4th International Conference on Mechanical Engineering,December 26-28, 2001, Dhaka,Bangladesh/pp. VI 107-111

A SIMULATION STUDY FOR SELECTION OF MATERIAL TRANSFER SYSTEM IN A FLEXIBLE MANUFACTURING SYSTEM BASED ON SCHEDULING RULES

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Abstract As scheduling depends on many conflicting parameters, including type of material handling systems in case of Flexible Manufacturing Systems/Cells (FMS/FMC), it is hard to identify any specific scheduling rule and policy because of interdependencies of these two aspects. In such a case, discrete-event simulation is expected to provide reasonably optimal solution. For this problem, taking mean flow time and mean tardiness as decision criteria for scheduling policies, and a conveyor-belt, a multi-purpose central robot, and an AGV as alternative material transfer systems, a multi-criteria decision making (MCDM) model was formulated to simulate the options for arriving at a decision.

Keywords: Scheduling, FMS, Material Transfer System

INTRODUCTION

Scheduling in a FMS is always a complex task. It is hard to identify any specific scheduling rule for a manufacturing system, which is yet to be designed. Additionally, as scheduling rule depends largely on type of material transfer system, it is not feasible, and impossible too, to design a manufacturing system prior to selection of scheduling rule. Because of interdependencies between scheduling rule and material transfer system, a discrete-event simulation is expected to provide reasonably optimal solution.

For this problem, mean flow time and mean tardiness were selected as decision criteria for scheduling policies, whereas, a conveyor belt, a central robot, and an AGV were the alternative material transfer systems. In order to avoid np-hardness from the schedule execution, a few important scheduling parameters were selected. Net Present Value (NPV), assuming equal lives for the alternatives, was the only economic parameter evaluation. Analytic Hierarchy Process (AHP) method of Multi-criteria Decision Making (MCDM) was used for arriving at a decision, since interdependency is conflicting in nature.

LITERATURE REVIEW

Many of the authors suggested simulation as a useful tool for building models and deriving performance measure values in order to arrive at a decision, which is otherwise too complex to solve mathematically. Carrie [Carrie, 1988] describes various aspects of using simulation for building manufacturing systems. Xu and Randhawa [Xu and Randhawa, 1998] also used simulation for finding out the best possible scheduling rule for a FMS system, using throughput, flow time, tardiness, tool utilization and machine utilization as performance measures. They used the rules of Earliest Due Date (EDD), Shortest Processing Time (SPT), First Come First Serve (FCFS), Least Operations Remaining (LO), etc. Jiang et. al [Jiang et al., 1988] used only SPT rule to find out assembly sequence in a two and three-robot cell. They also used simulation for decision making in such a combinatorial situation, which uses dynamic programming for developing an initial sequence. Later on, in the second stage, optimality was obtained through iteration process. Ishii and Talavage [Ishii and Talavage, 1994] have proposed a mixed dispatching rule, using heuristic search algorithm, for scheduling FMS. They also suggested that simulation is the only time-bound tool for developing a near optimal solution in a complex manufacturing environment. Karmazen [Karmazen, 2000 analyzed and compared the flow time and tardiness values in a batch processing

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industry, using a hypothetical case of a central robot and a conveyor belt. The simulation results show that the central robot is the best while higher variety flexibility is desired, and the belt performs better when larger volume is expected. Montazeri and Wassenhove [Montazeri and Wassenhove, 1990] gave a thorough over view of the performances of several available scheduling rules in a FMS environment. Teixeira and Mendis [Teixeira and Mendis, 1998] used central robot system as material transfer system. They developed a schedule using mixed integer programming model.

SELECTION OF MATERIAL TRANSFER SYSTEM

As factory system developed over the years, the need for an appropriate material handling system became important. More specifically, the idea of reducing, as much as possible, non-value-adding activities played an important role in preparing layout and schedules in any kind of manufacturing system. Out of three basic materials handling activities, namely picking up the load, transporting, and setting down the load, the transporting or transfer activities become a part of materials flow pattern through the shop layout. As materials flow pattern has a profound impact on throughput time and optimality in production plan, material transfer systems (MTS) become a part and parcel of layout design and schedule generation as well. Thus, the proper MTS needs to be selected while selecting schedules in a FMS.

