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PREDICTING THE PERFORMANCE OF FLEXIBLE MANUFACTURING SYSTEM – A MULTIPLE REGRESSION APPROACH

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Abstract: *This paper attempts to establish quantitative relationship between output indicators like Total Flow time, Resource utilization, AGV utilization and input variables like part arrival rate, uniform processing times at Machining centers and AGVs and decision rules such as Large remaining capacity, small number busy, cyclical and random rules in a dynamic dedicated FMS. Dummy data are generated and the system is simulated to produce the output indicator for a given set of input variables and decision rules. The simulation results are employed to develop Multiple Regression equations for each output indicator. Dummy dependent variables are used in the Regression. The results indicate a significant relationship between the variables and the output indicators.*
Key words*: Simulation, FMS, production planning and control, Regression analysis, AGV's*

1.INTRODUCTION

Flexible technology as the ability to produce several models on a single assembly line. Over time, it has become an integral aspect of modern or lean manufacturing. Other aspects are team work, just-in-time inventory management, decentralization of decision making, emphasis on flow through the factory, zero-tolerance quality control, etc. Functionally, an FMS can be decomposed into several subsystems in a hierarchy (MacCarthy and Liu, 1993; Changchien, Lin, and Sun, 1995): a material processing subsystem, a material transport subsystem, and a material storage subsystem. An FMS also contains a database management system, because FMS control needs access to a large set of distributed process data (Ranky, 1983; Bedworth, Henderson, and Wolfe, 1991; Lin and Fang,

1993). A controller at each level of the control hierarchy receives commands from the higher level control, makes control decisions, and sends commands to lower-level controllers, which then report the execution status to the higher level (Williams, 1988; Bedworth, Henderson, and Wolfe, 1991). In a leader-follower strategy, a hierarchical control decomposes a large complex problem by using results of the higher-level problem (the leader) as input to the lower-level sub problem (the follower). This reduces the complexity of any control module in the hierarchy, regardless of the FMS structure.

1.1. FMS scheduling: An overview

In scheduling, some commonly accepted objectives are (Nahmias, 1993) to meet due dates, minimize work-in-process inventory, minimize the average flow time of orders through the flexible manufacturing system, and achieve high machine utilization and output performance measures like total flow time, AGV Utilization etc.,FMS performance in meeting these objectives strongly depends on the scheduling strategies used. Scheduling problems are known to be NP-hard and generally involve a large number of machines and part types. Due to the complexity of an FMS, searching for optimal schedules in dynamic systems, such as an FMS, may not be practical, since it is too time consuming to provide the necessary quick response to real-time production needs. Therefore, analytical approaches with closed form exact solutions can be exploited only under certain stringent assumptions (see, e.g., Ahluwalia and Ji, 1991; Wein, 1990). Scheduling is either static or dynamic. Static scheduling assumes that parts of different types arrive at the same time, and decisions are made when parts enter the system. A dynamic approach schedules part type orders as they arrive continuously. Since orders arrive continuously in an FMS, sometimes in small order quantities, scheduling should be considered a dynamic problem. Dynamic scheduling decisions can be made at the completion of each operation by giving high priority to groups based on certain rules (Ahluwalia and Ji, 1991; Nahmias, 1993).

Using scheduling heuristics and priority rules can effectively ease computational burden and simplify implementation in a dynamic environment, even though optimal solutions are not guaranteed (Chan and Bedworth, 1991; Liu and Lin, 1993). Dynamic scheduling in the AMRF at any level of the hierarchy has four steps: selection of candidate scheduling rules, simulation of the scheduling performance, statistical analysis of the simulation results, and compromise analysis of the results for determining the schedule. Control is applied by coordinating the operations based on production cost. The AMRF scheduler therefore is a hierarchical, single-dispatching-rule-driven, multipleobjective, stochastic system. After investigating the AMRF and other research in FMS control, Boulet, Chabbra, Harhalakis, Minis, and Porth (1991) concluded that classical control theory cannot be applied directly due to the difficulty of defining transfer functions explicitly. Therefore simulation, heuristics, and expert systems may be used for real-time scheduling. Several other applications of hierarchical and dynamic scheduling have been reported. Shanker and Tzen (1985) use a hierarchical-heuristic approach for FMS scheduling. Wein and Chevalier (1992) use a two-step approach to scheduling with three dynamic decisions: assigning due dates to arriving orders, releasing orders to the shop, and sequencing orders at the machines. Since scheduling at the lower levels of an FMS can search for solutions in only a constrained problem space determined by the higher level, solution quality can suffer from the given poor higher-level results; for example, machine loading is limited to the orders scheduled to the system. Therefore, the final solutions may not achieve the system's global goals. This motivated Moreno and Ding (1993) to improve Shanker and Tzens's work by developing a constructive heuristic.With less-restrained higher-level results, the lower level has more searching space, so it can hope to improve the global solution.

