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Resource Allocation and Job Dispatching for Unreliable Flexible Flow Shop Manufacturing System

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Abstract. Resource allocation, product batching and production scheduling are three different problems in manufacturing systems of different structures such as flexible flow shop manufacturing systems. These problems are usually dealt with independently for a certain objective function related to production efficiency and effectiveness. Handling all of them in an integrated manner is a challenge facing many manufacturing systems in practice and that challenge increases for highly complicated and stochastic systems. Random arrival of products, machine setup time requirements, unexpected machine breakdowns, and multiple conflicting objective functions are some of the common complications in such systems. This research attempts to study the integrated problem under the mentioned complications with various objective functions. The decisions parameters are the batch size, the number of machines at each workstation, and the dispatching policy. Discrete event simulation is used as an optimization tools. The system is modeled using the ARENA software and different scenarios are tested for optimum parameter selection under different conditions.

Introduction

In practice, resource allocation, batching and dispatching (Scheduling) are integrated with each other. Nevertheless, they have been dealt with as separate optimization problems due to the complexity of the integrated model. Hence, solving the integrated problem is difficult especially under complex shop environment such as the flexible flow shop. Moreover, the problem becomes trickier under the existence of uncertainty. Sequence dependent setup times and machines breakdowns are additional sources of complexity that usually make the scheduling problem NP-hard even for a single machine.

In this paper a problem in which jobs of different types are processed in batches of certain sizes in a flexible flow shop composed of several work centers with multiple identical parallel machines is considered. Jobs arrive randomly and accumulate overtime to its predetermined batch size. Job processing times are not known and follow a normal distribution function. Changing production from one type of product to another requires machine set up with sequence dependent time. The production system is assumed that it is subjected to random failures. The objective is to optimize resources by machine allocations, batching and scheduling in each work center. Different dispatching rules are tested to find the best dispatching rule with respect to the average flow time and the optimal number of the resources and batch sizes are also determined. Due to the high stochasticness and complexity of the system, simulation based solution method is adopted. Simulation can easily entertain the dynamic and stochastic aspects of certain factors in manufacturing and can provide a robust solution. The simulation package ARENA is used to build the model and its optimization tool called OptQuest is used for optimization. Some of the data for this study is obtained from Chtourou et al [1] and Al-Turki et al [2].

The remaining of the paper is organized as follows. In the next section, a summary of the literature review is presented followed by the problem definition. The ARENA simulation model is then described followed by the description of the computational experiments and discussion of its results. Finally, the paper is concluded with possible directions for further research.

As flow shops are used extensively by manufacturers throughout the global economy, extensive researches and studies have been conducted to develop or improve models for overall efficiency optimization. Researchers usually study one of the resource allocation, batching, or dispatching problems and fix the other two. For example, most of scheduling theory assumes a fixed number of machines at each work center in the job shop and a fixed batching policy, where as in production planning literature, the optimum number of machine allocation is studied for a fixed dispatching and batching policies. The considered problem is resource allocation, batching and scheduling for a flexible flow shop with multiple identical machines where each machine has its own sequence-dependent setup times and it is subjected to breakdowns. A number of papers related to the considered problem are reviewed and classified based on the consideration of flexible job shops and/or machines unavailability.

