CHAPTER 6

6.0 DYNAMIC SCHEDULING AND COMPUTER SIMULATION OF MANUFACTURING SYSTEMS

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6.1 INTRODUCTION

The capacity planning of any manufacturing system depends on the effective scheduling of components to be processed. A scheduling system is dynamic when it accommodates addition of new components permitting alterations in schedules based on priorities. The processing time for these components can either be deterministic or stochastic. The model developed for dynamic scheduling has been based on the latter case due to the random nature of processing. This analytical approach for scheduling has been based on queuing theory that provided the expected steady state conditions for certain kind of situations and time distributions. Initially the studies were made for job shop manufacturing systems and subsequently extended to other systems like FMS and FMC. Dynamic scheduling helps to use the resources more effectively with schedule changes for machine breakdown, tool breakage etc.,

6.2 REVIEW OF SCHEDULING RULES

The work done by the researchers in evaluating scheduling rules for different performance levels in different environment is briefly reviewed and presented in the Chapter 2. The available data in the Literature are not adequate due to investigators failing to present the environment of the experiments. The effects of scheduling rules depend not only on the priority/criterion chosen but also on the configuration of the production system and its variables. The problem of dynamic scheduling compels one to try combined scheduling rules due to changing priorities and criteria. The illustrations given in chapter-2, (pages 10, 12) clearly show that the final choice of the combination of scheduling rules must be based on a detailed simulation study of the manufacturing system under dynamic conditions.
6.3 SCHEDULING RULES FOR ANALYSIS

A scheduling rule is used to select the next component to be processed from a set of components waiting in the queue for machining. This rule can also be used to introduce components into the system, route the components in the system and assign the components to machines. Scheduling rules can be either static or dynamic and these rules can be very simple or extremely complex and these are classified according to their attributes. Many scholars had come up with several scheduling rules, some of them are well known from classical job shop scheduling and the other rules are recently suggested by researchers who studied specific manufacturing systems. The following list of scheduling rules (the rules marked by an asterisk are static, the others are dynamic) with their descriptions and abbreviations are used for this analysis.

1) SIO (Shortest Imminent Operation)- Select the component with the shortest imminent operation from the queue, that is,

\[ \text{Select minimum } Z_i(t) \text{ Where } Z_i(t) = P_{ij}(t) \]

2) LIO (Longest Imminent Operation)- Select the component with the longest imminent time from the Queue, that is,

\[ \text{Select maximum } Z_i(t) \text{ Where } Z_i(t) = P_{ij}(t) \]

3) SPT *(Shortest Processing Time)- Select the component with the shortest processing time (Select the component which has minimum of sum of all operation time), that is,

\[ \text{Select minimum } Z_i(t) \text{ Where } Z_i(t) = TP_i \]
4) LPT*(Longest Processing Time)- Select the component with the longest processing time, that is,

Select maximum $Z_i(t)$ Where $Z_i(t) = TP_i$

5) LRO(Least Remaining Operation)- Select the component with the least remaining operation, that is,

Select minimum $Z_i(t)$ Where $Z_i(t) = RO_i(t)$

6) HRO(Highest Remaining Operation)- Select the component with the highest remaining operation, that is,

Select maximum $Z_i(t)$ Where $Z_i(t) = RO_i$

7) FIFO(First In First Out)- Select the first component in the queue, that is,

Select minimum $Z_i(t)$ Where $Z_i(t) = R_{ij}$

8) Highest Response-Ratio-Next (HRN) Scheduling: In this scheduling the priority of each component is a function not only of the components service time but also of the amount of component has been waiting for service. Dynamic priorities in HRN are calculated according to the formula

$$\text{Priority} = \frac{(\text{time waiting} + \text{service time})}{\text{service time}}$$

(time waiting + service time) is the system response time to the component if the components are to be initiated immediately.

Some more scheduling rules pertaining to slack and other combination exists. In this thesis, rules referred to above are only incorporated so that the test can be performed using these different scheduling rules to determine their effectiveness for various system performance criteria.
6.4 USE OF COMPUTER SIMULATION

In \( n \) component, \( m \) stage manufacturing shop floor problem, the possible number of sequences are \( (n!)^m \)

Eg.

