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An application of genetic algorithm into order scheduling of a textile company

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ABSTRACT
Scheduling not only poses a significant complexity problem in manufacturing inside each of enterprise but extending to the competitive landscape among enterprises as well. The footwear industry, particularly in the field of accessories for shoe production, is no exception to this challenge. This research paper addresses scheduling issues that arising in the dyeing plant, for the product of shoelaces with various restrictions such as color, machines resource and the demand uncertainty. By emerged the Genetic Algorithm (GA) as modeling evolutionary system, incorporating the two-point crossover, swap mutation operators, and k-tournament selection, which are the operators that mainly used in the job shop and flow shop environment, to the scheduling of machine in parallel environment. The purpose of such the application is to find the efficient allocation of jobs, focus on addressing order lateness by minimizing the total completion time of all batches. The optimization results demonstrate the schedule of a one-day scenario production, providing practical insights into the benefits of GA when comparing to the MILP and current scheduling method of the company. Overall, the research contributes valuable findings to the field of textile dyeing scheduling, offering a robust solution to enhance production efficiency, resource utilization, and order sequencing in the footwear auxiliary enterprise.

Keywords: *genetic Algorithm, machine in parallel, dye scheduling, total completion time*

1. INTRODUCTION

The scheduling problem poses a significant complexity across various industries involved in manufacturing. It transcends the internal challenges faced by individual businesses, extending to the competitive landscape among producers [1]. A more reasonable use of resources, equipment, and efficiently use of time, manufacturers could gain a lot of advantages such as cost reduction and optimal utilization of production facilities.

Research on optimizing production in textile dyeing often neglects the specific challenges of scheduling in dyeing workshops due to varying production conditions such as varying technologies and resources capabilities [2]. Studies by Pinto and Grossmann. [3] and Cerda et al. [4] emphasize the short-term scheduling of batch plants and multiproduct scheduling in parallel flow shop environments, respectively. The former study of Pinto and Grossmann focuses on determining production plans that align with demands for various products and due dates, while the latter study of Cerda et al. addresses the minimization of overall tardiness using Mixed-Integer Linear Programming (MILP) approach to optimize job allocation, considering constraints of job relationships and changeover times.

Beyond MILP, genetic algorithms gain popularity for their efficiency in addressing scheduling challenges with a reasonable computational time based on the principles of natural evolution by [5]. With the application of Genetic Algorithm into the textile dyeing batches, Huynh and Chien [6] has employ the Multi-Subpopulation Genetic Algorithm with Heuristics (MSGA-H) to minimize makes pan in textile dyeing scheduling, presenting a practical solution to alleviate bottlenecks in production schedules. In the case of flow shop, with the using of roulette wheel methods, mutation, and crossover processes, Harwin Kurniawan and authors has successfully created production schedules with a lower total makes pan its previous method, along with the application of GA to get a

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better result within a shorter time [7].

This research addresses scheduling challenges in the dyeing plant of one footwear auxiliary's enterprise. Specifically, the study considering parallel machines with identical functions across different machine lines, limitations on the colors and capacities of each machine can process, and a non-preemptive manufacturing environment. With the application of Genetic Algorithm (GA) has emerged as an as both a searching method and a modeling evolutionary optimization approach for the company's scheduling system [8], the primary research objective centers on the minimizing the total completion time of all batches in the production stage, from that mitigating order lateness. But do not limit at the calculation for example problem that provided by [6], the GA that this research develop is to apply in a case of real working situation of business, with utilizing real data processed for confidentiality from a dyeing auxiliary's enterprise and the employ of Python language. The case presented as follows: Section 2 outlines the manufacturing environment and mathematical model used for optimization. Section 3 decoding the genetic algorithm operators, while the final section presents computational results derived from the case study.

2. MATHEMATICAL FORMULATION

2.1. Problem Statement

The research focuses on the continuous production of the dyeing process, in a typically m identical machine in parallel P_m with set of M_j denotes the set of machines that can process job j [9], with the application of different types of genetic operators, which are mostly use in the case of flow shop and job shop, to apply into the case of machine in parallel environment. The application of GA in textile manufacturing has been proved the efficiency through various research [10-11]. For more detail, Paper addresses the constraints of machine resource capabilities with consideration for job due dates, the job is to assigned J batches on that M machines. Each of the batches will characterize by their color, weight, and due date. As the same concept, the machine also has its own capabilities and color to process, which means that, only the batches that have the appropriate weight and color could assigned to a specific machine that could process that batches.