Many researchers have developed models for handling complex structures (i.e. flexible job shops) and multi-decision problems such as expert systems and analytical hierarchical systems without considering systems failures or machines breakdowns. Felix et al. [3] developed an integrated approach for the automatic design of Flexible Manufacturing Systems (FMS). Liu et al. [4] formulated integer programming model with a Lagrangian relaxation-based approach for production scheduling of flexible flow shops considering sequence-dependent setup times. Chtourou et al. [1] developed a simulation based expert system for finding the optimal number of machines with respect to due date related performance measures in a manufacturing system. Cao et al. [5] developed a combinatorial optimization model to select the machines and their schedule with the objective of minimizing the holding costs and tardiness. Kyparisis and Koulamas [6] considered the multistage flexible flow shop scheduling problem with uniform parallel machines in each stage and developed a heuristic with the objective of minimizing makespan. Kuadt and Kuhn [7] focused on a batch scheduling problem for flexible flow lines considering different product type and sequence dependant setup times by presenting a solution approach that consists of two nested genetic algorithms with the objective of minimizing setup costs and mean flow time. Badr [8] proposed an agent-oriented scheduling framework that can be integrated with a real or a simulated flexible manufacturing system (FMS) which works in stochastic environments with a dynamic model of job arrival. Chen et al. [9] considered a job shop scheduling problem with parallel machines and re-entrant process by developing a scheduling algorithm which uses two modules that help dispatchers in selecting one of the parallel machines and then to schedule the sequences and the timing of all operations assigned to each machine. Al-Turki et al. [2] considered the problem of resource allocation and scheduling for a flexible job shop with a sequence dependant set up times using simulation with the objective of selecting the best dispatching rule with respect to a desired performance measure along with its corresponding batch size and optimum number of machines in each center.

On the other hand, there are a number of papers in which systems failures or machines breakdowns was considered. Allahverdi [10] considered scheduling in two proportionate machine flow shop with a maximum lateness objective function where machines are subject to random breakdowns. It was proved that, under appropriate conditions, Longest Processing Time (LPT) sequence minimizes the objective function with probability 1 when only the first machine is subjected to breakdowns whereas Shortest Processing Time (SPT) sequence minimizes the objective function with probability 1 when the second machine only is subjected to breakdowns. Allahverdi and Tatari [11] used simulation for solving a two-machine flowshop scheduling problem where machines are subject to random breakdowns. The makespan for each of the defined five sequencing rules were investigated and the rule with best performance is identified when uptimes and downtimes follow exponential distribution. Allahverdi [12] dealt with the problem of scheduling in a two-machine flowshop with constant and known processing times while minimizing the total flow time where the machines are prone to failures and no buffer size is assumed between machines. The problem has been formulated and a sequence that minimizes the objective function is obtained when the failure is associated with the first or second machine. The study concluded that under certain conditions on the breakdown process and processing times, the SPT, SPT1 and SPT2 sequences provide the optimal schedule. Ruiz et al. [13] proposed a simple criterion to schedule preventive maintenance operations to the production sequence in order to minimize the makespan of the sequence considering machine breakdowns. Aghezzaf et al. [14] formulated a multi-item capacitated lot-sizing model on a system that is periodically renewed and minimally repaired at failure for an integrated production and preventive maintenance environment. The objective is finding an integrated lot-sizing and preventive maintenance strategy of the system that satisfies the demand for all items over the entire horizon without backlogging, and which minimizes the expected sum of production and maintenance costs. Allaoui et al. [15] solved a stochastic scheduling problem in which jobs to be scheduled jointly with the preventive maintenance in a single machine subject to breakdowns by formulating a dynamic programming model with the objective of minimizing expected total earliness and tardiness costs with a common due-date. Moradi et al. [16] investigated the flexible job shop problem (FJSP) with preventive maintenance activities under the multi-objective optimization approaches considering failure rates. They compared four multi-objective optimization methods to find the Pareto-optimal front of the problem with the objective of minimizing the makespan and the system unavailability for the maintenance part.

Problem Definition

Objective

The objective of this study is to compare different dispatching rules for minimizing the average job flow time. For each dispatching rule, the batch size and the number of machines at each work center are to be determined.

Assumptions

The considered problem is scheduling jobs of different types arriving to a flexible flow shop composed of several work centers where each work center has multiple identical machines.

- Jobs are grouped into batches of n jobs of the same type and each batch is ready for processing once it is formed.
- All machines in all work centers are assumed to be continuously ready for processing throughout the scheduling period. However, they are subject to random breakdowns.
- No machine may process more than one operation at the same time.
- Setup operations can be done only when the machine is completely free.
- A batch must be completed on a work center before moving to the next one.
- Machine setup times are assumed to be constant and sequence dependent.

