulation, and two additional products are introduced, each at different points in the course of the simulation. Lines 10 and 11 control the collection of queue length and machine utilization data, and define the length and number of runs in the simulation.

The simulation model is listed in Tables 2-8. For each section of the model, a narrative is provided to supplement the annotations that are included in the model.

In this scenario a multi-function machine center will be introduced at some point in the simulation. The machine center has the capability to perform the functions of each of the separate machines in the job shop, and can perform some operations simultaneously on a single order. Its setup and processing times are lower, and it can operate overnight with minimal operator intervention. The decision to invest in this technology was made at the start of the simulation. Table 2 includes the code for modeling this introduction as a five activity PERT network with stochastic event times and precedence relationships. The capital cost for each of the five phases is recorded when a stage is initiated, although the machine center is not available for production until the final activity in its installation is complete.

Table 3 initiates the production of each product type, and

Table 1. Siman Experiment File for Prototype Scenario

```
Begin;                    SIMAN IV SIMULATION LANGUAGE
   ;
   ;        Operations Planning and Costing Experiment Frame
   ;
   ;--------------------------------------------------------------------------------------------
 1 Project,Costing and Pricing,GBK,7/11/90;
   ;
 2 Attributes: Product Type:
               Unit Cost:
               Arrival Time;
   ;
 3 Resources: Machine(6),0,1,1,1,1,1;
   ;
 4 Queues: 12: 13,Finish;
   ;
 5 Stations: 26: New Product Intro, 27;
   ;
 6 Files: Quarterly Report, "Quarter.WKS",SEQ,WKS,ERR;
   ;
 7 Sequences: 1, 1 & 6:
              2, 2 & 6:
              3, 2 & 3 & 4 & 5 & 6:
              4, 4 & 3 & 5 & 2 & 6:
              5, 3 & 4 & 5 & 6:
              6, 5 & 3 & 4 & 6:
              7, 8 & 9 & 10 & 11 & 12 & 13 & 15 & 16 & 17 & 18 & 19
                 & 20:
              8, 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17
                 & 18 & 19 & 20;
   ;
 8 Variables: Investment in Center (5):
              Cost of Job (5), 50,60,70,80,90:
              Product started (5):
              Beginning time (5):
              Capital Cost (5):
              Starting Cost (5), 5,10,15,20,25:
              Number of lots:
              Starting percent (5), 5,4,3,2,1:
              Ceiling (5), 1000,2000,3000,4000,5000:
              EOQ (5), 5,6,7,8,9:
              Shop path (5), 2,3,4,5,6:
              Production ordered (5):
              Transactions (5,5):
              Optime:
              Operation Time (5,6), 1,1,1,1,1,
                                    2,2,2,2,2,
                                    3,3,3,3,3,
                                    4,4,4,4,4,
                                    5,5,5,5,5,
                                    6,6,6,6,6:
              Center operating cost allocated to unit:
              Materials Cost (5,5), 1:
              Set Up Cost (5,6), 1:
              Wage Rate, .01:
              Operating Cost (5):
              Float Cost:
              Float Rate, .1:
              Number produced (5):
              Revenue (5):
              Price (5), .10,.20,.30,.40,.50:
              Week end:
              Production efficiency, .9:
              Total demand (5):
              Growth rate (5), .005,.003,.001:
              Additional demand:
              Quarter:
              i;
   ;
 9 Arrivals:1,Station (New Product Intro),0,,1:
            2,Station (New Product Intro),0,,2:
            3,Station (New Product Intro),0,,3:
            4,Station (New Product Intro),8400,,4:
            5,Station (New Product Intro),16800,,5;
   ;
10 Dstats: 1,NQ(1), Line 1:
           2,NQ(2), Line 2:
           3,NQ(3), Line 3:
           4,NQ(4), Line 4:
           5,NQ(5), Line 5:
           6,NR(1), Mach 1:
           7,NR(2), Mach 2:
           8,NR(3), Mach 3:
           9,NR(4), Mach 4:
          10,NR(5), Mach 5:
          11,NR(6), Mach 6;
   ;
11 Replicate,5,0,42000;
   ;
   End;
```

