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Faculty of Engineering

Common Cycle and Cyclic Scheduling in Job Shop Production Systems

By

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B.Sc. in Mechanical Engineering (Production Section)

A thesis submitted for the degree of M.Sc. in Mechanical Engineering (Production Section)

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Statement

This thesis is submitted, to Ain Shams University, for the degree of M.Sc. in Mechanical Engineering (Production Section).

The work included in this thesis was carried out by the author in the Department of Design and Production Engineering, Ain Shams University.

The author carried out the work included in this thesis, and no part of this thesis has been submitted for a degree or a qualification at any other university or institution.

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Abstract

Research in the field of the Job-Shop Scheduling was given little attention as compared to that given to the Flow-Shop Scheduling Problems. In addition, most of researches, which tackle the scheduling problems, aim at minimizing the total make-span and in most of the cases with no-wait allowed for the products. Little attention has been given to consider the role of cost on determining such schedules. In the present work the Common Cycle Scheduling Problem (CCSP) and the Cyclic Scheduling Problem (CSP) in the job-shop environment are considered. This production problem is concerned with determining the optimal production schedule and lot sizes for a given set of products using a number of machines. The CCSP is based on scheduling a number of products using a common (base) cycle time, so that the lot size for each product is the forecast demand of certain product over the base cycle time. The CSP is based on allocating different products to different basic cycles, so that each product is produced in equal lot sizes spaced equally apart, by a period that is an integer of the basic cycle time. The produced quantities should satisfy the expected demand in that period, until the product is reproduced. When producing the same products repetitively, it is preferred to minimize the production costs rather than the make-span. The costs considered are the setup, in-process inventory, queuing, finished products inventory holding, as well as machine delay and lost-sales costs. Genetic Algorithm is used to solve the CCSP for a multi-stage, multi-product, job-shop environment under deterministic and stationary conditions, allowing the products to wait between the different stages. The same Genetic Algorithm is used with an allocation procedure, to allocate the products to the different basic cycles, for the same problem. Applying the proposed model to minimize the make-span of benchmark instances was used as a factorial experiment to adjust the Genetic Algorithm's parameters. The model was proved to be successful in determining the common cycle and cyclic schedules that minimize the total scheduling cost per unit time in a job-shop environment.

The keywords: Common Cycle Scheduling, Cyclic Scheduling, Job-Shop Scheduling, Lot Sizing, Genetic Algorithm.

Summary of the M.Sc. Thesis entitled:

"Common Cycle and Cyclic Scheduling in Job Shop Production Systems"

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Scheduling problem is one of the most detailed problems in production planning area as it requires detailed information of the processing times and production sequences. Many efforts were made to solve optimally the scheduling problems under various configurations; however, due to the combinatorial nature of the problem, as it is proven to be NP-Hard problem, reaching optimal solution is not an easy task. Efforts are diverted to heuristic techniques and algorithms, opting to reach near optimal solutions besides they can easily be applied. Most of the developed heuristics and algorithms targeted the flow-shop and job-shop problems in which make-span is minimized with no-wait. Much less work was done to consider the role of cost on determining such schedules. In the present work the Common Cycle Scheduling Problem (CCSP) and the Cyclic Scheduling Problem (CSP) in the job-shop environment are considered. This is concerned with determining the optimal production schedule and lot sizes for a given set of products processed on a number of machines.

In the Common Cycle Scheduling Problem (CCSP) a set of products is being manufactured in the same scheduling sequence and lot sizes in repetitive cycles to meet continuous stationary demand. The objective is to obtain the sequence and the quantities being manufactured during the cycle. The CCSP can be applied in both flow-shop and job-shop environments. The job-shop exists excessively in the batch production system.

In the Cyclic Scheduling Problem (CSP) a set of products is being manufactured in the same lot sizes in repetitive cycles to meet stationary continuous demand. Each product has a certain period over which it is reproduced. The period is an integer of a basic cycle time, which may differ from one product to another. This integer is determined using a heuristic that depends on cost elements as well as the demand rates. The allocation of products to the different basic cycles depends on the total work content of the products and cycles to obtain close cycle times. The sequence of each basic cycle and the quantities being processed of each product are obtained by following the CSP scheduling concept. The CSP can be applied in both flow-shop and job-shop environments.

