Scheduling Performance Evaluation in Hybrid Production Environments

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Abstract - **The configurations inside firms are most often neither pure flow-shop nor pure job-shop in practice. A scheduling performance evaluation is proposed to extend and integrate several ideas into a research framework where results can be referred to real-world manufacturing situations. The investigation therefore composes in which some of simple and popular scheduling rules are examined in hybrid shops comprising both job-shop and flow-shop. The average flow time is specifically the principle performance measure taken into account to estimate how closely the rules accomplish jobs relative to their due dates. The research effect indicated that the SPT rule is oftentimes preferred to cater for customers' requests and CR is of a kind to the contrary. In addition, this paper supplies a basis for extending the conclusions beyond the boundaries of the specific scenario presented with some believability. Regarding the computational results the approach has the potential to be applied to practical hybrid manufacturing systems and can probably obtain desirable performance by using either of these rules as the basis while using some of the very elementary rules researched over years in considerably unrealistic operations research models.**

Keywords - **Hybrid environment, simulation, scheduling rules, average flow time, performance**

I. INTRODUCTION

Many enterprises face radical changes within global production. Discovering new customers in new markets makes it necessary to offer highly customized and innovative products to meet customer's needs [17]. Within this context, companies have to solve the change towards flexible, demand driven production. In consequence, for the majority of real factories, the facility layout and processing flow inside the shops are most often neither pure flow-shop nor pure job-shop. The jobs in a flow-shop conventionally require the nearly identical routing through the shop. A preferable way to configure the facility for suchlike situation is to set apart production lines to the required sequence. A job-shop to the contrary is customarily described as dealing with a series of specific orders requiring distinct routings through the facility. As a rule, it allots to group similar machines or services in identical place [8, 9]. Quite a few of production with a plentifully large volume actually benefits from a flow-shop deployment but there invariably appears to be a number of separate, customized orders that necessitate a job-shop configuration. Hence, a market driven production essentiality is indeed a hybrid works from these two types of shops, but even then scheduling jobs in either type or a combination shops have been scrutinized over the years under manifold viewpoints with methodologies ranging from optimal to heuristic [13].

Production scheduling seeks optimal combination of short manufacturing time, stable inventory, balanced human and machine utilization rate, and short average customer waiting time. From the point of view of a supervisor, to evaluate a scheduling performance is an important issue in production management. The supervisor must define the system capacity and then uses some indices to evaluate the scheduling performance [6]. Traditionally, the basic principle of production in a workshop is supposed to minimize production cost under the condition of meeting customers' needs as far as possible. Production scheduling is a part of the production management process which covers all planning and control-oriented activities to achieve a time, quality, and cost-effective production. Production scheduling on an aggregated level is accomplished with the help of the production planning system. The production scheduling problem for manufacturing systems has attracted the attention of numerous researchers and has been addressed quite extensively. Production scheduling concerns itself with the detailed planning and control of individual production units. It has been recognized that production scheduling ultimately determines the operational performance of a production system [12, 16].

Yet, in spite of the vast body of research that has been carried out in this field, and the fact that many practitioners in operations management are convinced of the fact that practical scheduling requires improvement, the industrial practice of production scheduling has not changed substantially in the last few decades. However, merely a few instinctive senses are implemented to acquire feasible schedules in which go short of endeavors concerning refinements. Graves [8] observed that there is a gap between scheduling theory and practice because most previous research effort has been spent developing more powerful algorithms and/or more effective heuristics for standard production scheduling problems.

In other words, although scheduling is well researched area, and numerous articles and books have been published. Classical scheduling theory has been little used in real production environments. We profoundly believe that scheduling research has much to offer industry and commerce, but that more effort is needed to endeavor to shorten the gap between theory and practice. Therefore, the purpose of this paper is to explore the performance of several rules into account in real-world-type shops with reference to scheduling decisions involved in the designate mixed configuration. This study endeavors to elaborate a few of the issues faced by schedulers in elementary scheduling rule like slack time expense, due date sequence or shortest processing time [19]. A simulation-based work was conducted in which some of the simple, well known scheduling rules were compared in these combination shops, that is, shops that have some orders with the same routing and others with job-shop requirements. The results of this investigation are reported here and are intended to provide schedulers with some additional insight into the relative performance of a few rules in shops that look like theirs.