Table 2. Siman Model File for Prototype – Part I

```
Begin;                    SIMAN IV SIMULATION LANGUAGE
   ;
   ;        Operations Planning and Costing Model Frame
   ;
   ;------------------------------------------------------------------------------
 1 Synonyms: Machine center up = MR (1): Lots waiting = NQ (1);
   ;------------------------------------------------------------------------------
   ;        Machine Center Installation Project Network
   ;------------------------------------------------------------------------------
   ;        This submodel simulates a PERT project through which the
   ;        machine center is brought into operation. At its conclusion
   ;        the machine center is activated. 'Investment in center' is
   ;        treated as a capital cost.
   ;
 1           Create;
 2 Job1      Assign: Investment in Center (1) =
                     Investment in Center (1) + Cost of Job (1);
 3           Delay: Unif(2100,4200);
 4           Branch,2:
                  Always,Job2:
                  Always,Job3;
 5 Job2      Assign: Investment in Center (1) =
                     Investment in Center (1) + Cost of Job (2);
 6           Delay: Unif(2100,4200):Next (Job4);
 7 Job3      Assign: Investment in Center (1) =
                     Investment in Center (1) + Cost of Job (3);
 8           Delay: Unif(4200,6300):Next (Job5);
 9 Job4      Assign: Investment in Center (1) =
                     Investment in Center (1) + Cost of Job (4);
10           Delay: Unif(2100,4200):Next (Job5);
11 Job5      Queue, Finish;
12           Combine:2;
13           Assign: Investment in Center (1) =
                     Investment in Center (1) + Cost of Job (5);
14           Delay: Unif(700,1400);
   ;
15           Alter: Machine (1), 1: Dispose;
   ;
   ;------------------------------------------------------------------------------
   ;        New Product Introduction
   ;------------------------------------------------------------------------------
   ;        This submodel introduces into the production system a starting
   ;        number of lots determined as a percentage of the ceiling of the
   ;        logistic curve. The arrivals to this submodel are staggered
   ;        over time depending on when the product is to be started.
   ;
```

Table 3. Siman Model File for Prototype – Part II

```
16           Station, New Product Intro;
17           Assign: Product started (Product Type) = 1;
18           Assign: Beginning time (Product Type) = TNOW;
19           Assign: Capital Cost (Product Type) =
                     Capital Cost (Product Type) +
                       Starting Cost (Product Type);
20           Assign: Number of lots =
                          AINT (( Starting percent (Product Type) *
                                  Ceiling (Product Type)) /
                                ( 100 * EOQ (Product Type) )) - 1;
21           Assign: Production ordered (Product Type) =
                     (Number of lots + 1) * EOQ (Product Type);
22           Duplicate: Number of lots: Next (Floor);
   ;
   ;------------------------------------------------------------------------------
   ;        Production Submodel
   ;------------------------------------------------------------------------------
   ;        This submodel represents the production system itself. The
   ;        machine center is Station (1). Station (5) contains two
   ;        machines in parallel. The increments to operating cost and to
   ;        unit cost are adjusted as the products move through their
   ;        respective paths. Also transaction counts are kept by product
   ;        and center for use in allocating overhead and capital costs when
   ;        the simulation is done.
   ;
23 Floor     Branch,1:
                  If, 'Machine center up' == 1. AND.
                      'Lots waiting' <= 10, Center:
                  Else, Shop;
   ;
24 Center    Assign: NS = 1: Next (Dispatch);
25 Shop      Assign: NS = Shop path (Product Type): Next (Dispatch);
26 Dispatch Route;
   ;
27           Station,1-4: Mark (Arrival Time);
28           Assign: Transactions (Product Type,M) =
                     Transactions (Product Type,M) + 1;
   ;
29 SendOn Queue, M;
30           Seize: Machine (M);
   ;
31           Assign: Optime = Operation Time (Product Type,M);
32           Assign: Center operating cost allocated to unit =
                     Materials Cost (Product Type,M) +
                       Set Up Cost (Product Type,M) +
                         Wage Rate * Optime;
```

assesses a product introduction charge which could reflect advertising, new distribution channel development, or initial cost of material handling, tooling etc. Table 4 routes orders for production of the different products to stations, accumulates the number of transactions at these stations, allocates direct costs, and computes inventory carrying costs (see Line 37). The operation time for each product at the appropriate work station is specified in the experiment file.

