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# Development of Multivariate Quality Control Charts on Theoretical Flexible Manufacturing System Simulation

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***Abstract:*— This paper attempts to the problem of predicting and controlling the performance of Flexible Manufacturing System (FMS). The FMS operations comprising of Pallet station, Machining Centers and Unloading station with an Automated Guided Vehicle (AGV) system are simulated under a dynamic environment. The dynamism in the system is created by assuming stochastic arrival rate for parts, uniform processing times at machining centers, AGVs for handling materials. This environment is simulated using ARENA 10.0. The results of a hypothetical FMS simulation are utilized as inputs and output parameters such as AGV utilization and Resource utilization and multivariate analysis were conducted and establishing the control limits for performance measures. The results indicate a significant relationship between the global decision rules and the output indicators.**

***Keywords:*-- Arena 10.0, Automated Guided Vehicle (AGV), Flexible Manufacturing System (FMS), Multiple Regression Model, Multivariate Quality Control.**

## I. INTRODUCTION

A flexible manufacturing system (FMS), through a careful combination of computer control, communications, manufacturing processes and related equipment, enables a section of the production-oriented aspects of an organization to respond rapidly and economically, in an integrated manner, to significant changes in its operating environment. Such systems typically comprise: process equipment, material handling equipment, a communications system and a sophisticated computer control system. Some of the advantages of FMS include: improved capital/equipment utilization, reduced work-in-progress and set up, substantially reduced throughput times/lead times, reduced inventory and smaller batches, and reduced manpower. The high investment cost of FMS justifies the use of computer simulation support. For example, in the operation phase of the installed manufacturing system, it is required to maintain high system performance by predicting the system behavior under any feasible production schedule which can meet the daily production requirements and by selecting the most effective production schedule among the alternatives prior to its implementation. These considerations may dictate the use of computer simulation techniques during the design and operation phases of FMS. In this thesis, an attempt is made to look at the operational problems of FMS through simulation. 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 subproblem (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 the 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 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. 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 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 Rules)*

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 result 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 a 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 Multivariate control problem is presented in section 4. The Testing and results of the multivariate quality control charts are presented in section 4.1. The conclusions are shown in section 5.

## II. THE FMS MODEL

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 workstation to other. AGV's are capable of delivering parts at varying speeds and in desired order/rule; there are two AGVs

 

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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 and B. Similarly pallets are 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.

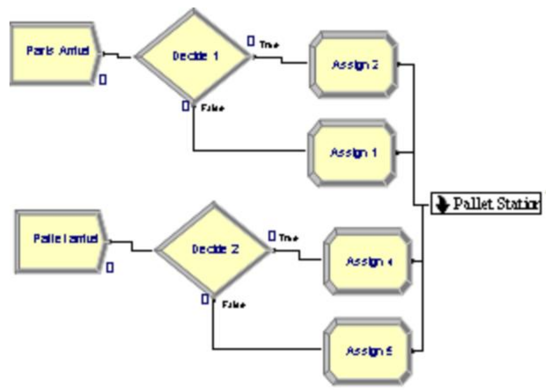


**Fig. 1**

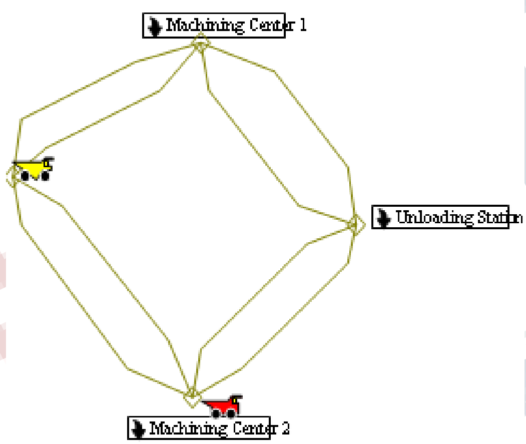


**Fig. 1 : Arena Model for the flexible manufacturing system**

The final workstation is an unloading station, where the products are unloaded and shipped. 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 workstations (Machining Center-1 and Machining Center-2). After completion, the line follows unloading station.

Material handling is automated at the manufacturing line and sensors keep track 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 features, such as flexibility of machines and it is highly automated. However utilizing the resource set 1 and AGV up to the capacity is of importance.