Simulation Model

The considered problem in this study is highly stochastic in terms of jobs arrival times, jobs processing times and machines sequence dependent setup times. Accordingly simulation is the most suitable tool under these conditions. In this study, we have developed a simulation model using ARENA for a specific shop structure consisting of five work centers and three types of jobs. The model is built to study the performance of the shop under different scheduling (dispatching) decisions and data sets for different objectives. The required data for the simulation model is: inter-arrival times for all jobs, processing times of all jobs on different machines, setup times for each job type on all machines and travelling time for the jobs between work centers. Jobs are accumulated to form batches of the same type in a defined batch size. Batch travel time between work centers is assumed to be 10 minutes. Jobs processing times are assumed to be normally distributed with mean as shown in Table 1 and common standard deviation of 0.2 minutes. Set up times are also given in Table1. Jobs inter-arrival times are assumed to be exponentially distributed with mean of 50 minutes. The machines failure rates are assumed to be exponentially distributed with mean of 50 minutes and breakdown duration exponentially distributed with mean 5 minutes. Limited buffers are assumed with capacity of 100 jobs for all work centers except the first work center which has a buffer of infinite size. The number of machines at each work center is limited by ten machines and the batch size is limited by ten units. Machine utilization rate is required to be between 60% and 90%.

Table 1: Model parameters and input data

Product	Work Center	Processing time (min)	Setup time (min)		
			P1	P2	P3
P1	M1	10	0	6	6
	M2	11	0	5	5
	M3	12	0	4	4
	M4	11	0	5	5
	M5	10	0	6	6
P2	M1	10.5	6	0	6
	M2	11.5	5	0	5
	M3	12.5	4	0	4
	M4	11.5	5	0	5
	M5	10.5	6	0	6
P3	M1	11	6	6	0
	M2	12	5	5	0
	M3	13	4	4	0
	M4	12	5	5	0
	M5	11	6	6	0

The optimization of the resources and the batch size in our case is achieved by using the optimization tool in ARENA called OptQuest. It tests multiple combinations of a range of variables to help determine the best association of values. The model is run for different dispatching rules for the considered performance measure. For a given performance measure, the best combination of resources and batch size along with the suitable dispatching rule are obtained.

The optimization process starts with initializing the input parameters and identifying the performance measure for the simulation model. Then, a dispatching rule is selected. The optimization decision variables are defined in the model and the OptQuest optimization process is run until it converges. The statistics are collected and the process is repeated for another dispatching rule under consideration.

Computational Results

The model randomly generated 2000 problems with different processing times. Each problem was run for 5 replications for 1000 hours each to obtain the best combination of resources and batch size in order to optimize a selected performance measure. A warm-up period of five hours is inserted in the simulation model. The performance of two dispatching rules, namely FIFO (First-In-First-Out) and LIFO (Last-In-First-Out), is evaluated under optimal resource allocation and batching policies with respect to average flow time. Therefore, for each dispatching rule the optimal number of machines and optimal batch size is determined for each problem generated. For each rule the average performance of five replications is shown in Table 2.

Table 2: Optimal resources and batch sizes and average performance for different dispatching rules

Dispatching Rule	Optimal Resource Configuration (number of machines at each work center)					Optimal Batch Size			Performance Measure	No. of Completed Jobs
	M1	M2	M3	M4	M5	P1	P2	P3	Avg. Flow Time (min)	
FIFO	3	3	4	3	3	1	3	2	178.61	4,750
LIFO	3	3	4	3	3	3	3	1	186.46	3,019

Conclusion

Resource allocation, batching and dispatching problem is considered for jobs of different types arriving to a flexible flow shop consists of several work centers with multiple identical machines at each. A simulation model has been developed using ARENA for this problem which is highly stochastic in terms of the arrival times of the jobs, jobs processing times at each work center and machines sequence dependent setup times. The objective of this study is to find the best dispatching rule with respect to minimizing average flow time while determining the batch size and the optimal number of machines at each work center. Two dispatching rules were tested and FIFO was found to give better results for the considered performance measure. The developed model can be used for deciding upon the number of machines and the way of batching and dispatching for any flexible flow shop with similar configuration.