Station 6 in the model represents the completed product generating revenue for the firm. It would be easy to delay the product by some transportation time, and adjust inventory investment valuation as well. This code is listed in Table 5. Table 6 schedules the start and stop of production on a daily and weekly basis. We have argued that the strength of this approach is that daily production can be modeled in the same system as quarterly financial analysis. Table 6 is an illustration of this. Machine reliability (Line 70) can be incorporated in simple or sophisticated ways, and machines can start and stop under various assumptions. Here we assume that the machine center operates continuously from Monday morning until Friday afternoon. The full job shop is an eight hour per day, five days per week operation.

The product life cycle is a model of accelerating and decelerating demand for a product over its time in the marketplace. Table 7 is the model code for our assumptions regarding the demand for each of the products during time. SIMAN includes the functions necessary to model a logistic curve, and we compute the number of production lots demanded during each period according to the growth rate modeled for the demand of each product.

Table 4. Siman Model File for Prototype - Part III

```
33          Assign: Operating Cost (Product Type) =
                      Operating Cost (Product Type) +
                        Center operating cost allocated to unit;
34          Assign: Unit Cost = Unit Cost +
                      Center operating cost allocated to unit;
 ;
35          Delay: Optime;
36          Release: Machine (M);
 ;
37          Assign: Float Cost = Unit Cost * Float Rate *
                                  (TNOW - Arrival Time) / 8400;
38          Assign: Unit Cost = Unit Cost + Float Cost;
39          Assign: Operating Cost (Product Type) =
                      Operating Cost (Product Type) + Float Cost:
                 Next (Dispatch);
 ;
40          Station,5: Mark (Arrival Time);
41          Assign: Transactions (Product Type,M) =
                      Transactions (Product Type,M) + 2;
 ;
42          Queue, 5;
43          Select,  CYC:
                      First:
                      Second;
44 First    Seize: Machine (5);
 ;
45          Assign: Optime = Operation Time (Product Type,5);
46          Assign: Center operating cost allocated to unit =
                      Materials Cost (Product Type,5) +
                        Set Up Cost (Product Type,5) +
                          Wage Rate * Optime;
47          Assign: Operating Cost (Product Type) =
                      Operating Cost (Product Type) +
                        Center operating cost allocated to unit;
48          Assign: Unit Cost = Unit Cost +
                      Center operating cost allocated to unit;
 ;
49          Delay: Optime;
50          Release: Machine (5): Next(Float);
 ;
51 Second    Seize: Machine (6);
 ;
52          Assign: Optime = Operation Time (Product Type,6);
53          Assign: Center operating cost allocated to unit =
                      Materials Cost (Product Type,5) +
                        Set Up Cost (Product Type,6) +
```