II. SCENARIO STATEMENT

Of many changes to which business must respond in order to succeed in today's turbulent business environment, none is more

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vital than being customer focused and being able to adjust production schedule quickly to handle production variation. Flexible production gives a firm the ability to adjust operational decisions quickly in response to new information [11]. For the purpose of quick response to customer needs in the market, the mode of production scheduling at each stage within a company is hinged on distinct market surroundings. Scheduling therefore plays an increasingly important planning role for organizations that strive to keep pace with market changes. A large amount of research has been devoted to the development of scheduling algorithms, experiments on the behavior of algorithms, and the development of scheduling decision support as well as expert systems. It is undeniable that scheduling mechanisms gave rise to process organization and, as a result, monetary improvements. However, there is only limited knowledge on how good the solutions are.

Production scheduling is the task to assign jobs to machines over time. The general target of production scheduling is the optimal allocation of limited resources and competing tasks or jobs over time taking into account different constraints which have to be complied. Many researchers focus on the scheduling problems [1, 2, 3, 8]. Most of earlier researches preliminarily deal with the development and implementation of a heuristic based on an elementary scheduling rule like processing time or due date sequence. In any production setting, managers enthused in search of programming a set of orders on a number of machines such that the sequence, timing, and machine assignment of these orders is optimal with respect to single or multiple objectives.

As often as not the objectives are conflicting, stemming from trade-offs between holding inventory, production changeovers, satisfaction of production-level needs, and due dates. While management typically probes to maximize the utilization of finite resources or to minimize related costs, scheduling objectives also frequently include objectives directed toward minimizing operating burden, enhancing system stability, lessening confusion, and conciliating exacting customers. It is commonplace that in a given shop two or more conflicting objectives need to be achieved simultaneously. Due-date conformity is one of the performance measures most frequently encountered in practical scheduling problems. The total tardiness criterion, in particular, has been a standard way of quantifying this conformance. All things considered, the scheduler has to seize and coordinate various performance criteria, schedule and dispatch work in such a way that quite a few stated and unstated conflicting goals are conformed.

The scheduling problem is most often characterized as sequencing n jobs on m machines in such a way that a certain performance criterion is optimized. This problem is frequently referred to as the n-job, m-machine problem. In the flow-shop scheduling problem it is endowed with a set of m machines (M_1, M_2, …, M_m) and a set of n jobs(J_1, J_2, …, J_n); each of the n jobs has to be processed on the m machines M_1, M_2, …, M_m in that order, i.e. a job J_i (i=1, 2, . . ., n) consists of a sequence of m operations O_{1i}, O_{2i}, …, O_{mi}, where O_{mi} has to be processed on machine M_m for a given uninterrupted processing time p_{mi}. Each machine can process at most one job at a time, and each job can be processed by at most at one machine at a time [4, 10]. The universal target is to generate a schedule program that minimizes the maximum completion time. The flow-shop scheduling problem has been shown to be NP-complete by Garey and Johnson [7]. As a result, for practical purposes, it is often more appropriate to apply an approximation method which results in an approximate solution in a relatively efficiently time. For most of these approximation methods, no worst-case analysis exits. In other words, there is no upper bound that is guaranteed for the maximum completion time of the schedules produced by these methods when applied to any instance of the problems.

The job shop scheduling problem has been well-known as one of the hardest combinatorial optimization problems and numerous exact and heuristic algorithms have been proposed. Suchlike production environment is a multi-operation job shop under a make (assemble)-to-order policy. Customers arrive dynamically and each customer order is characterized by a certain volume, mix and an agreed due date. Each order requires several operations on different machines; the routes, which are characterized by a bill of processes, are not necessarily the same for each order. Rochette and Sadowski [15] compared the performance of simple dispatching rules for a particular set of job-shops. Various approaches have been applied to job shop scheduling including mathematical programming, fuzzy set theory, dispatching rules, neural networks, expert systems and so on.

Naturally, in these job shop scheduling problems, various factors, such as processing time, due date and so forth, have precisely been determined at some specific values. In general, an $n\times m$ job shop scheduling problem is formulated as follows. Let n jobs J_i(i=1, 2,..., n) be processed on m machines M_r(r=1, 2,..., m), and let the operations of job J_i on machine M_r be $O_{i,j,r}$, where $j\in$ {r=1, 2,..., m} shows the position of the operation in the technological sequence of the jobs. In other words, $O_{i,j,r}$ expresses the j^{th} operation of job i processed on machine r [9, 14].

The job-shop scheduling problem is more complex than the flow-shop problem because the jobs do not have the identical technical ordering. That is, all jobs follow the same path along a production line in a flow-shop, but no such pattern exists in a job-shop. Job-shop scheduling problem is one of the most well-known machine scheduling problems and one of the strongly NP-hard combinatorial optimization problems. Developing effective search methods is always an important and valuable work. Due to advances in manufacturing systems (e.g., FMS, CAM, CIM, etc.), due-date-based scheduling research has received considerable attention in the last decade and a wealth of literature has been reported in this area.