The objective is to minimize the make span, representing the total completion time of all the batches. The paper assumes no preemption, meaning batches must be completed without interruption once production begins. All batches have equal processing times denoted as p_j and each machine can process only one batch at a time. Simultaneously, each batch can be assigned to at most one machine with the ability to process it. Additionally, both machines and batches are available at time 0, allowing immediate integration into production after scheduling.

2.2. Mathematical Notations

Sets and Indexes:

M: Set of machines, M = {1, 2, ..., k}
J: Set of batches, J = {1, 2, ..., n}
F: Set of color family, F= {1, 2}
m: machine index
j: batch index
f: color family indexes

Parameters:

$\alpha_{j,f} = 1$ *if batch j belongs to color f*, 0 *otherwise*
$p_{j,m}$: *processing time of batch j on machine m.*
d_j : *due date of batch j*
$W_{j.i}$: *weight in kilograms of batch j*
Cap_m : *Capacity of machine m*
$\beta_{m,f} = 1$ *if machine m could process color of family f*, 0 *otherwise*

Decision variables:

$X_{j,m} = 1$ *if batch j is processed on machine m*, 0 *otherwise*
C_j: *Completion time of batch j.*
$t_{j,m}$: *starting time of batch j on machine m*

2.3. Mathematical Model

Objective Function:

$$Min\ F = Min\ \sum_1^J C_j \qquad (1)$$

Contraints:

$\sum_1^J X_{j,m} \leq 1,\quad \forall\, m \in M;$ (2)
$\sum_1^M X_{j,m} = 1,\quad \forall\, j \in J;$ (3)
$X_{j,m} \leq \alpha_{j,f} * \beta_{m,f},\quad \forall\, f \in F;$ (4)
$X_{j,m}\ W_j \leq Cap_m,\quad \forall\, j \in J;\ \forall\, m \in M;$ (5)
$\sum_1^J X_{j,1}\ p_{j,m} \leq 24,\quad \forall\, m \in M;$ (6)
$t_{j,m} \geq t_{j',m} + p_{j',m}\ X_{j',m}\quad$ *for* j' *is processed before* j, $\forall j, j' \in J;\ \forall\, m \in M;$ (7)

$C_j = t_{j.i,m} + p_{j,m}\ X_{j,m}$ $\forall j \in J; \forall m \in M; (8)$
$t_{j,m}, C_j \geq 0,$ $\forall j \in J; \forall m \in M; (9)$
$X_{j,m} \in \{0,1\},$ $\forall j \in J; \forall m \in M; (10)$

The objective of the model is to find a feasible schedule of batches that gives a minimum value total processing time (1), from that aim to minimizing the total lateness of all batches in the production while satisfying all the resources constraints as follows. (2) One machine is not assigned to more than one activity in any given slot, (3) every batch is assigned to at most one resource of machine, these 2 constraints ensure that the situation of more than 1 different batches is assigned into one slot of a machines. Constraint (4) is the capabilities constraints; Batches are eligible for assignment to a machine only if their color aligns with the machine's capability. (5) denotes machine capacity constraint, if one batch is assigned into a machine, then its weight cannot exceed the current capacity of that machine. Simultaneously, constraint (6) state that the total processing time of one machine for all batches assigned to it in 1 day cannot exceed 24 hours. Constraint (7) ensure the non-overlapping sequence of batches that assigned on the same machines, the starting time of the following batch must equal or larger than the sum of starting time and completion time of previous batch. Constraint (8) define the completion time of each batch in one machine. Constraint (9) verify the value of variables of starting time, lateness and completion time of batches are nonnegative. Constraint (10) guarantee the binary value of assignment variables.