As future work, other possible dispatching rules can be considered for improving various performance measures in additions to the ions considered here. Furthermore, some assumptions can be relaxed for testing under general conditions with respect to processing times, inter-arrival times and maximum resource availability. More detailed sensitivity analysis may be conducted with respect to problem parameters and shop conditions.

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References

[1] H. Chtourou, W. Masmoudi and A. Maalej: *an expert system for manufacturing systems machine selection*. Expert Systems with Applications, Vol. 28 (2005), p. 461

[2] U.M. Al-Turki, S. Arifusalam, M. El-Seliaman and M.Khan: *Resource allocation and batch sizing in a flexible job shop*. Advanced Materials Research, Vol. 264-265 (2011), p. 1758

[3] T.S.C. Felix, J. Bing and K.H.T., Nelson: *the development of intelligent decision support tools to aid the design of flexible manufacturing systems*. International Journal of Production Economics Vol. 65 (2000), p. 73

[4] C. Liu and S. Change: *scheduling flexible flow shops with sequence dependent setup effects.* IEEE Transactions on Robotics and Automation Vol. 16 (2000), p. 408

[5] D. Cao, M. Chen and G. Wan: *parallel machine selection and job scheduling to minimize machine cost and job tardiness*. Computers and Operations Research Vol. 32 (2005), p. 1995.

[6] G. Kyparisis and C. Koulamas: *flexible flow shop scheduling with uniform parallel machines*. European Journal of Operational Research Vol. 168 (2006), p. 985

[7] D. Quadt and H. Kuhn: *batch scheduling of jobs with identical process times on flexible flow lines*. International Journal of Production Economics, Vol. 105 (2007), p. 385

[8] I. Badr: *an agent-based scheduling framework for flexible manufacturing systems.* World Academy of Science, Engineering and Technology, Vol. 40 (2008), p. 363-369

[9] J.C. Chen, K.H. Chen, J.J. Wu and C.W. Chen: *a study of the flexible job shop scheduling problem with parallel machines and reentrant process.* The International Journal of Advanced Manufacturing Technology Vol. 39 (2008), p. 344

[10] A. Allahverdi: *two-machine proportionate flow shop scheduling with breakdowns to minimize maximum lateness*. Computers and Operations Research Vol. 23 (1996), p. 909

[11] A. Allahverdi and M. Tatari: *simulation of different rules in stochastic flowshops*. Computers and Industrial Engineering Vol. 31 (1996), p. 209

[12] Ali Allahverdi: *stochastically minimizing total flow time in flow shops with no waiting space.* European Journal of Operational Research Vol. 113 (1997), p.101

[13] R. Ruiz, J. Diaz and C. Maroto: *considering scheduling and preventive maintenance in the flowshop sequencing problem*. Computers and Operations Research Vol. 34 (2007), p. 3314

[14] E. Aghezzaf, M. Jamali and D. Ait-Kadi: *an integrated production and preventive maintenance planning model*. European Journal of Operational Research, Vol. 181 (2007), p. 679

[15] H. Allaoui, A. Artiba, G. Goncalves and E. Elmaghraby: *scheduling n jobs and preventive maintenance in a single machine subject to breakdowns to minimize the expected total earliness and tardiness costs*. Proceedings of the 17th World Congress, the International Federation of Automatic Control, Seoul, Korea (2008).

[16] E. Moradi, S. Ghomi and M. Zandieh: *bi-objective optimization research on integrated fixed time interval preventive maintenance and production for scheduling flexible job-shop problem*. Expert Systems with Applications, (2011), in press.