1.2. Scheduling with a single objective vs. multiple objectives (single rule vs. multiple objectives)

From the scheduling literature, it is known that simple heuristics benefit specific objectives. For instance, processing-time-based rules (e.g., shortest processing time, SPT) result in MULTIPLE-OBJECTIVE SCHEDULING 383 shorter flow time but suffer from increased job tardiness (Rochette and Sadowski, 1976). When multiple performance objectives are considered, no single rule consistently outperforms all other rules. Therefore, rules should be chosen according to the prevailing objectives in particular applications (Montazeri and Van Wassenhove, 1990; Kim, 1990). Ishii and Talavage (1994) use a mixed dispatching rule (MDR) in FMS scheduling by mixing four rules: next in, next out; SPT; largest slack first; and first in, first out. Using a search strategy that selects a scheduling rule by focusing on bottleneck machines, MDR outperforms any of the four single rules in mean flow time, mean tardiness, weighted mean flow time, weighted mean tardiness, and combinations of these. However, MDR does not work as efficiently for multiobjective scheduling as for single objectives. Since tardy jobs results in delay penalties, customer dissatisfaction, and increased rush shipping cost, Vepsalainen and Morton (1987) .

An effective FMS scheduling system should have the following capabilities:

1. Select orders for processing to achieve the system's global production goal.
2. Meet the multiple performance objectives of the system, including parts arrival rate, uniform processing times and machining centers and AGVs.
3. Be computationally efficient for real-time applications.
4. Offer flexibility to allow the user to make informed production control decisions and choose scheduling rules that suit particular applications (Montazeri andVanWassenhove, 1990; Grabot and Geneste, 1994).
5. Support flexible software implementation and easy modification to accommodate system changes (Larin, 1989; Lin, Wakabayashi, and Adiga, 1994).

It is therefore evident that no single rule or an arbitrary combination of rules gives satisfying solutions to the multiple objectives. Further, consistency in selecting the rules is not discussed. Also, a systematic study that aims at explaining the relationship between output performance indicators and the large number of input variables and decision rules is needed. In this paper an attempt is made to achieve the twin objectives of consistency and explanatory capacity of the decision variables through the use of a Multiple Regression model, the data for which has been generated through a simulation approach. In section 2, the FMS model considered is presented. The simulation model with ARENA is presented in section 3. The Regression model is presented in section 4. The Testing and results of the simulation model are presented in section 5. The conclusions are shown in section 6.

2. THE FMS MODEL

The proposed simulation modeling research is done based on how to build a reconfigurable simulation model to meet the customer requirements as well as improve system performances. A hypothetical FMS is considered in this paper. The model uses an automated guided vehicle (AGV) for transportation of parts/semi finished parts from one workstations to other. AGV's are capable of delivering parts at varying speeds and in desired order/rule, there are two AGVs of this kind. The assembly starts at one of two starting points. The first point is parts arrival and second is the pallets arrival. Parts are differentiated into two kinds A,B. Similarly pallets also as Pallet A, and Pallet B. Pallet station is one where parts are loading on their respective pallets. Machining centers 1 & 2 are fully automated. The final work station is an unloading station, where the products are unloaded and shipped.