3. SOLUTION APPROACH

The Figure 1 illustrating how the Genetic Algorithm applied into the scheduling research [12, 13]. Initially, batches are reorganized to align with the representation of chromosomes participating in the optimization process, which will be discussed in the section of 3.1. Feasible schedules, referred to as chromosomes in the evolutionary system, are defined to satisfy constraints and are added to the Initial population. Subsequently, the algorithm calculates fitness values and conducts selection for reproduction, the selection of individuals in the population will be based on their fitness value, the selection strategy that the research using is the K-tournament selection. The research employs two-point crossover, where genes between two random crossover points on parent chromosomes are exchanged (Section 3.2). Additionally, the mutation method that the research apply is the Swap Mutation Operators [14], mutating a random semester block by swapping one gene with another (Section 3.4). The reproduction process continues iteratively until it meets the termination criteria, which is the convergence of when the objective function remains unchanged for a specified number of reproduction cycles. At this point, the algorithm concludes and exports the current results as the best solution identified within the iterative schedule generation loop.

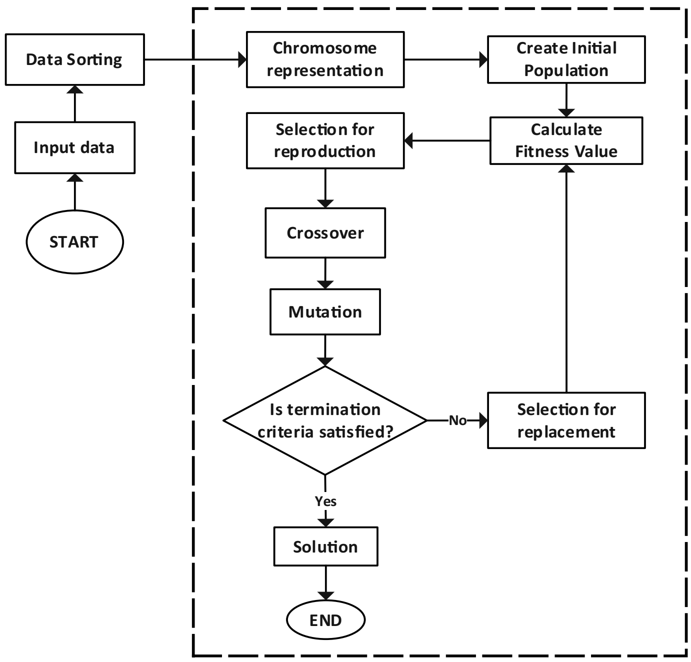

Figure 1. Methodology of the research

3.1. Chromosome Representation

The proper representation of chromosomes plays a crucial role in the efficacy of Genetic Algorithms (GAs) within various applications. In this research, we adopt the chromosome representation method proposed by [15], which involves utilizing a string of machine resources that corresponds to each slot of the gene in the chromosome as illustrated in Figure 2.

