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SIMULATION AND DECISION ANALYSIS IN FMS JUSTIFICATION

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Abstract

It is a concensus among practitioners that the problem of justifying a flexible manufacturing system is complex, difficult, and often paradoxical. In many instances, the FMS is designed for uncertain objectives. Some parts that the FMS is supposed to make may not be conceived/designed yet at the time the system is being evaluated. This paper presents a methodology which applies queueing theory, decision theory, and simulation to analyze the economic merit of an FMS application. At each decision point the decision-maker interacts with the simulation model by specifying alternative courses of actions to be evaluated. The capacity of the flexible manufacturing system may be augmented if projected demand exceeds current capacity. An after-tax analysis provides the decision-maker the performance measure for selecting the best alternative.

I. Introduction

Traditionally, the choice of automated manufacturing systems has been limited to stand-alone NC machines (job shop) and the automated transfer line.

The transfer line is part-dedicated. This forces the users to truncate engineering changes too early in a product's life cycle or pay substantial retooling costs to accomodate engineering changes. Moreover, while the transfer line is being updated, additional capacity must be obtained by farming out the work or by building up a large inventory. Consequently, the transfer has a high economic breakeven point and is not viable until high production, on the order of 10,000 parts per year, is reached. This is rather unfortunate. The job shop is frequently preferred in low to medium production, notwithstanding the fact that the relative cost per unit produced may run 100 to 1 in a job shop when compared to a transfer line [6].

1.1 Flexibility— the raison d'etre of the FMS

The phenomenal growth in computer technology has made automation in the mid-volume-mid-variety range economically feasible. The flexible manufacturing system (FMS) permits random access of machining centers and provides management information through the joint implementation of NC machines and an automated material handling system— all under computer control. Because of low set-up/changeover costs, the FMS is adaptable to a wider range of volume requirement and product variety than either the transfer line or the conventional job shop. The FMS can respond to growth/collapse in market demand and changes in design specifications by simply reprogramming the system software and minor expenses in refixturing, retooling, and start-up. For the mid-volume range, the manufacturing cost in a conventional job shop would be too high, and the transfer line would have many areas of obsolescence in just four to five years.

1.2 Matching Investment with Required Capacity

The FMS provides the users the options in dealing with the uncertainties of the market. The decision-maker may incrementally upgrade the production capacity of the FMS. Expansion in market demand for the FMS means adding modules to the system, matching investment with the required capacity over a period of time. Alternatively, a transfer line may be added to relieve the FMS of some loads. Typically, the spillover to the transfer line consists of parts where the design can be "frozen."

If the market for the intended parts collapses, the FMS can be reprogrammed for making new parts.

1.3 Traditional Justification Techniques are Inadequate

Traditional justification techniques minimize the net present value of all quantifiable inputs. The inputs may include equipment investment and disposal costs, raw material costs, equipment operating costs, direct and indirect labor costs, taxes, maintenance,. quality assurance and other overhead costs. However, manufacturing is not an isolated entity. Manufacturing methods do have considerable impact on other management variables, such as product quality reputation, ability to deliver in a competitive manner, and ability to cope with volume/mix uncertainties. The first users of FMS are typically adventuresome advocates with their corporate strategy aimed at technology leadership. The move to FMS application has been slower than might be expected. The primary factor that has caused reluctance of management to accept the change has been the failure of traditional justification techniques to provide a quantitative proof that proposed FMS will perform as advertised.

The raison d'etre of the FMS is its flexibility. A mechanism is needed that can prove to managers that FMS works, by highlighting the economic value of the robustness of the FMS. Simulation is such a mechanism. In this paper, a dynamic decision analysis approach to the justification of the FMS is developed and presented, embedding queueing theory with simulation.

II. The Decision Analysis Process

Decision analysis provides a rational methodology in decision making under risk and uncertainty. Typically, a decision analysis cycle consists of three phases. The first phase is the "deterministic phase," where the variables affecting the decision process are identified and the relationship among the variables defined.

The second phase is the "probabilistic phase," where probability measures are assigned to critical variables. This phase also introduces the concept of "risk preferences" of the decision-maker in selecting among mutually exclusive alternative courses of action. The third phase is the "information phase," which provides the decision-maker the required information for interacting with the decision analysis model.