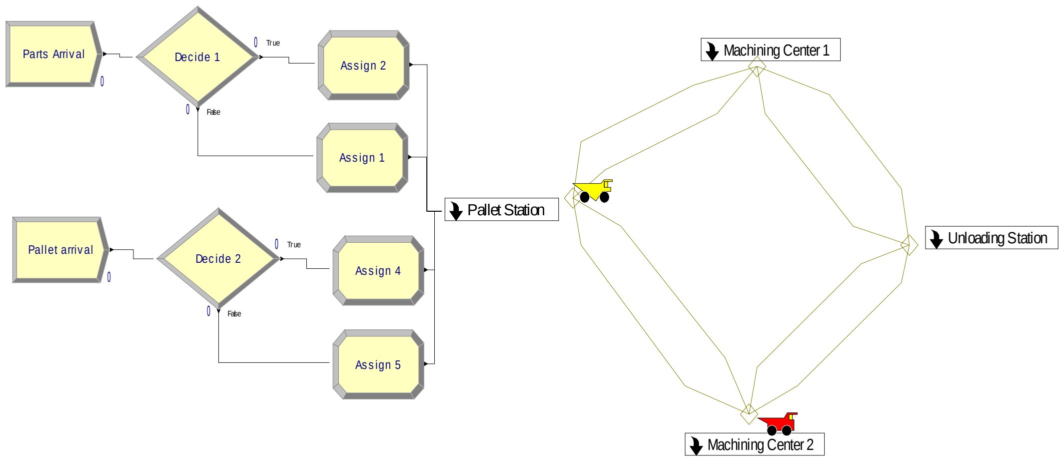

Fig. 1 : Arena Model for the flexible manufacturing system

The manufacturing line is fully automated. Also the system is equipped with automated guided vehicle that knows where the part came from, and what the destination of the part is. The AGV's are responsible for routing the part to the correct workstation.

The manufacturing line consists of two loops, each loop consists of two work staions (MC-1, MC-2). After completion, the line follows unloading station. Material handling is automated at the manufacturing line and sensors keep tract of each pallet and direct it accordingly. The manufacturing line flows well and was designed with a great deal of forethought and it is capable of meeting the current demand and has very nice features, such as flexibility and it is highly automated. However utilizing the resource and AGV upto the capacity is of importance. This can be achieved by the following arena model.

3. SIMULATION ENVIRONMENT

Arena Model:

Arena provides an intuitive, flowchart-style environment for building an as-is model of the FMS operations process. Arena model created in this paper consists of two Create, one pallet Station, four Processes in two Machining centers and one unloading station flowchart modules.

The two Create modules are called 'Parts Arrival' and 'Pallets Arrival'. The two machining centers consists of two processes of each machining center, 'AGV' and 'Unloading station'. The Dispose module is called 'Parts ready for shipment'. Different pictures from the media library are used to represent each flowchart module. All the dynamic processes are defined with set values and conditions by double clicking on the basic processes blocks and validating the appropriate fields. Arena keeps internal lists of different kinds of names. It presents existing lists to you where appropriate. It helps you remember names and protects you from typos. All the names you made up in a model must be unique across the model, even across different types of modules.

In Arena all the dynamic processes have 'nodes' through which the entities flow. All the nodes are typically connected and finally the entity terminates in the Dispose module. The dynamic processes are connected using the 'connect' button on the standard tool bar.

The create block in Arena is used to generate the entities. This model uses two create blocks to generate the two different types of parts. The first create block generates entity which represents a Parts arrival order. The name of the entity can be defined in the 'Entity Type' text field. In this case the entity is called 'Parts arrival'. The second create block generates the Pallets arrival. The entities are recognized by the same attribute or name until they are disposed in the dispose box. In this model two different entities are flowing through the model and Arena distinguishes the two types of entities viz. Parts arrival order and Pallets arrival order by their name. The create block can be defined in the 'Name' text-field. The name of the create block and the name of the entity that it creates are not correlated. The time between arrivals, in other words the creation of new entity, is governed by any one of the four formulae in the 'type' section of create block. The four formulae are random, schedule, constant and expression. The 'random' option generates the entity randomly and does not follow any type of distribution. For this option the input data modeling is not required to determine the type of distribution followed by the data. The simulation of this type of input involves high degree of randomness. In the 'schedule' and 'constant' option the randomness is relatively less and the user defines the input pattern. The 'schedule' option requires the user to specify the arrival patterns for length of time. The 'constant' option creates entities periodically with fixed time interval between two creations. For the 'expression' option Arena provides quite a few distributions. The various types of expressions available to randomly create an entity are Exponential, Normal, Triangular, Uniform, Erlang, Beta, Gamma, Johnson, Constant, Lognormal, Weibull and Poisson. The 'expression' option is most common in the practical simulation studies in the industrial environment. The type of 'expression' to be chosen depends on the input modeling. After running the data through the Arena Input Analyzer the type of distribution is determined. This distribution is selected for the 'expression'. In this model after the input analysis the Input Analyzer defined the data to follow exponential distribution. Hence the create block in the model uses the exponential distribution. The units for time between arrivals are selected as minutes. The other parameters that need to be specified in the create block are 'entities per arrival', 'maximum arrival' and 'first creation'. First creation is the time when first entity will be created. Entities per arrival field is used to specify the number of entities created at a time. The maximum arrival is the total number of entities created during the period of simulation. The 'replication length' on replication parameters dialog and the 'maximum arrival' decide the length of the simulation. The simulation stops as soon as the replication length, in other words the maximum time for one simulation cycle, is reached or maximum number of entities are created.