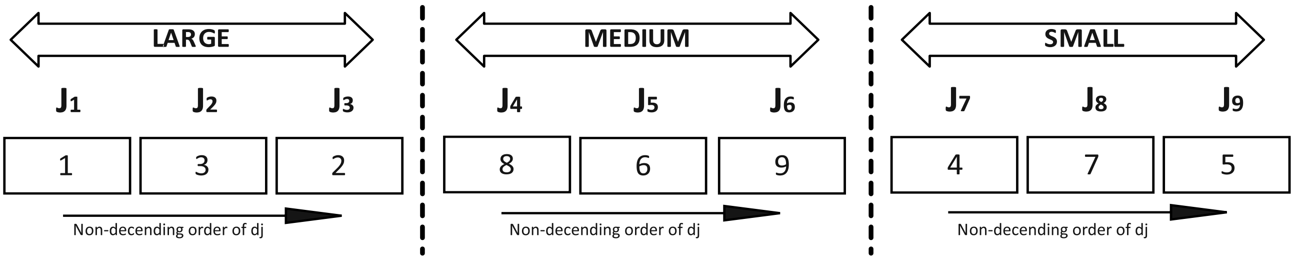

Figure 2. Chromosome representation

To elaborate, a preprocessing step is introduced wherein 9 batches are initially categorized into Large, Medium, and Small based on weight, aligning with machine capacities. Within each weight category, orders then sorted in non-descending order of due date (d_j) which prioritize those with the nearest deadlines during machine assignment (Figure 2). In which J_1, J_4 and J_7 within the chromosome responsively acquire the highest and second-highest priority in each of the string types. The length of each chromosome is set equal to the total number of batches that require processing; the GA then allocates the appropriate machine M_k to handle the assigned batch J_j by leveraging the gene slot. The initial appearance of a machine signifies that the associated batch will be processed during the first time slot, the second appearance will process the corresponding batches at second time and so on. This utilization of machine capabilities in different time slots enhances the adaptability of the algorithm.

3.2. Crossover

The crossover in GA is aiming at generating new chromosomes (offspring) from pairs of parents. The specific method utilized is the Two-point crossover, involving the cutting and random exchange of Batch types (categorized as Large, Medium, and Small) between parent pairs, then create the offspring from those interchanged segments. For each parent pair, three random numbers (between 0 and 1) are generated. At the first random number, if it smaller than the given crossover probability, then the first part will be taken from the Parent 1, otherwise it is inherited from Parent 2, the scenario is the same to the remaining parts of the parents with another two times of random generated number.

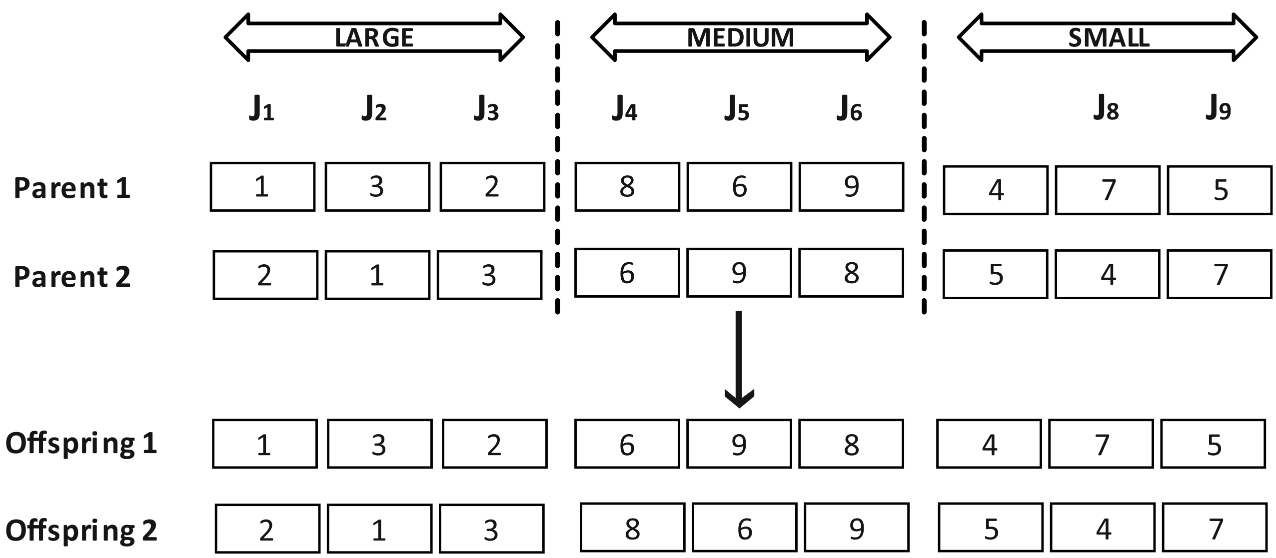

Figure 3. Two – point crossover

3.3. Mutation

The mutation is representing one new offspring when being generated would suffer a chance of being change after the selection (with the given mutation probability). The Swapping mutation used in the research randomly selected 2 batches from one strings of order type (Large, Medium, or Small) and swap the 2-slot position. In the provided Figure, for instance, machines 8 and 9 are selected for swapping in the sequence of operations. The same mutation scenario applies to both large and small order strings if a mutation event occurs during reproduction.