2.1 The Deterministic Phase: Systems Synthesis

In the deterministic phase, the efforts devoted to modelling are distinguished from the efforts devoted to analysis. In modelling, the system variables are defined and selected. In analysis, the extent changes in the variables affect the worth (value) of each alternative is examined. This sensitivity analysis is highly effective in refining the formulation of the problem.

One unique feature of the approach presented here is the capability of the simulator to model interactively the time-phased system synthesis process. The decision to augment production capacity in anticipation of higher future demand is a dynamic process. The decision-maker may decide to add a machining center or an automatic guided vehicle system for the FMS alternative or add another transfer line to complement the current one. On the other hand, one may defer the investment decision to some future date by dropping or subcontracting one or more product lines from the production plan.

The deterministic phase determines the initial conditions for the analysis as well as for generating alternative FMS system configurations in the succeeding stages of the analysis. The FMS synthesis model constitutes this phase.

2.2 Decision Variables and Assumptions

The FMS synthesis model is an application of CAN-Q. CAN-Q is a recursive algorithm for solving a closed-form analytical model of production systems. The package is based on Jackson's queueing network [9, 10], which was extended in [3]. CAN-Q is described in [17, 18, 19]. The model is an interactive computer software providing an integrated approach to the part selection and machine requirements planning decision process. The decision variables include the number of hours of operation per year, the number of units for each machine type, the product families to be included in the production plan, and the material handling capacity.

The model assumes the following:
1. A list of FMS-compatible part families has been identified,
2. the corresponding process plan, machine types, machinability data, and cycle times are known,
3. the production requirements have been estimated, and
4. the investment costs of the machines of each type are known.

A logic flow chart of the model is shown in Figure 1.

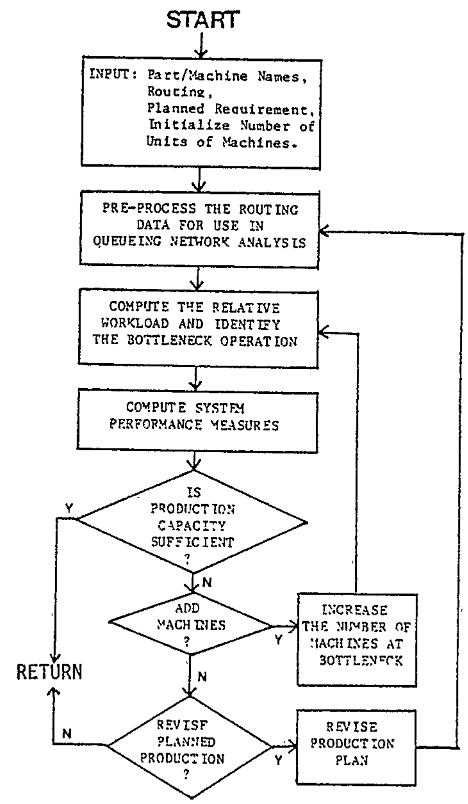

Figure 1: Logic Flow Chart For The System Synthesis Model

2.3 The Probabilistic Phase and the Information Phase

The probabilistic phase is also differentiated in terms of modelling and analysis. In the probabilistic modelling phase, probability distributions are assigned to the stochastic variables. The distribution of worth for each alternative course of action is calculated during the analysis phase. If stochastic dominance exists between a pair of alternatives, the stochastically dominated alternative is discarded. If stochastic dominance cannot be established, comparison of alternatives may be resolved based on the decision-maker's relative aversion to risk. The decision-maker's risk preference may be represented by a utility curve-like "risk profile" [5]. The decision-maker's ranking of alternatives can be based on the "expected utilities" of the alternatives.

The probabilistic phase and the information phase are interwoven to form a dynamic decision process. The entire decision process is dynamically partitioned into stages, each stage corresponding to a year in the planning horizon.

2.4 The Simulation Model

The decision analysis model allows the decision-maker to dynamically interact with a computer program for evaluating the cost effectiveness of the flexible manufacturing system, as well as deciding on a suitable configuration for the system. The following are

assumed to be random variables:
1. Product Demand and Part Mix
2. Product Routing/Engineering Design

The decision-maker is expected to have some prior knowledge of the probability density functions of these random variables. The method of subjective probability (see, for instance, reference [16]) is recommended in estimating the parameters of the random variables. Also, the decision-maker is expected to classify the different cost inputs into recurrent and non-recurrent costs, fixed costs versus variable costs. An excellent reference for the computation of these cost items can be found in [4].