Out of many available MTSs, three basic types are: i) Conveyor belt – Though it is traditionally an old system, it has been proved to be economical in many cases. The belt runs continuously along the line of work centers' physical positions. A closed loop, or an open terminal belt can be selected. This study considers a closed-loop belt, as the shop area is small and number of operations is few, thus, the design requires input and output to be done at the same point. ii) A central robot – It is the most flexible option of modern automation in factory. While a belt system is constrained in unidirectional movement of materials, the robot can move in any direction. Thus, materials flow pattern can be of any type, until the precedence constraint is not violated. iii) Automated Guided Vehicle (AGV) – The AGV runs along a rail-type path, which is fixed but the paths are joined together across the parallel lines, and thus, the AVGs get additional paths of moving forward and backward in many directions, though materials flow pattern flexibility is less than in a central robot system, but more than a conveyor belt system. Thus, in terms of flexibility, its position is in-between.

In a FMS, the central control system controls and coordinates the MTS's physical movement in accordance with the schedule generated by it. A large number of scheduling options are available in this case, though mean flow time and tardiness would serve the best as this study considers a semi-flow type shop.

SCHEDULING OPTIONS

In dealing with job attributes in a FMS, performance measures of a schedule need to be found. Quantitative performance measures are usually functions of job completion times. Out of a few measures, two most important quantities are mean flow time and mean tardiness for a set of released jobs [French, 1982]. For Job J_i,

$$\text{Flow time, } F_i = C_i - r_i\text{, and} \tag{1}$$

$$\text{Tardiness, } T_i = \max\{L_i, 0\}\text{, where } L_i = C_i - d_i.$$

Here, d_i is the due date, C_i is the completion time, L_i is the lateness, and r_i is the ready-time for a set of jobs J_i. If W_{ik} is the waiting time of J_i preceding its k th operation and p_{ij} is the processing time of job J_i, for a set of machines/operations 1-m, then,

$$C_i = r_i + \sum_{k=1}^{m} (W_{ik} \_ p_{ij(k)}) \tag{2}$$

In case of n jobs, mean flow time $\overline{F}$ and mean tardiness $\overline{T}$ can be calculated as follows:

$$\overline{F} = \tfrac{1}{n} \sum_{i=1}^{n} F_i \quad\text{, and } \overline{T} = \tfrac{1}{n} \sum_{i=1}^{n} T_i \tag{3}$$

Materials dispatching policies for schedule generation were Shortest Processing Time (SPT), Earliest Due Date (EDD) and Critical Ratio (CR).

OTHER FACTORS

Other than the flow time and tardiness, the Net Present Value for the MTS was taken into account for AHP model. In addition to these two quantitative criteria, two qualitative factors of MTS, such as availability of technical-know-how and ease of control were considered together as a single criterion.

SIMULATION MODEL AND RESULTS

The FMS considered four stages of operations, each having input and output buffer stations. The work centers are named as W1, W2, W3, and W4. Three products A, B, and C are considered, each having separate job orders, namely J_a, J_b, and J_c, i.e. i = 1 to 3 in equations (1), (2) and (3) above. Information on materials feeding and operations are as in the table (Table 1). The conveyor belt has unidirectional flow constraint, and thus, if the operations sequence is not according to the sequence w1-w2-w3-w4, then the materials may be routed more than once along the closed-loop.

Table 1: Product and process parameters. Processing time mean (standard deviation)

Product	Arrival pattern	Rate Per day	Operations Sequence (proc'ing time in minutes)
A	Uniform	15	w1-w2-w4-w3 5(1)-3(1)-4(2)-5(2)
B	Uniform	18	w1-w3-w4-w2 4(1)-6(2)-8(2)-1(1)
C	Uniform	20	w2-w1-w4-w3 5(1)-3(1)-2(1)-4(1)

Table 2: Statistical parameters.