Relative studies in connection with abovementioned problems in real manufacturing situations have explored for decades, yet, little has been achieved to quantitatively resolve the problem for realistic situations [1]. Frazier's study [5] has demonstrated the superiority of exhaustive scheduling in both job-shop and flowline cells. The primary reason lies in the fact that the basic problem is NP-complete for most realistic formulations. Resolutions to small, special flow-shop problems have been known for years. For example, minimizing of the total elapsed time with n jobs and 2 machines can be solved by Johnson's rule and minimizing the number of tardy jobs with m machines and 1 job in a flow-shop can be solved by using graphical techniques and Gantt charts. However, for problems in which the number of machines is larger than three, no general, closed form solution exists. In short, former endeavors in scheduling research are numerous and significant. This study looks for the extension and integration of several opinions into a research framework where results can be used in actual production settings.

III. STAGE DIRECTION FOR SCHEDULING PERFORMANCE EVALUATION

We chose the average flow time as the primary performance assessment measure in this study. The reason concerned is that it highlights a frequently encountered goal in the real world. It is necessary for a moderate enterprise to accomplish jobs as rapidly getting across the possessive system as possible with a view to increasing throughput and decreasing work-in-process simultaneously. Furthermore, under ordinary circumstances jobs that require similar machine set-ups should follow each other at a work center.

As for a hybrid manufacturing, there are a near infinite number of assortments exist for combining features of flow-shop and job-shop. It is impossible to model all possible combinations of flow-shop and job-shop jobs, so a wide range of conditions were ultimately simulated seeking to explore the performance of the designate rules and to discover any general trends that could be parlayed into suggestions for scheduling real shops. Namely, a simulation-based approach was adopted in which the imitative hybrid shop was modeled containing a crowd of jobs within the designate system. Suchlike imitative shop is composed of the percentage of incoming jobs that were allocated whatever routings. The percentage stands for two conditions while most jobs own the same processing sequence and a fraction possess different processing sequences in the light of flow-shop, or when most jobs have a unique sequence and a fraction has an identical sequence in accordance with job-shop.

The process of determining which job to start first on some machine or in some work center is known as sequencing. Sequencing rules are the rules used in obtaining a job sequence. In this paper we selected five very customary rules for the evaluation of scheduling activities in hybrid production systems. They are FCFS (first come first served), EDD (earliest due date), SPT (shortest processing time), CR (critical ratio), and LST (least slack time), respectively. They have been reported to be particularly good at reducing tardiness under various scheduling conditions [18].

To evaluate the benefits and costs of determinative sequencing rules, it is necessary to consider a large number of cases in a simulation environment. The resulting solutions can be compared for solution quality, speed, and cost. The solution quality may depend on the objective functions that are relevant in a particular scheduling environment. Thus, the problem of evaluating heuristics is a multiple-criteria decision-making problem. By and large, experience says that FCFS has many shortcomings; SPT does perform well, supervisors like it but have to watch out for long processing time orders. CR works well on average job lateness criterion. It may focus too much on jobs that cannot be completed on time forcing more jobs to miss promise dates.

We applied a simulated permutation of the specific shops to explore the potential for more intelligently using the simple results from unrealistic optimization models to sequence in hybrid shops. The results of this investigation intended to provide schedulers with some additional insight into the relative performance of a few rules in shops that look like theirs. In an attempt to evaluate how the performance of scheduling rules concerned we adopt fundamental statistical analysis to display solid quantitative interpretations of the data. Moreover, the results allow development of the intuitive comprehension into trends and tendencies that can be beneficial in practice.

The portability and reusability are important advantages considered in developing simulation environment. Thus, we selected the software tool eM-Plant to build this application, that is, the different simulation scenario depicted by eM-Plant was utilized for aforementioned evaluation of scheduling performance measures with reference to the assigned five rules. The simulations are eventually finished on an Intel Pentium 4 3.0GHz under eM-Plant development environment. As the number of machines increases, the possible routings increase too. Furthermore, all scheduling evaluations are lay in a dynamic environment in which signifies that jobs turned up randomly and intermittently throughout the anticipated planning horizon and the incurred queues are instantly rescheduled. In addition, the processing times at the different workcenters and the possible routing assigned to the job are randomly determined. As is known to all, jobs may not require processing on all machines for the job-shop. The arrival process is modeled using a uniform distribution. After all steps in the simulated factory were completed, the job was obviated from the process and the required statistic summary was recorded.