In literature, there are many algorithms that were developed to solve the scheduling problem of multi-products on a single stage and for multi-products on multi-stages in both flow-shop and job-shop. However, research in the field of the job-shop scheduling was given little attention as compared to that given to the flow-shop scheduling. One of the algorithms which proved to be superior in determining a near optimal solution in general and the job-shop problem in particular is the Genetic Algorithm (GA). The governing factors of the performance of the GA are the crossover and mutation operators, the population size and the mutation rate. Many crossover operators were developed to suit the job-shop scheduling problem such as: Set-Partition, Precedence Preservative, Partially Mapped, and Subsequence Exchange. Some mutation operators were developed for the scheduling problems such as: Adjacent Swap, Random Swap, Shift Mutation and Inversion Mutation. The GA is not widely used in solving CCSP due to the difficulty of forming a chromosome containing the products' sequence and the lot size.

The purpose of this research is to solve a CCSP and a CSP for a multi-stage production facility, each product is assumed to be produced in lots of sufficient size to satisfy the demand of that product (if possible) until it is

reproduced in the next cycle. A job-shop production environment is assumed, where all products follow different routes over the machines (stages). The processing order of the products over the machines and the processing times are known. Machines setup times are known and they are independent of the previous product being processed on the machine. It is also allowed for the products to wait between the different stages if the next machine is still busy processing another product. The objective is to find the sequence and lot sizes which minimize the total cost per unit time.

The total cost consists of the holding (carrying up) costs of waiting product inventory, the total setup cost, total machine delay cost and lost-sales cost. Inventory cost (holding cost) is calculated based on the condition of the material being processed, which may take one of the following three forms. First, holding cost is calculated for in-process inventory when lot items are either waiting for their order to be processed on the machine or waiting for the rest of the lot items to finish processing before being pushed to the next stage within a lot. Second, holding cost is calculated if lots are waiting the next machine to finish processing of a previous lot in the sequence. Third, the holding cost is calculated for finished product inventory when the finished products are stored during consumption according to the demand rates. Setup cost is calculated each time the machine is set for the next lot; it is independent on the lot size, and the previous lot being processed on the machine. The total machine delay cost is calculated per unit time for the time the machine is being idle, either waiting for the next lot to arrive for processing or the lot sizes of the products produced during the previous cycle to be consumed if they satisfy the demand for a period longer than the cycle time. Lost-sales cost is calculated per unit and it may take place when the lot size is less than the demand during the cycle time.

As previously mentioned, scheduling problem in general is considered NP-hard problem due to their combinatorial nature. In order to solve such problem GA is used, where the total cost per unit time is the fitness function and the chromosome consists of two parts, the first part represents the lot size (as represented by the consumption time, which is the time needed to consume the products), and the other part represents the sequence. The consumption time is represented as decimal numbers, while the sequence part is represented by the operation-based representation presented by Sannomiya et al. The crossover operator is Two-Points crossover for the binary form of the consumption time part and a newly developed Best Hybrid crossover for the sequence part. The mutation operator is Inversion for both parts. The Population Size is 20, the Crossover Fraction is 0.9, the number of elite children for each generation is one, and the number of generations is 2000. The initial population is generated randomly and the selection function is stochastic uniform.

The developed model is tested on 82 job-shop benchmark instances to find the optimal make-span in order to test the ability of the model to solve job-shop scheduling problems, and determine the best GA parameters. The developed model is used to solve randomly generated problems to study the effect of changing the demand rates and the different cost parameters on the total cost per unit time. Lot sizes of each product and the production sequence are randomly generated and set to be fixed then each of them is changed separately and the total cost per unit time is calculated to understand their effect on the total cost function. Then the demand rates as well as each cost parameter are changed individually and the problem is solved using the developed model.

Randomly generated problems are used to compare the performance of the CCSP and CSP approaches. Each instance is solved twice, once to minimize the total cost per unit time associated with the CCSP approach, and the other to minimize the total cost per unit time associated with the CSP approach. The CCSP and CSP approaches are compared under different cost parameters and different demand rates.

Finally, Experiments are made for randomly generated problems to compare the different objective functions, namely minimizing the adjusted cycle time and minimizing the total cost per unit time. Each instance is solved thrice. The first objective function is to minimize the adjusted cycle time and the associated total cost per unit time is calculated as a CCSP. The second objective function is to minimize the total cost per unit time as a CCSP and the corresponding adjusted cycle time is calculated. The third objective function is to minimize the total cost per unit time as a CSP and the corresponding adjusted repeated cycle time is calculated. All adjusted cycle times are compared as well as the total cost per unit time associated with each solution, under different cost parameters and different demand rates.

The model has proved to be successful in reaching the optimal or near-optimal make-span of the tried benchmark instances. The results proved that, in most cases it is more economical to consider minimizing the total cost other than minimizing the make-span, where in certain cases both objectives are approximately equal. The cyclic scheduling approach proved to be superior to the common cycle scheduling approach in most cases, especially when the variation between the products is high in the demand rates, holding costs and total setup costs.