Activities other than processing	Distribution	Parameters (minutes)
Transfer 1) Belt 2) Robot 3) AGV	Normal	 $\mu = 3, s = 2$ $\mu = 2, s = 1$ $\mu = 3, s = 1$
Loading/ Unloading	Normal	All operations: $\mu = 1, s = 1$

Table 3: Facility configuration.

Routes between	Cartesian distance (meter)
L/U-w1	8
w1-w2	10
w2-w3	15
w3-w4	10
w4-L/U	8
Connection across	10
w1-connection	5

L/U – Loading/Unloading station.
Note: In case of AGV, system, a single line connecting the parallel lines across is considered enough, as it is a small cell.

This model was run in Simple++, an object-oriented simulation system. In this system, objects are defined as information carriers. An object library provides all the basic building blocks. These are built in SIMTALK language of SIMPLE++. A building block, in this case, is a machine, having a single operation. The characteristics of the machines are set by changing attributes or properties of the basic building blocks [Hasin et al., 2000].

Different types of feeding rules were followed : i) all components and raw materials are released at the same time, ii) materials for bottleneck machine are released earlier, and iii) materials were released for the operations in sequence. In these three cases, different average lead times were required, as it is known that over-all lead time, or through time depends not only on flow time and flow pattern, but also on materials feeding policies.

It was seen that ultimately, the combinations were among: i) three alternative feeding policies (as given in the previous paragraph), ii) three alternative scheduling policies (SPT, EDD, CR), iii) two scheduling performance measures (mean flow time, mean tardiness), iv) three products having different sequence and product mix, v) and three alternative MTSs. In addition to these combinations, there remain qualitative measures (ease of control and availability of technical know-how) as well. For such a complex combinatorial manufacturing environment, no algorithm exists which can solve the problem for at least a near optimal solution. That's why simulation is the only choice left for a reasonably acceptable result.

The simulation data were gathered from the technical information supplied by the system manufacturers. These required additional elements for simulating as a real system, as given below:

State variables: number of products and product mix, state of the machines (idle, or busy), state of the route, specially the constraint in case of AGV path, and central robot systems (idle or busy).

Performance of the system as a whole: average queue in from of each machine. Though it is assumed that any level of queue is allowed, in case of acute space constraint, this may not be allowed. In that case, the simulation model would add another level of complexity by adding a new queuing constraint.

Average waiting time in front of the machines and for the robot and AVG.

Stability was reached only after twenty runs of warming period. The results were gathered for consecutive thirty runs, as it is believed that a trade-off is necessary between more accuracy through more runs and time required for results. Thirty runs were believed to be statistically acceptable, as it can justify a normal distribution, even if population standard deviation is not known.

Results and Analysis

As there are a number of combinatorial options, the simulation runs produced a huge amount of output data. This paper presents only the top five ranked according to mean flow time and mean tardiness, performances of each station and the whole shop.

It is logical that as robots have more routing flexibility, its utilization would be less than others. This was proved in this simulation run. The question of belt utilization does not come because of its functional and physical characteristics.

Table 4: Performances of stations and the shop

Combination	Avg. queue in all four m/cs	Avg.utilization of MTS
SO, CR, Robot	80	70
SO, CR, AGV	85	85
SO, SPT, Robot	90	75
SO, SPT, AGV	100	80
SO, SPT, Belt	110	--

Table 5. Final results for use in AHP

Combination	Mean flow time (minutes)	Mean tardiness
SO, CR, Robot	80	15
SO, CR, AGV	85	16
SO, SPT, Robot	90	15
SO, SPT, AGV	100	15
SO, SPT, Belt	110	17

F: Feeding policy – i) BA- materials released earlier for the bottleneck, ii) S- materials released simultaneously for all stations, iii) SO- materials released according to sequence of operations.