\( n = 4, \text{ and } m = 4, \)

The total number of sequences = \( (4!)^4 \)

\[ = 3,31,776 \]

So it is not possible to find the optimal sequence from these manually. So the use of computer is a must in selecting the optimal sequence from the available sequence.

6.5 DESIGN OF SIMULATION EXPERIMENT FOR SCHEDULING

6.5.1 Specification of Simulation Model

The various designs or alternatives to be simulated are as follows:

Case (i) : The System is simulated treating all components as normal, for scheduling rules viz., SIO (Shortest Imminent Operation), LIO (Longest Imminent Operation), SPT* (Shortest Processing Time), LPT* (Longest Processing Time), LRO (Least Remaining Operation), HRO (Highest Remaining Operation) and FIFO (First In First Out).

Case (ii) : When hot (urgent) components are taken into account, the system is simulated separately by giving to them non-preemptive priority and pre-emptive resumed priority to the scheduling rules.
6.5.2 Specification of the length of the run

Usually the random variable is drawn from an infinite population that has a stationary probability distribution with a finite \( \mu \) and finite variance \( \sigma^2 \). This means that population distribution is not affected by the number of samples already made, nor does it change with time. If, further the values of one sample is not affected in any way by the value of any other samples, the random variables are independent. Random variables that meet all these conditions are said to be independently and identically distributed (i.i.d). Under broad conditions that can be expected to be held for simulation data, the central limit theorem can be applied to i.i.d. data. The theorem states that the sum of \( n \) i.i.d. variables, drawn from a population that has a mean \( \mu \) and a variance of \( \sigma^2 \), is approximately distributed as a normal variable with a mean of \( n\mu \) and a variance of \( n\sigma^2 \).

Any normal distribution can be transformed into standard normal distribution, that has a mean "0" and a variance '1'. Let \( x_i, (i = 1, 2, \ldots \ldots n) \) be the i.i.d random variables. Using the central limit theorem, and applying the transformation, gives the following (approximate) normal variate:

\[
Z = \frac{\sum_{i=1}^{n} x_i - \mu}{\sqrt{n} \sigma}
\]

Dividing top and bottom of this fraction by \( n \), and defining

\[
x = \frac{1}{n} \sum_{i=1}^{n} x_i, \quad Z = \frac{x - \mu}{\sigma / \sqrt{n}}
\]
The variable $x$ is the sample mean. Since the sample mean is the sum of random variables, it is itself a random variable. As a result, a confidence interval about its computed value, needs to be established. Generally while estimating required sample sizes, it is assumed that the samples are independent and uncorrelated. For many simulation models this is a poor assumption. The term autocorrelated indicates those situations where a future value of the output will be directly influenced by the present value. Blocking or batching method is used very commonly to handle correlated data. It can be described as follows:

After truncating the initial part (unsteady portion) of the run (to remove initial bias), the single run is divided into a number of segments to separate the measurements into batches of equal size i.e., a run consisting of $T$ observations are broken into $N$ batches of size $K$. In effect, the experiment is equivalent to repeating an experiment of length $K$ a total of $N$ times, such that the final state of one run becomes the initial state of the next. Fishman's procedure is used to determine whether these samples are independent batches.

Let $X_j$ denote the mean of the $j^{th}$ replication after reaching equilibrium and $N$ the number of replications, then the grand mean is

$$X = \frac{\sum_{j=1}^{N} X_j}{N}$$

Furthermore, if the $X_j$'s are assumed to be independent and normally distributed, then the test statistic

$$C = 1 - \frac{1}{N} \left[ \sum (x_j - \bar{x})^2 \right] / \left[ \sum \frac{(x_j - x)^2}{2} \right]$$

Submitted By: V. SELLADURAI
Guide: Dr. P. Aravindan, Prof. of Mech. Engg., PSG Tech.
is approximately normally distributed with mean $\mu$ and a variance equal to $\frac{(N-2)}{(N^2 - 1)}$

Now a two-sided hypothesis test is defined,

$$H_0 : \text{Independent batches}$$

$$H_1 : \text{Correlated batches}$$

$H_0$ is rejected in favour of $H_1$, if the absolute value of

$$Z_0 = C \sqrt{\frac{(N-2)}{(N^2 - 1)}}$$

is greater than

$$Z_{\text{varian}, Z_c}$$

$$Z_c = 1.642 \text{ at } 90\% \text{ confidence level.}$$

This method has the advantage of the repetition method (Where experiment is repeated with independent random number series for same sample size) without the necessity of eliminating the initial bias on each repetition.