To perform such scheduling evaluation, a few of assumptions need to be fixed on this research. They are presented separately as follows:

1. No breakdown for each machine;
2. Due dates of orders are known and secured.
3. Each machine deals with, at most, one job at a time;
4. No cancellations for each job, each job consists of a chain of operations, each of which needs to be processed during an uninterrupted time period;
5. Each job is only advanced on one machine at a time;
6. No preemptive priorities allowed for each operation;
7. The processing times are independent and randomly determined;
8. In-process inventory is allowed and is built into the machine queues;

The aforementioned problem has captured the interest of a significant percentage of incoming jobs that were allocated whatever routings and of a complexity resulted from machine quantities. The simulation scenario settled on a set of jobs and a set of machines. On the one hand, the percentage of incoming jobs have arranged for the imitative mixed shop under three situations which are low ratio, medium ratio and high ratio, respectively, ranging from 5% to 15%. On the other hand machine amounts were in compliance with the identical thought of incoming jobs (amounts of less, medium and more) so as to explore the scheduling performance based upon diverse system complexity.

IV. PERFORMANCE EVALUATION RESULTS

Because of contrasting the performance of designate scheduling rules in the hybrid factory, it is necessary to implement basic statistical analysis for further comprehension. The results ought to be durable for bringing about more thorough realization in an actual hybrid circumstance. We examined pair-wise statistical tests for each combination of mixed scenario to ascertain whether the different scheduling rules cause a statistical variation in the selected performance measures. A confidence level of α=0.05 was used in all test cases.

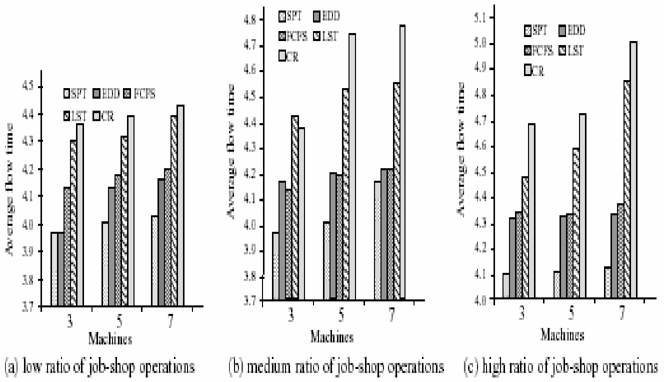

Fig.1. Hybrid shop with corresponding separate ratios of job-shop operations under different machine amounts

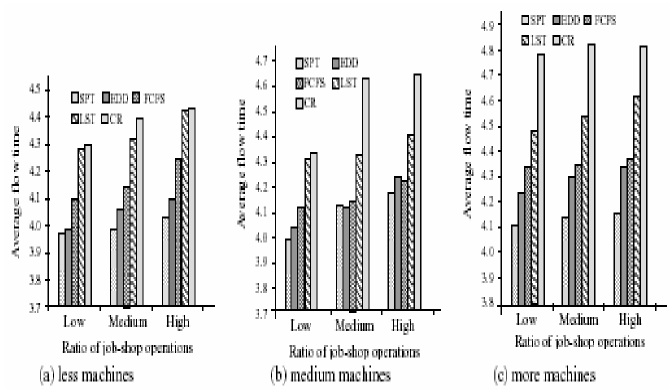

Fig.2. Hybrid shop with corresponding individual machine amounts under different ratios of job-shop operations

When we disposed a fixed ratio of job-shop jobs and an increasing amount of machines in the mixed shop, there exists a general trend that average flow time increases as the machine amounts increase. Fig. 1 illustrated such situations. Although the ratio of job types is fixed, there are more routings possible with more machines in series. It is as a result of an augment in throng suffusing the whole system. The observation coincides greatly with operation perception. To the contrary when we deployed fixed machines, the average flow time inclined upward as the ratio of job-shop jobs increases (Fig. 2). In consequence of the variety in the system, a larger portion of job-shop jobs has more different routings, and results in an increase of the overall average flow time. The upshot of the evaluation was that these trends are entirely comprehensible and represent coherence insight into general operation intuitions. It is strongly suggests that rule SPT may usually bring about a smaller average flow time, that is, the total time a job remains in the system, when a portion of job-shop gobs are operated in a mixed shop. The observations demonstrate that rule SPT is more effective and ordinarily the best option for most of the situations when the minimum average flow time is a matter of concern inward the scheduling objective.