***Simulation Model With Arena***

Arena provides an intuitive, flowchart-style environment for building an as-is model of the FMS operations process. Arena model in the fig.1 was created in this paper. The Parts arrival will generate into the system based on an Exponential distribution with a mean of 5 units. As soon as the parts are received at loading station, they are loaded into a no. of pallets and thereafter dispatched for processing. The part along with the pallet is stored in the empty buffer space of the concerned machine otherwise returned back to the loading/unloading station. Two varieties of parts have been considered in this work, Part A and Part B. Part A requires two operations in process 1 and process 3, based on an exponential distribution with a mean of 30 units. In this example, the Process 1 Operators set contains three resources, R1, R2, and R3. These members may be contained an efficiencies of 0.9, 0.85 and 0.75. The decision rules for selecting among the available set members are specified within the Process module. Part B requires another two operations in process 2 and process 4 based on an exponential distribution with a mean of 30 units of single resource in each. The AGV request module has to be used for transport, here we uses different types of decision rules. Parts are differentiated by decide module as a batch two parts are allowed to be transported for unloading station through AGV. Finally in the Unloading Station all the parts are disposed-off. We have pallets they are sent to pallet station. Parts A and B are shipped.

***Multivariate Quality Control***

Typically process monitoring applies to systems or processes in which only one variable is measured and tested. One of the disadvantages of a univariate monitoring scheme is that for a single process, many variables may be monitored and even controlled. Multivariate quality control (MQC) methods overcome this disadvantage by monitoring several variables simultaneously. Using multivariate quality control methods, engineers and manufacturers who monitor complex processes may monitor the stability of their process. A quick way to see the advantages of MQC is to superimpose univariate control charts on top of each other and create a graph of all the points of each control chart in an area of space. This is shown in the following Fig. 4.1. This Fig. shows a scatter plot of multivariate data composed of two variables, p=2. The individual control limits for each variable's respective univariate chart are shown in the control

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rectangle. This particular pattern shows that the process is in-control for each individual variable since the data points fall within the control rectangle [Mastrangelo et al., 1996; Tracy et al., 1992]. However, when the variables are correlated (and they often are when from the same process), superimposing univariate charts is not a very accurate method of monitoring processes because relationships between the variables are not capitalized upon and the probability of both charts simultaneously plotting in control is not 1-a . If a process is in-control, the probability of p means plotting in control is $(1 - a)^p$. Thus, the joint probability of a type I error is much larger: $(1 - a)^p$ [Alt, 1982; Alt, 1984; Jackson, 1985]

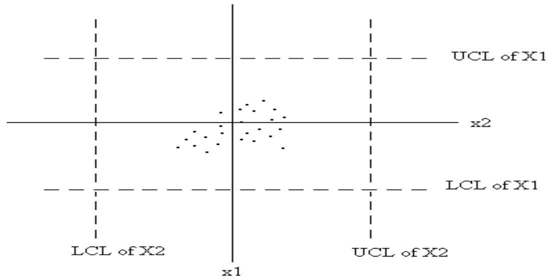


***Fig. 4.1: A scatter plot of multivariate data composed of two variables, p=2***

### *4.1. Testing And Results*

To collect the statistics on the data is generated for 10 samples with 5 observations for the hypothetical FMS model. After simulation runs, the output performance measures such as AGV utilization, Resource utilization, Total flow time, Parts throughput, and System number out are considered for which the control limits and X-bar and R charts are obtained for optimal decision rules for individual output indicators. Similarly, the data is generated for the above model with global optimal decision rules of AGV transporter and Resource set. After simulation runs the output performance measures such as AGV utilization, Resource utilization, Total flow time, Parts throughput, and System number out are considered for which the control limits and X-bar and R chart are obtained for Global optimal decision variable rules for the five output performance measure.

Table 4.1 & 4.2 shows for the AGV Utilization output performance measure for individual and global optimal decision variables. There are many situations in which the simultaneous monitoring or control of two or more related quality characteristics if necessary. In our FMS model two output performance measures of different variables, one is independent and other is dependent together determine the usefulness of the parts. Suppose the first parameter represents the AGV Utilization and the second parameter represents the Resource utilization. Monitoring these two quality characteristics independently can be very misleading.

***Table: 4.1 Data generation for Optimal Decision Variable Values for AGV Utilization***
***AGV Request Decision Rule: Random***
***Resource set 1 Decision Rule: Cyclical***

| | Observations | | | | |
|---|---|---|---|---|---|
| AGV Utilization | Replication 1 | Replication 2 | Replication 3 | Replication 4 | Replication 5 |
| Sample 1 | 0.82 | 0.95 | 0.96 | 0.465 | 0.762 |
| Sample 2 | 0.844 | 0.984 | 0.49 | 0.915 | 0.926 |
| Sample 3 | 0.952 | 0.958 | 0.86 | 0.99 | 0.96 |
| Sample 4 | 0.982 | 0.958 | 0.934 | 0.9 | 0.943 |
| Sample 5 | 0.586 | 0.965 | 0.92 | 0.97 | 0.93 |
| Sample 6 | 0.985 | 0.844 | 0.85 | 0.778 | 0.939 |
| Sample 7 | 0.989 | 0.918 | 0.919 | 0.579 | 0.721 |
| Sample 8 | 0.963 | 0.742 | 0.92 | 0.934 | 0.935 |
| Sample 9 | 0.948 | 0.531 | 0.982 | 0.941 | 0.561 |
| Sample 10 | 0.91 | 0.958 | 0.964 | 0.952 | 0.948 |