6.5.3 Specification of the number of independent simulation runs

In the case where there are $N$ replications with system variable $x$ observed on each replication, then

$$X = \frac{1}{N} \sum_{i=1}^{N} X_i$$

is a point estimate of the parameter (mean $x$).
Method 1: If it has been decided in advance that \( N \) replications are to be made and \( N \) is large, and at \( (1-\alpha) \) confidence level, the confidence interval on mean \( x \) is

\[
\hat{x} \pm K_{\alpha/2} \frac{S_x}{\sqrt{N}}
\]

where \( S_x = \frac{\sum (x_i - \bar{x})^2}{N-1} \) and \( K_{\alpha/2} \) is read from a table of normal distribution. The size of the confidence interval depends upon the confidence level chosen. Typically, the confidence interval depends upon the confidence level chosen. Typically, the confidence level might be 90% in which case \( k_{n/2} \) is 1.642. The statement then says that \( \bar{x} \) will be covered by the confidence interval \( (\bar{x} \pm (1.642 S_x / \sqrt{N})) \) with probability 0.9: meaning that, if the experiment is repeated many times, the confidence interval can be expected to cover the value of \( x \) on 90% of the repetition.

Method 2: On the other hand, if a desired confidence interval length is specified as length \( \delta \) and sampling is to be continued in a sequential manner until a \( (1-\alpha) \) confidence statement may be made, a good stopping rule is when

\[
\sum_{j=1}^{N-1} y_i \leq (i^2 / 4 k_{n/2}^2) (n - 2.676 - 1 / 2 k_{n/2}^2)
\]

where

\[
y_i = l / i (i \pm 1) (i x_{i+1} - \sum_j X_j)^2
\]

\[
\sum_{j=1}^{i}
\]
Method 1 is followed and ten replications are made for each alternative and results are tabulated to the user requirement.

6.5.4 Specifications of the variables for measurement

The variables to evaluate the performance of the system are measured in two ways and these are explained below.

Point Estimate: Point estimate is a single number used as an estimate of the value of an unknown population parameter. It estimates the result from one simulation run or replication. In general, if a series of independent simulations are performed, the value of a point estimate provides no information about the variability of the point estimator and so it can be misleading to use a single point estimate to get the expected value of a random variable.

Interval Estimate: The variability of a point estimate can be taken into account quantitatively by using the sample standard deviations to form interval estimates for the expected values of the corresponding random variable. An interval estimate of population parameter is a pair of numbers determining an interval within which the value of the parameter may lie. The interval for a pair of numbers randomly selected is called a confidence interval. A confidence coefficient, such as 90% or 95%, is assigned to this interval to indicate the confidence level, or degree of confidence. The variables that are used to evaluate alternatives are utilisation levels of machines, average waiting time, maximum number in queue, average number waiting in queue, work-in-process inventory and throughput.

6.5.5 Validation of the model

Several replications (or runs) of the stochastic model are made to determine the amount of stochastic variability. The confidence intervals are determined by taking the variability into account. Confidence intervals are obtained for the system output variables of each set of experimental conditions and each type of parameters of interest. It is usually desirable
to construct the model of accuracy range with the lengths of the confidence intervals as small as possible. The shorter the lengths or smaller the sizes, the more useful and meaningful the specification of the model range of accuracy will usually be. The length increment result in the decrease of the confidence levels. Variance reduction techniques are used when collecting observations from a simulation model to decrease the variability and thus obtain a closer range of accuracy. The lengths can be shortened by increasing the sample sizes.

6.6 SUMMARY

This chapter contains eight popular rules chosen for the dynamic scheduling of batch manufacturing systems. The design of system simulation model and the procedure of validation of this model are discussed in this chapter. This model enables to simulate the system behaviour when different scheduling rules are adapted. The analyses of dynamic scheduling of different batch manufacturing systems using this model are given in chapters 7-9.