Table 5. Siman Model File for Prototype - Part IV

```
                          Wage Rate * Optime;
54          Assign: Operating Cost (Product Type) =
                      Operating Cost (Product Type) +
                        Center operating cost allocated to unit;
55          Assign: Unit Cost = Unit Cost +
                      Center operating cost allocated to unit;
 ;
56          Delay: Optime;
57          Release: Machine (6): Next(Float);
 ;
58 Float     Assign: Float Cost = Unit Cost * Float Rate *
                                  (TNOW - Arrival Time) / 8400;
59          Assign: Unit Cost = Unit Cost + Float Cost;
60          Assign: Operating Cost (Product Type) =
                      Operating Cost (Product Type) + Float Cost:
                 Next (Dispatch);
 ;
 ;------------------------------------------------------------------------------
 ;         Revenue Submodel
 ;------------------------------------------------------------------------------
61          Station,6;
 ;
62          Assign: Number produced (Product Type) =
                      Number produced (Product Type) +
                        EOQ (Product Type);
 ;
63          Assign: Revenue (Product Type) =
                      Revenue (Product Type) + Price (Product Type) *
                        EOQ (Product Type):
                 Dispose;
 ;
 ;------------------------------------------------------------------------------
 ;         Daily and Weekly Start Up and Shut Down Submodel
 ;------------------------------------------------------------------------------
 ;        This submodel handles shift changes on weekdays and weekends.
 ;        It is needed in order to synchronize production with financial
 ;        calculations. Note that the machine center operates 24 hours
 ;        a day when it is up. The other machines only operate during
 ;        the day shift. All machines stop on weekends after quitting
 ;        time on Fridays and they all start up again on Monday mornings.
 ;
64          Create;
65 NewWeek  Assign: Week end = 0;
66          Delay: 96 + 8 * Production efficiency;
67          Assign: Week end = 1;
68          Delay: 64 + 8 * (1 - Production efficiency): Next (NewWeek);
```

6. SAMPLE OUTPUT AND ANALYSIS

Table 8 outlines the recording of output data to the Lotus 123 program. Figure 1 represents the spreadsheets produced for two different quarterly periods. Note that the number of product types under production changes from Quarter 1 to 5, and that the capital costs for the machine center are accumulated although it is not yet "on-line." Also note that product 4 has begun production by the beggining of quarter 5 in this simulation run.

A Cash Flow plot is provided in Figure 2 for a single run of a sample scenario. We envision plots such as this one to be a significant input in planning for a variety of financial scenarios, market conditions, and production technologies. The purpose of this paper is to demonstrate an application for simulation that responds to expressed needs in manufacturing. The prototype scenario that we have modeled here indicates the power of this approach.

Five replications of the simulation model shown here required slightly more than 2 hours on an IBM/AT with a math coprocessor.

7. SUMMARY AND RESEARCH DIRECTIONS

The short term random queueing and scheduling phenomena common to production processes can be integrated with the long term periodic processes involved in financial and accounting analysis in one simulation format. The calendar mechanism and efficiency of state-of-the-art discrete event languages now beginning to appear on the market make this kind of large scale integrated simulation possible and practical. We have given an example which shows how in principle this integration could take place. We have sketched out how various costing procedures can be introduced into such a model and how these proce-

Table 6. Siman Model File for Prototype - Part V

```
    ;
69           Create,,.01;
70 NewDay Delay: 8 * Production efficiency;
    ;
71           Branch,1:
                 If, Week end == 1 .AND. 'Machine center up' == 1,
                    WeekEnd:
                 Else, WeekDay;
    ;
72 WeekDay  Assign: NS = 7: Next (TimeOff);
73 WeekEnd  Assign: NS = 8: Next (TimeOff);
    ;
74 TimeOff  Route;
    ;
75           Station,7-12;
76           Queue,M;
77           Preempt: Machine(M-6):Next (TimeOff);
    ;
78           Station,13;
79           Delay: 16 + 8 * (1 - Production efficiency);
80           Delay: 48 * (Week end == 1);
    ;
81 TimeOn   Route;
    ;
82           Station,14-19;
83           Release: Machine(M-13):Next (TimeOn);
    ;
84           Station,20;
85           Assign: IS = 0: Next (NewDay);
    ;
    ;-----------------------------------------------------------------------------------------
    ;        Market Penetration Submodel
    ;-----------------------------------------------------------------------------------------
    ;        This submodel computes total accumulated demand by product.
    ;        This demand is modeled by the logistic curve.  Based on this
    ;        accumulated figure and past orders sent to the floor, another
    ;        set of orders for each product is sent to the floor each week.
    ;
86           Create,,168: 168;
87 PLoop    Assign: i = i + 1;
    ;
88           Assign: Product Type = i;
    ;
89           Assign: Total demand (Product Type) =
               (Product started (Product Type) == 1) *
                  Ceiling (Product Type) /
```