Parts arrival create module, describes how parts arrive into the system. Entity type is parts. The expression is used for the time between arrivals, with a mean of 5 units, Entities per arrival are 1 and max. number of arrivals is infinite. In the decide module with 2 way by chance is created and percent true is 50%. Parts coming 50 % are considered as Part A and other 50% are of Part B. Attributing the parts entering this as Part A and time in is taken. Assign the attributed parts entering this as part B and time in is taken for Part B. Similarly Pallets will arrive from create 2. Time between arrivals are constant and its value is 1 hour, entities per arrival are 8 and max arrivals 1.These pallets are differentiate into two kinds Pallet A and Pallet B, two way by chance, with true percent as 50%.

In the Pallet station first we differentiate the parts and pallets by decide module. The respective pallet A or B are hold until parts A or B arrives after that respective parts will be held by respective pallet. For this we use queues to hold pallets. After that each pallet with respective part are transported to processing in the machining center. The request module has to be used for transport, here we uses smallest distance as decision rule and the transporter we used is AGV for moving parts from pallet station to machining center.

AGV Movement:

The parts from pallet station are moved to machining centers by using AGV's. The transporter network is follows one transporter from pallet station and other from unloading station. The parts are first taken to Machining center 1 by one transporter and after that other transporter will send second group of parts to machining center 2. After completion of the process, it will take parts that are finished in machining center 1 to machining center 2 and vice versa. After completion they will unload it in unloading station for disposal.

Machining Centers:

Machining Center 1:

Here parts will be processed. Here we have one resource in all. For parts A and for parts B we have two different process 1 and process 2. Parts are first differentiated by decide module. After process is completed, as a batch two parts are allowed to be transported for further processing. Again request for transport is placed and AGV is used.

Machining Center 2:

Here also same parts are distinguished and are sent for respective process 3 and Process 4. Parts are differentiated by decide module as a batch two parts are allowed to be transported for unloading station through AGV.

Unloading Station:

Here all the parts are disposed off. We have pallets they are sent to pallet station. Parts A and B are shipped.

4.1.THE REGRESSION MODEL

Dummy variables model have a consumption function which has different intercepts, but a common slope, in AGV Request and Resource set 1 decision rules The specification for the unrestricted model is given in the equation 1.1

$$\begin{bmatrix} y_1 \\ y_2 \end{bmatrix} = \begin{bmatrix} i_1 & 0 & x_1 \\ 0 & i_2 & x_2 \end{bmatrix} \begin{bmatrix} \alpha_1 \\ \alpha_2 \\ \beta \end{bmatrix} + u \qquad (1.1.)$$

Where the subscript 1 refers to AGVRequest and the subscript 2 to Resource set 1 . This model may be written as

$$Y_t = \alpha_1 D_{1t} + \alpha_2 D_{2t} + \beta X_t + u_t$$

t = 1,2,3, . . .n (1.2)

D_{1t} and D_{2t} are dummy variables whose sample values are given in the first
two columns of the data matrix in Eq.(1.1).That is,

$D_{1t} = \begin{cases} 1 \\ 0 \end{cases}$ if t indicates a AGV Request decision rule

if t indicates a Resource set 1 decision rule
and

$D_{2t} = \begin{cases} 0 \\ 1 \end{cases}$ if t indicates a AGV Request decision rule

if t indicates a Resource set 1 decision rule

4.2.Two or More Sets of Dummy Variables used in our fms model

Suppose we wish to incorporate two qualitative variable in a regression equation, each such variable being represented by a set of dummy variables. To be specific suppose the variables are AGV Request (4 classes) and Resource Set 1 (4 classes). We then define