For cash flow analysis purposes, the expenses are assumed to be "end-of-the-year" cash outflows, while all investments are assumed to occur at the beginning of the year. For after-tax computations, the depreciation allowances are computed using the straight-line method (although it is very easy to alter the computer program to accomodate other methods of depreciation). Manufacturing costs and depreciation allowances are tax-deductible and therefore represent reduction in cash outflows. For simplicity, the actual economic value of fixed assets are assumed to be equal to the book value.

A flow chart of the decision analysis model is shown in Figure 2. The computer program prompts the decision-maker for the input data which include: the planning horizon, the number of working hours per year, the corporate tax rate, the production plan and routing, the frequency and cost of engineering changes, and the initial system configuration (from Phase I).

The routing (which reflects product design/engineering) and actual production for each simulation run and the system performance for each configuration are evaluated using CAN-Q. Statistics for each year are summarized. At this point, the decision-maker is asked if there are system configurations not worthy of further evaluation (fathoming). For the following year, the machine requirements are computed based on projected production requirements and the decision-maker is asked to specify a new system configuration to be evaluated. The simulation procedure is repeated until the end of the planning horizon is reached.

The stochastic processes are modelled in Function RANDEM and Subroutine ROUTING. Function RANDEM(I) generates a sample value for the demand of product family I. Subroutine ROUTING models the uncertainty in product design/engineering by generating the routing and processing times for each product family. The routing process is modelled in the example in Section III by a Markov transition matrix, while the processing times and the actual production quantity are assumed to be uniformly distributed.

III. A Hypothetical Example

The viability of the flexible manufacturing system must be evaluated vis a vis the effectiveness of the conventional job shop as well as the transfer line. Because of the "dynamic programming" nature of the model, it is recommendable to evaluate the three alternatives separately to avoid the pitfall of the "curse of dimensionality." For illustration purposes, this section illustrates the decision analysis of the FMS alternative only. The same procedure applies for

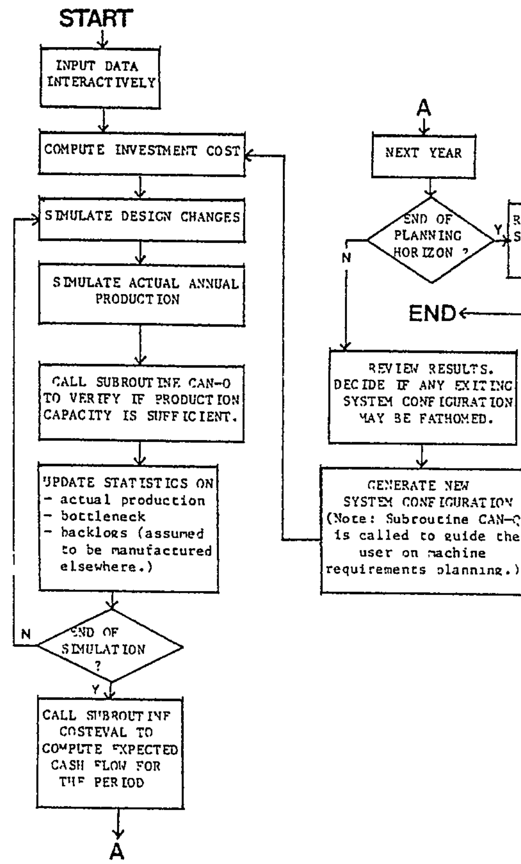

Figure 2: Logic Flow Chart For The Decision Analysis Model

evaluating the conventional job shop and other alternatives.

Consider a system with three machining operations—milling, drilling, and turning. Together with inspection and loading/unloading, the machining stations are integrated by the material handling system under computer control.

Three part families are processed in the system. The planned requirement and processing times are assumed to be uniformly distributed random variables, while the process routing is modelled as a random walk described by a Markov transition matrix. In practice, the probability density functions must be estimated either through historical data or the method of "subjective probability."

3.1 Phase I: System Configuration Analysis

Phase I is the "deterministic phase." The routing and the planned requirements are assumed to be known, and the computer program is executed to determine a set of initial system configurations for a given production requirement. First, the computer program prompts the decision-maker for the input data as shown in Table 1.