On the other hand, we made arrangements for a constant machine amounts and increasing ratios of jobs with job-shop routings. The results accordingly are identical to the detections made previously in which generate the substantial influence of increasing average flow time. Meanwhile, we investigated hypothesis testing for each pair of the scheduling rules in which generated significantly different average flow time for the less complicated system. The results in Table 1 and Table 2 indicated that at whatever evaluation scenarios the lowest average flow time associated with rule SPT has significantly difference from the average flow time caused by FCFS, CR, LST, but nearly no difference from EDD. Such upshot pointed out evident that rule SPT evolves mainly the best scheduling option, rule CR is usually the worst, and other rules are not substantially discernible in applications.

TABLE I
HYPOTHESIS TESTING RESULTS FOR EACH PAIR OF THE SCHEDULING RULES UNDER LOW RATIO OF JOB-SHOP JOBS

Pair-wise statistical tests	# of machines		
	3	5	7
FCFS vs. EDD			
FCFS vs. SPT	*		
FCFS vs. CR	*	*	*
FCFS vs. LST		*	
EDD vs. SPT		*	*
EDD vs. CR	*	*	*
EDD vs. LST			
SPT vs. CR	*	*	*
SPT vs. LST	*	*	*
CR vs. LST			

* indicates those pairs of scheduling rules which had a significantly different average flow time at α=0:05

TABLE II
HYPOTHESIS TESTING RESULTS FOR EACH PAIR OF THE SCHEDULING RULES UNDER LESS MACHINES

Pair-wise statistical tests	ratio of job-shop jobs		
	low	low	low
FCFS vs. EDD			
FCFS vs. SPT	*		
FCFS vs. CR	*	*	*
FCFS vs. LST		*	
EDD vs. SPT			
EDD vs. CR	*	*	*
EDD vs. LST	*	*	*
SPT vs. CR	*	*	*
SPT vs. LST	*	*	*
CR vs. LST			

* indicates those pairs of scheduling rules which had a significantly different average flow time at α=0:05

In addition, we made arrangements for a constant ratio of job-shop jobs with job-shop routings and increasing the number of machines. Rule SPT still creates the significantly smallest values of average flow time in the simulated shop with medium-size machines for low ratio of job-shop jobs and is indistinguishable from several other rules as the shop becomes more complex with high ratio of job-shop jobs. The results are representative and similar of that detected in all of the conditions involving performance measure of the average flow time. It deserved to be mentioned that rules CR and LST are without the slightest difference when the production system is more complex with less machines (see Fig. 2(a)).

Anterior figures distinctly reveal that the scheduling rules tend to bring about remarkable different average flow times for the less confused systems associated with fewer machines but no differences in the most complicated plants with more machines. On the other hand, the largest average flow time associated with CR is different from the average flow times of SPT and FIFO but none of the others. Apparently, it is without the slightest difference that no exceptional rule happened during the simulation work was dominant to rule SPT when average flow time was the key performance index. In addition, one of the interesting aspects is that using the SPT rule consistently produces among the modest-high value of total changeover costs, but the fact that EDD, LST and FIFO are imperceptible. Besides, rule CR invariably generated statistically inferior effects during most simulation scenarios. In short, it is consequently recommended that SPT can be used for catering to a majority of production requests.

The only significant conclusion that appears reasonable here is that the SPT rule seems to perform better when the average flow time is evaluated as the dominant performance measure. For the practitioner, SPT would be recommended because it seems to perform no worse than other rules for all in the vast majority of cases better than most rules for many of them over a wide range of situations. As observed from the simulation results, it seems apparent that SPT is generally the best rule, CR is generally of a kind, and the other three are in the middle and not distinguishable.

V. CONCLUDING REMARKS

This paper concerns the performance of several sequencing rules in real-world-type shops that contain both flow- shop and job-shop works. The average flow time is all along an accustomed judgment that measures how swiftly a job passes through a designate shop, and then reflecting WIP. Since it is manifestly impossible to model all possible combinations of job-shop and flow-shop jobs, a wide range of conditions are simulated exploring to reveal any ordinary trends that could be treated as suggestions for scheduling actual production environments. In consequence, the scheduling rules tested in this paper tend to work better in mixed shops. As a whole, the simulation effects propose that minimizing average flow time in a production system with a majority of flow-shop features can be accomplished in many cases by using sequencing rule SPT, even for a much higher complex environment suchlike rule performs as well as any of the others. In addition, from a practical viewpoint, SPT is certainly the preferred ruled if one wishes to minimize average flow time. We supply a basis for extending the conclusions beyond the boundaries of the specific scenario presented with some believability. With respect to the computational results the study has the potential to be applied to practical hybrid manufacturing systems and can probably obtain desirable performance by using either of these rules as the basis while using some of the very elementary rules researched over years in considerably impractical operations research models.

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