$E_i = \{$ 1 if observation relates to AGV Request i ,

0 otherwise

and

$S_j = \{$ 1 if observation relates to Resource Set 1 j,

0 otherwise

1

i = 1,2,3,4 j = 1,2,3,4

If we now specify Y as a function of both AGV Request and Resource Set 1, we might be tempted to write

$$Y= \alpha_1 E_1 + \alpha_2 E_2 + \alpha_3 E_3 + \alpha_4 E_4 + ß_1 S_1 + ß_2 S_2 + ß_3 S_3 + ß_4 S_4 + u \quad (1.4)$$

Thus there is an expected value of Y for each combination of AGV

Request and Resource Set1

4.3TESTING AND RESULTS

To collect the statistics on Resource utilization, AGV utilization, Total flow time and to determine the relationship between the decision rules of AGV selection and Resource set 1 and to obtain a Multiple Regression Equation. Parts arrivals into the system is exponential distribution with a mean of 5 units, and conduct the experiment with the four decision rules such as cyclical, random, smallest distance and largest distance rules used for Transport Request with AGV's. The Resource set 1 has the four decision rules such as cyclical, random, small number busy, largest remaining capacity were given the performance measures of AGV utilization , total flow time, and resource utilization. In this paper the simulation results was investigated to find the regression equations between decision rules of AGV and Resource set s. Based on the input data the output result of the AGV utilization has been mention the following table.1

Table.1 Data generation for AGV Utilization Regression model

	AGV UTILIZATION Y	E_1/S_1	E_2	E_3	E_4	S_2	S_3	S_4
1	78.02	1	0	0	0	0	0	0
2	83.07	1	0	0	0	0	0	0
3	90.40	1	0	0	0	0	0	0
4	89.00	1	1	0	0	0	0	0
5	94.85	1	1	0	0	0	0	0
:		:	:	: : : :	: : : :	: : : :	: : : :	: : : :
46	93.12	1	0	0	1	0	0	1
47	94.85	1	0	0	1	0	0	1
48	93.36	1	0	0	1	0	0	1

AGV Request Decision Rule Resource Set 1 Decision Rule

E_1 = Cyclical S_1= Cyclical

E_2 = Random S_2= Random

E_3 = Smallest Distance S_3= Small number busy

E_4 = Largest Distance S_4=LargeRemainingcapacity

The estimated Regression equation for the AGV Utilization is

(AGV Utilization) $Y = 84.831 + (0) E_2 + 8.43 E_3 + 8.07 E_4 + 7.529 S_2 + 1.98 S_3 + 0.41 S_4 + 0.555$

Similarly, Total flow time, Resource utilization measures Regression equations
(Total Flow time) $Y = 5.62 + (0) E_2 + 10.26 E_3 + 6.54 E_4 + 6.02 S_2 + 2.38 S_3 – 0.00015 S_4 - 0.002$

(Resource Utilization) $Y = 32.77 + (0) E_2 + 14.1 E_3 + 19.33 E_4 + 19.34 S_2 + 3.75 S_3 + 0.16 S_4 - 0.166$

4.3.1 VERIFICATION

Verification is the process of insuring that the ARENA model behaves in the way it was intended according to the modeling assumptions made. Verification deals with both obvious problems as well as the not so obvious. Verification is fairly very easy for developing small class room size problems. When we start developing the problem, more realistically sized models, we will find it is a much more difficult process and never been cent percent sure on very large models. One easy verification method is to allow only a single entity to enter the system and follow that entity to be sure that the model logic and data are correct. If this model is used to make the real decisions and also check to see how the model behaves under extreme conditions. For example introduce only one part type or increase or decrease the part inter arrival times and in different replication lengths and choose the best one which fits to the current conditions.

4. CONCLUSIONS

The aim of this paper is to find the regression model of decision rules for AGV's and Resource Set1. Each decision rule in selection rule of AGV is selected and the decision rule in Resource Set1 is changed to get various values for AGV Utilization, total flow time, and resource utilization. The system is set to run for 480 units, like wise for three replications i.e. for three times. Each time we observe the values for output parameters we considered. Dummy data are generated and the system is simulated to produce the output indicator for a given set of input variables and decision rules. The simulation results are employed to develop Multiple Regression equations for each output indicator. Dummy dependent variables are used in the Regression. The statistical results indicate a significant relationship between the variables and the output indicators.

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