In all cases in the top five, it was found that it would be feeding policy does not affect the mean flow time and tardiness, as there are no branches in the manufacturing layout. But these affect the queue in front of the machines and the MTS. If the utilization of the MTSs is near 100%, then these policies would have significant role. If there are space constraints for the buffers, this would have a role as well. Thus, SO (i.e. materials released according to the sequence of operations) gave a better result , not in terms of mean flow time, or tardiness, but in terms of queue only.

As no penalty is involved in ordering, EDD was out-performed by the other two options, namely SPT and CR.

AHP Solution

The Analytic Hierarchy Process, developed by Thomas Saaty, is a multi-attribute decision making technique. The major advantage of this evaluation technique, over others, is its ability to handle conflicting, as well as qualitative criteria [Tabucanon, 1988].

The economic criterion used in this model is Net Present Value (NPV), considering life of the system as whole as 7 (seven) years. MARR for a rate of 20% was justified as gathered from a similar company. It may be noted that this company produces selected automobile parts in batches. It was necessary to evaluate the NPVs of the MTSs only, without taking into account the costs of the whole system, as the machines and loading/unloading stations cost the same irrespective of the MTS types. The cost components, considered in this study, are : initial purchase price of MTS and the annual preventive maintenance cost. It is guaranteed that the supplier would replace any parts including service free of charge within the next 7 years. That's why the life has been considered as 7 during evaluation. As the company concerned desired confidentiality in pricing and other technical informal, only the final NPV values are given as: Robot: 30 million bath (Baht is Thai currency. In the year of 2000, 1 US$ was equal to 35 baht approximately), AGV – 31 million Baht, Belt- 25 million bath.

The AHP model considers the five options, given in Table 5, as alternatives at level three in the AHP hierarchy. The attributes at level two are : mean flow time, mean tardiness, ease of control, technical know-how and NPV. As the values for all attributes are obtained in the previous section, those gave the final results as stated in Table 7.

Table 6: Attributes and their weights

Attribute	MFT	MT	NPV	EC	TKH
MFT	1	4	1	2	2
MT	1/4	1	1/4	1/1.5	1/1.5
NPV	1	4	1	2	2
EC	1/2	1.5	1/2	1	1
TKH	1/2	1.5	1/2	1	1

Attri. – Attributes;
MFT – Mean Flow Time; MT – Mean tardiness;
EC – Ease of control; TKH – Technical Know-how.

Table 7: Over-all result.

Combination	Composite weight	Rank
SO, CR, Robot	0.24	1
SO, CR, AGV	0.21	2
SO, SPT, Robot	0.20	3
SO, SPT, AGV	0.17	5
SO, SPT, Belt	0.18	4

Over-all inconsistency is 0.01, or 1%, which is significantly less than the maximum allowable limit of 10%. So, the result is acceptable.

The table (Table 7) shows that the central robot system would perform the best if materials are released in accordance with the sequence of operations and the scheduling rule is as per critical ratio of jobs.

CONCLUSION

It was found that Critical Ratio (CR) rule performed the best, and it is for the central robot system. Obviously this is case specific, but a more general conclusion was also obtained, as below.

It must be noted that these results gave an optimal design requirements, along with a schedule. As it was known that the manufacturing systems (machines and MTS) can serve 7 years, without major change in the system, the study found the results assuming that the products would retain its level of market demand and market pattern as well, thus, logically justifying the use of the same scheduling policies with other combinations. It is further necessary to note that if the level of demand and demand pattern (including product type and its mix) changes, the design may require change and new simulation runs.

The study found that optimality and effectiveness of scheduling rules and associated policies largely depend on material flow pattern. On the other hand, material flow pattern depends on type of material handling systems. Thus, logically, selection of scheduling rules and policies depend on type of material transfer system. It would be logical to select material transfer system along with an effective scheduling rule simultaneously. The overall combination becomes too complex to handle mathematically in a computer. As simulation is a tool that simplifies complex mathematical enumeration, it would work well in such a complex combinatorial problem.

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