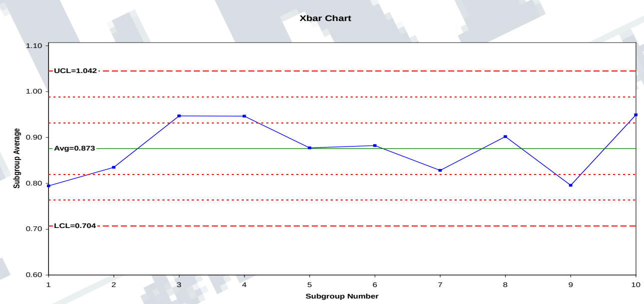


***Fig. 4.1.1: X bar chart for optimal decision variable***

***Table: 4.2 Data generation for Global Optimal Values for AGV Utilization***
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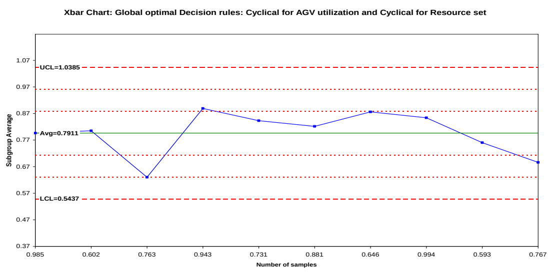


*Fig. 4.1.2: X bar chart for Global optimal decision variable*

### *4.2. Verification*

Verification is the process of ensuring 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 classroom 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 the current conditions.

## III. CONCLUSIONS

The aim of this paper is to find the multivariate quality control problem of decision rules for AGV's and Resource Set1. From the above X-bar and R chart, the AGV utilization is under control. The necessary mean, LCL and UCL are represented. Similarly for the other output performance parameters, such as Resource utilization, Total flow time, Parts throughput, and system number out were drawn the control charts. Multivariate control charts work well when the number of process variables is not too large say, 10 or fewer. As the number of variables grows, however, traditional multivariate control charts lose efficiency with regard to shift detection.

From the fig.4.1 that one observation appears somewhat unusual with respect to others. That point would be inside the control limits on both of the univariate X-bar chart for two output indicators(AGV and Resource utilization) when we examine the two variables simultaneously the unusual behavior of the point is fairly obvious. The process monitoring procedure increases as the number of quality characteristics increases. Process monitoring problems in which several related variables are of interest are sometimes called Multivariate quality control problems.

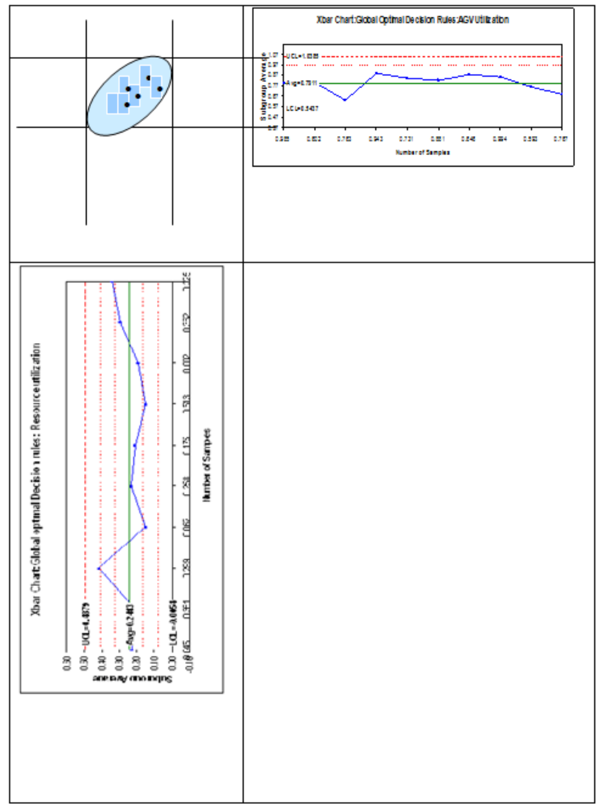

*Fig. 5.1: Control region using independent control limit for AGV and Resource utilization*

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