Table 7. Siman Model File for Prototype - Part VI

```
               (1 + ((100 - Starting percent (Product Type)) /
                 Starting percent (Product Type)) *
                    EP ( - Growth rate (Product Type) *
                      Ceiling (Product Type) *
                         (TNOW- Beginningtime (ProductType))/ 8400));
    ;
90           Assign: Additional demand = Total demand (Product Type) -
               Production ordered (Product Type);
    ;
91           Assign: Number of lots =
               AINT ( Additional demand / EOQ (Product Type));
    ;
92           Duplicate: Number of lots, Floor;
    ;
93           Assign: Production ordered (Product Type) =
               Productionordered (ProductType) + (Numberof lots >= 0)
                  * Number of lots * EOQ (Product Type);
    ;
94           Branch, 1:
               If, i == 5, PDone:
               Else, PLoop;
95 PDone    Assign: i = 0: Dispose;
    ;
    ;-----------------------------------------------------------------------------------------
    ;        Quarterly Accumulated Report to 123 Spreadsheet Submodel
    ;-----------------------------------------------------------------------------------------
    ;
96           Create;
97 Quarter  Delay: 2100;
    ;
98           Assign: Quarter = Quarter + 1;
99           Write, Quarterly Report: Quarter, NREP;
    ;
    ;        Quarterly Output to LOTUS by Product Type
    ;
100          Write, Quarterly Report: Revenue(1),Revenue(2),Revcnue(3),
                    Revenue(4),Revenue(5);
101          Write, Quarterly Report: Operating Cost(1),OperatingCost(2),
                    OperatingCost(3),OperatingCost(4),OperatingCost(5);
102          Write, Quarterly Report: Capital Cost(1),Capital Cost(2),
                    Capital Cost(3),Capital Cost(4),Capital Cost(5);
103          Write, Quarterly Report: Total demand(1),Totaldemand(2),
                    Total demand(3),Totaldemand(4),Totaldemand(5);
104          Write, Quarterly Report: Number produced(1), Number
                    produced(2), Number produced(3), Number
                    produced(4), Number produced(5);
```

dures may be associated with discrete event structures like the station concept in the SIMAN language. The research adgenda that such an approach suggests is extensive and varied.

Kaplan and others have argued that accurate costing must be geared more directly to the production process itself. Various factors involved in this logic like transaction counts at stations, machine usage and downtime, and so on must be the basis not only for allocating operating costs but also for allocating overhead and capital costs. It is fairly straightforward to include in simulation models the logic of at least some version of how these costing procedures might be implemented. For example, our model includes the calculation and report of transaction counts and delay times, materials usage at stations and so on. The focus of the important research here lies not in simulation but rather in the accounting and organizational issues. What should the accounting procedures be and what should their logic be in order to get the accurate costing that modern flexible manufacturing systems require while still maintaining an organizational orientation that does not stifle or warp the production process? This is the kind of question that accounting researchers like Kaplan and like Keating and Jablonski are now raising.

On the simulation side of the research adgenda, we need to invent formats that reside within one simulation language for dealing with both the production and financial-accounting sides of the system simultaneously. While our example in this paper and an earlier example presented by Kilgore and Kleindorfer show how this combination can be accomplished in principle, in practice current simulation formats are cumbersome in actually carrying out such an exercise. We need a combined simulation format that allows flexible interaction between the production or inherently discrete-event side of the model and the other periodic financial accounting side. Such a combined format must allow the really difficult issues to be studied: those in which financial considerations as they arise affect the production pro-