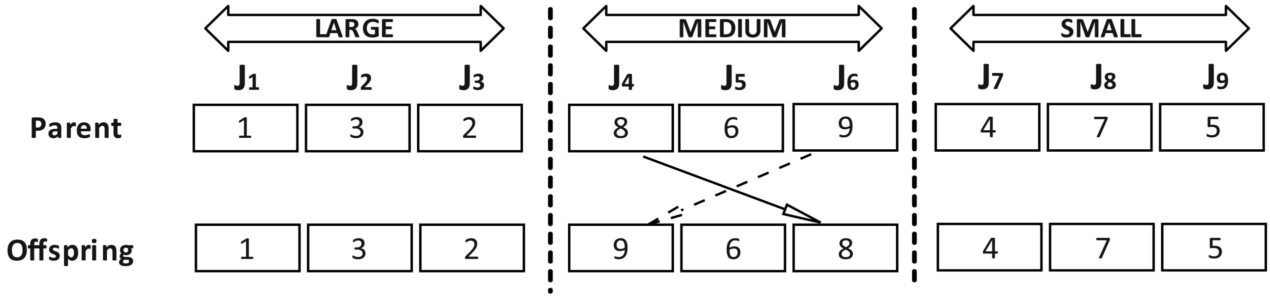

Figure 4. Swap mutation

3.4. Selection Method

The selection method is used to choose the good pairs of parents for the reproduction in the steps of crossover and mutation. The K-tournament selection conducted in this research selecting k individuals from the population, organizing a tournament among them, and selecting the winner with the highest fitness value for reproduction. The selection will be repeated until the desire number of individuals are inserted into the population. The k value represents the selection pressure, which the larger value promotes the prior to the current individuals with the good fitness while the smaller value favoring the exploration of new individuals. K-tournament maintaining the variability in the population, contributing to the GA's ability to explore a broader solution space and potentially discover more optimal solutions to the given problem.

4. OPTIMIZATION RESULT

4.1. GA optimization result

The case study undertaken in this research involves scheduling one-day orders for the company. The input data comprises 132 batches categorized by weight and color from customers (Appendix), and the due date is converted to hours using the formula: d_j *(hours) = [*d_j *(date) – scheduling date]* * 24. The aim is to allocate these batches to the machine resources with 48 machines specifically with the color capability and the capacity, the processing time of all batches is 6 hours (Appendix). The scheduling model with GA is conducted using the Python language on a computer equipped with a 3.20 GHz CPU and 8.0 GB RAM. The result showed in the figure 5 below illustrates the changes in the fitness per generation. Figure 6, on the other hand, provides the Gantt chart for the best schedule obtained after 200 convergences of fitness values, with the crossover and mutation rate are 0.8 and 0.2, respectively to all scenarios provided in the Table 1. The term "generation convergence" refers to instances where new generations are created without a concurrent improvement in fitness values. The running time of the model is 332 seconds with 3 late batches of 7, 8 and 16.