Notice that the decision-maker is asked to provide a "first guess" for the machine requirement. In the

```
ENTER THE NUMBER OF MACHINE TYPES.
5
ENTER THE NUMBER OF PRODUCT TYPES.
3
ENTER THE NAME OF THE MATERIAL HANDLING SYSTEM.
CARTS
ENTER THE NUMBER OF CARRIERS AVAILABLE.
1
ENTER THE INVESTMENT COST FOR THE MATL HANDL SYST.
400
ENTER THE AVERAGE TRANSPORTING TIME.
1.35
ENTER THE NAME OF MACHINE TYPE          1
MILLING
ENTER THE NUMBER OF UNITS OF THIS MACHINE TYPE.
1
ENTER THE INVESTMENT COST FOR ALL UNITS OF THIS TYPE.
800
        :
ENTER COST OF COMPUTER, AUX EQUIPT, ETC.
1000
ENTER THE NO. OF WORKING HOURS AVAILABLE PER YEAR.
1750
ENTER THE NAME OF PRODUCT TYPE
AAAA
ENTER THE NO. OF OPERATIONS REQUIRED.
9
        :
ENTER THE PRODUCTION REQUIREMENT
PRODUCT TYPE        1
4000
PRODUCT TYPE        2
4000
PRODUCT TYPE        3
4000
```

Table 1: Example of Interactive Data Input

absence of any a priori information, the decision-maker may specify the minimum of one machine per machine type.

The computer program then proceeds to compute the system performance measures using CAN-Q. The production capacity is compared with the planned requirement and the bottleneck operation is identified. Also, the investment requirement is updated. A typical response is shown in Table 2.

At this time, the decision-maker interacts with the computer by indicating whether he/she wishes to add one or more machines for the bottleneck operations or that the production plan is to be revised. This procedure is repeated until the desired production capacity is reached or when the investment requirement exceeds the budget constraint.

For illustration purposes, two system configurations were selected. The first configuration is based on the maximum expected production requirement in the 10-year planning horizon, while the second configuration is based on the expected production requirement for the first year.

3.2 Phase II: Interactive Simulation

Phase II is the stochastic phase. As in Phase I, the computer program prompts the decision-maker for all the input data required to run the program. For each year, the actual production requirement and routing are simulated for each run and Subroutine CAN-Q(0) is called to compute the system performance measures. An example of the performance evaluation report is shown in Table 3.

At the end of each year, the executive program calls Subroutine CAN-Q(1) to verify if the current system configuration is sufficient for the planned production of the following year. Information on which machine type to add, and the number of units to be added, is provided. A typical response is shown in Table 4.

The decision-maker interacts with the computer by introducing a new system configuration to the decision tree. Also, the decision-maker may fathom one or more existing configuration(s) if it is believed that further evaluation of these configurations is not necessary. Finally, a cash flow summary is provided for each year, as shown in Table 5. At the end of the planning horizon, an "optimal" path is traced. The same procedure should be followed in evaluating the conventional job shop alternative.

STATION	NUMBER OF SERVERS	VISIT FREQUENCY	AVERAGE PROCESSING TIME	RELATIVE WORKLOAD	WORKLOAD PER SERVER
1 MILLING	1	0.12821	31.90000	4.08974	4.08974
2 DRILLING	1	0.20513	14.60000	2.99487	2.99487
3 LATHE	1	0.10256	21.65000	2.22051	2.22051
4 INSPECT	1	0.20513	4.67875	0.95974	0.95974
5 LOADING	1	0.35897	9.35714	3.35897	3.35897
6 CARTS	1	0.07692	1.85000	1.85000	1.85000

```
NUMBER OF ITEMS IN SYSTEM =          4
MEAN NO. OF OPERATIONS TO COMPLETE AN ITEM=    13.00000


PRODUCTION RATE =   0.7471721   /HOUR OR    1307.551    /YEAR.
REQUIRED PRODUCTION =   12000.00    /YEAR.
THE BOTTLENECK MACHINE IS MILLING
AVERAGE FLOW TIME =    321.2112      MINUTES
SYSTEM UTILIZATION =    917.7462      PERCENT
SYSTEM COST IS =    3970.000


ENTER 1 TO REVISE PART SELECTION.
ENTER 2 TO ADD MACHINE(S).
OTHERWISE, ENTER 0
2


ENTER NO. OF ADDITIONAL UNITS OF MACHINE MILLING .
1
ENTER ADDITIONAL COST.
800
```