Table 8. Siman Model File for Prototype – Part VII

```
;
;          Quarterly Output of capital costs by Production Center
;
105        Write, Quarterly Report: Investment in Center(1),
                  Investment in Center(2),Investment in Center(3),
                  Investment in Center(4),Investment in Center(5);
;
;          Quarterly Output of transactions by Product Type and
;          by Production Center
;
106        Write, Quarterly Report: Transactions(1,1),Transactions(1,2),
                    Transactions(1,3),Transactions(1,4),Transactions(1,5);
107        Write, Quarterly Report: Transactions(2,1),Transactions(2,2),
                    Transactions(2,3),Transactions(2,4),Transactions(2,5);
108        Write, Quarterly Report: Transactions(3,1),Transactions(3,2),
                    Transactions(3,3),Transactions(3,4),Transactions(3,5);
109        Write, Quarterly Report: Transactions(4,1),Transactions(4,2),
                    Transactions(4,3),Transactions(4,4),Transactions(4,5);
110        Write, Quarterly Report: Transactions(5,1),Transactions(5,2),
                    Transactions(5,3),Transactions(5,4),Transactions(5,5):
              Next (Quarter);
;
End;
```

cess and vice versa. At present these two spheres of simulation and of planning exist separate from one another in rather insular domains. Perhaps the invention of simulation formats that make such matters easier to represent will make the study of such complicated interconnected planning processes possible.

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```
                                         1      2      3      4       5
****************************************************************************

Quarter    1


                                          Product Type
                                         1      2      3      4       5


               Units Demanded           149    299    179      0       0
               Units Produced           145    282    175      0       0


                                          Product Type
                                         1      2      3      4       5


               Revenue ($K)             $87   $282   $140     $0      $0
               Operating Cost ($K)      $59   $400   $204     $0      $0
               Capital Cost ($K)         $5    $10    $15     $0      $0


                                          Production Center
                                         1      2      3      4       5


               New Investment ($K)      $50     $0     $0     $0      $0


                                          Transactions by
                                          Production Center
                                         1      2      3      4       5


          Trans-          1              0     29      0      0       0
          actions         2              0     49     49     49      98
            by            3              0     25     25     25      50
          Product         4              0      0      0      0       0
          Type            5              0      0      0      0       0

****************************************************************************
```

```
                                         1      2      3      4       5
****************************************************************************

Quarter    5


                                          Product Type
                                         1      2      3      4       5


               Units Demanded            76     85    533    202       0
               Units Produced            85    252    742    176       0


                                          Product Type
                                         1      2      3      4       5


               Revenue ($K)             $51   $252   $594    $70      $0
               Operating Cost ($K)      $34   $208   $621   $101      $0
               Capital Cost ($K)         $0     $0     $0    $20      $0


                                          Production Center
                                         1      2      3      4       5


               New Investment ($K)      $90     $0     $0     $0      $0


                                          Transactions by
                                          Production Center
                                         1      2      3      4       5


          Trans-          1              6      9      0      0       0
          actions         2              5      9     11     11      74
            by            3             39     66     66     37     132
          Product         4             10      0     15     15      24
          Type            5              0      0      0      0       0

****************************************************************************
```

Figure 1. Cost Analysis for Two Quarterly Periods of a Single Simulation Replication

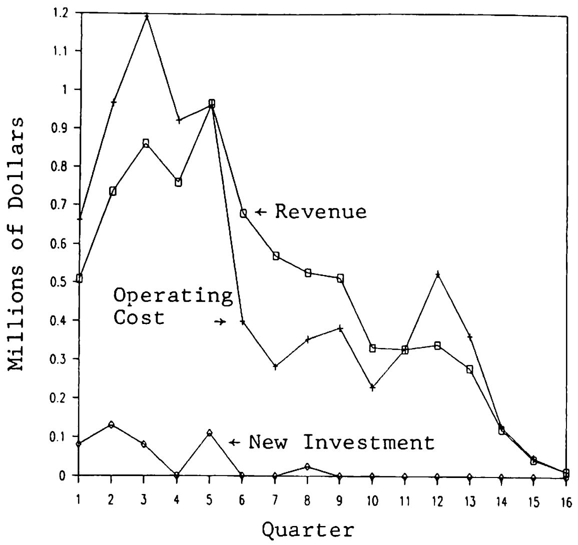

Figure 2. Plot of Quarterly Cash Flow for a Single Simulation Replication

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