Table 2: Typical Response of the System Synthesis Model

```
CONFIGURATION  1 :
                                  CHANCE OF
MACH TYPE   NO. OF UNITS BOTTLENECK
 milling              2      0.27
 drilling             1      0.00
 turning              1      0.00
 inspect              1      0.00
 loading              1      0.73
 carts                1      0.00


FOR PART AAAA   ,   40. UNITS MUST BE PROCURED AT $   320.86
FOR PART BBBB   ,   35. UNITS MUST BE PROCURED AT $   298.16
FOR PART CCCC   ,   34. UNITS MUST BE PROCURED AT $   321.52
```

Table 3: Example of a Performance Evaluation Report

```
TO MEET PLANNED REQUIREMENT...
1 ADDITIONAL UNITS OF milling  ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO ADD.
1
WHAT IS THE COST OF EACH MACHINE ADDED ?
800
1 ADDITIONAL UNITS OF drilling ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO ADD.
1
WHAT IS THE COST OF EACH MACHINE ADDED ?
700
0 ADDITIONAL UNITS OF turning  ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO ADD.
0
0 ADDITIONAL UNITS OF inspect  ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO ADD.
0
1 ADDITIONAL UNITS OF loading  ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO ADD.
2
WHAT IS THE COST OF EACH MACHINE ADDED ?
20
0 ADDITIONAL UNITS OF carts    ARE REQUIRED.
INDICATE THE NUMBER OF UNITS YOU WISH TO   .
0


FATHOM ANY CONFIGURATION WHICH ARE NOT WORTHY OF FURTHER CONSIDERATION.

HOW MANY CONFIGURATIONS ARE TO BE    EVALUATED FURTHER ?
4
PLEASE LIST THE CONFIGURATION NUMBERSIN INCREASING ORDER.
ONE LINE FOR EACH CONFIGURATION.
1
2
4
6
```

Table 4: A Typical Response of the Decision Analysis Model

```
CONFIGURATION  3 :

CAPACITY OF THE FMS                 =    3502.568
NUMBER OF ENGG CHANGES              =           2
CASH FLOW ANALYSIS:
  VARIABLE    COST =    93.39083
  FIXED       COST =    100.0000
  PROCUREMENT COST =    2675.584
  ENGINEERING COST =    15.00000
TOTAL ANNUAL COST                   =    2883.975
LESS : TAX DEDUCTABLES
  FROM ANNUAL COST =    1297.789
  FROM DEPRECIATION=    256.9500
AFTER TAX ANNUAL COST               =    1329.236
PLUS : INVESTMENT THIS PERIOD       =    4440.000
TOTAL CASH FLOW FOR THIS PERIOD     =    5769.236

NET PV UP TO THIS PERIOD            =    13404.39
```

Table 5: Example of a Cash Flow Summary

3.3 Confidence Interval for Cost Estimation

The output from simulation is observed samples of random variables. Inferences on the performance of the system should consider the inherent variability of the simulation output.

In the preceding illustration, the conditional costs were estimated as single numbers commonly referred to as point estimates. As a result of chance variation, a point estimate will likely deviate from the unknown population parameter (costs) being estimated. To measure the accuracy of an estimate, the confidence interval provides a probability statement specifying the likelihood that the parameter being estimated falls within the prescribed bounds. Interval estimates, together with the test of hypotheses regarding the expected value of costs for each configuration, provide a better decision criteria for fathoming in the decision analysis process.

IV. Summary

A dynamic decision approach for the justification of a flexible manufacturing system is developed in this paper by imbedding queueing theory with simulation in a decision analysis framework. The methodology calls for the decision-maker to interact with the model based on the statistics generated at each state of analysis.

A two-phase procedure for the economic justification of the FMS is recommended. Phase I is an interactive model based on queueing theory for resolving the part selection and machine requirements planning problems. The system configurations generated in Phase I are evaluated in a decision analysis model which constitutes Phase II. At each decision point the decision-maker interacts with the simulation model by specifying alternative courses of actions to be evaluated. The interactions involve:

1. Fathoming one or more configuration(s) which is not worthy of further consideration, and
2. generating new system configurations based on knowledge about the current state (year) and projections for the subsequent stage (year).

The decision process is carried out dynamically. The capacity of the flexible manufacturing system may be augmented if the planned requirements projected for the following year exceed current capacity. An after-tax analysis provides the decision-maker the performance measure for selecting the best alternative.

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