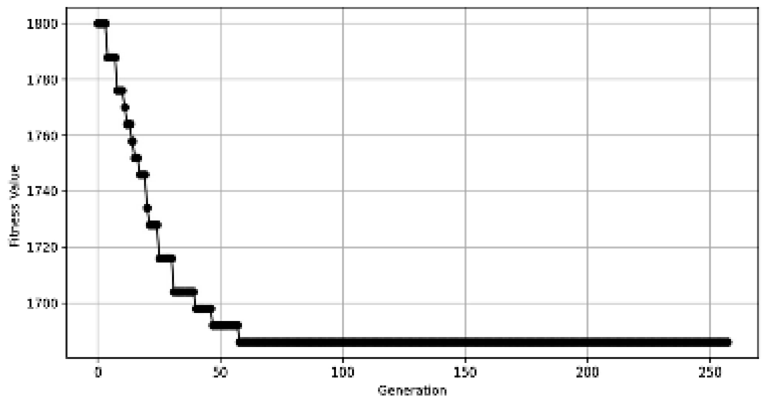

Figure 5. Fitness evolution respective with generations

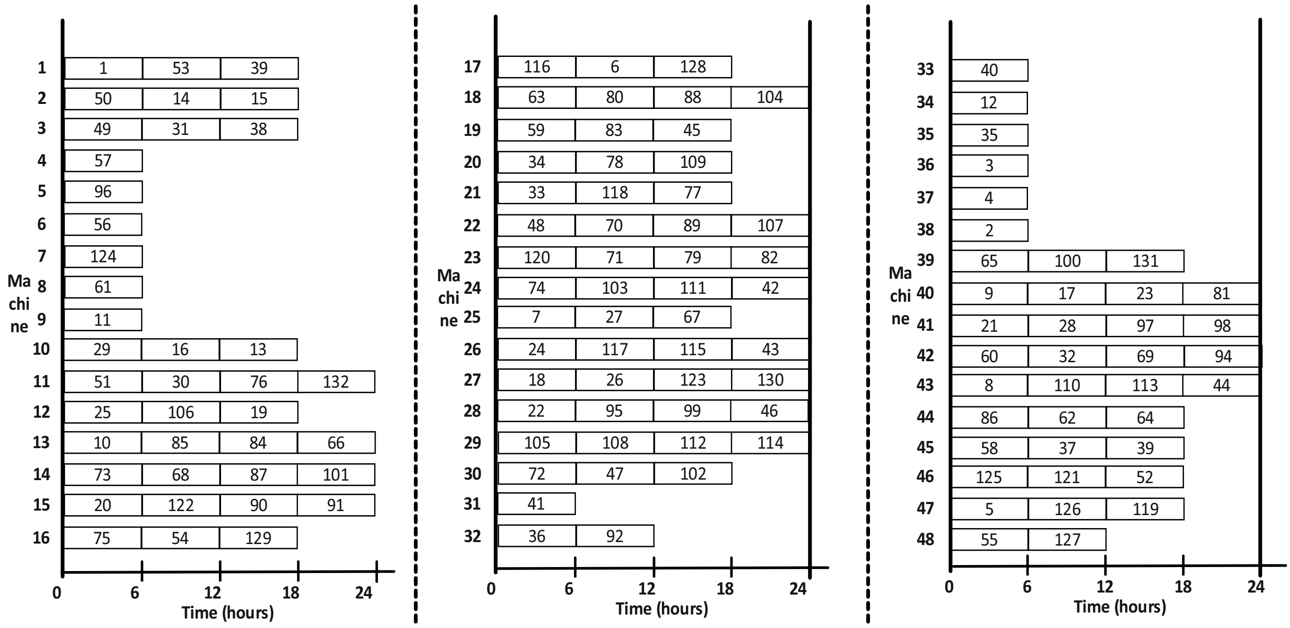

Figure 6. Gant chart

4.2. Comparation of Methods

In other to demonstrate the efficiency and the contribution of the GA initialization in generating dyeing schedule within a multiple machine type in parallel environment. The scheduling experiment has been launched using the application of Mix Integer Linear Programming (MILP), using the Excel Solver to solve for the model. The result of the scheduling by MILP along with the comparation to GA results will be provided in the Table 1.

Table 1. Comparation of Scheduling methods

Method		Calculating time (seconds)	Total Completion Time	Number of Late batches	Late batch
Scenario	Loop Convergence				
GA 1	50	53	1710	6	7, 8, 53, 15, 16, 31
GA 2	100	124	1698	4	7, 8, 50, 53
GA 3	200	332	1686	3	7, 8, 16
MILP		1920	1686	3	7, 8, 16

The schedule results from the GA with 3 different number of the loop convergence (a termination criteria that counted the number of generations which has no changes in the fitness value) showed a significantly improvement in the fitness function and the number of late batches. Alongside with the solution of GA is the application of the model by using MILP, which also give a similar result as the best solution that GA provided among 3 scenarios. The two approaches give a feasible schedule while minimizing the total completion time and reduce the number of late batches from 46 late batches (using the current scheduling method of the company) to 3 batches only, which contribute a lot to the planning stage of the business. However, the calculating time that the MILP model takes is more than 6 times longer than the calculation time of GA application, it would affect to the working environment as applied into the real situation, so that for a better working experience, the use of GA has contribute more compared to both the MILP and the current scheduling method of the company.

5. CONCLUSION AND FUTURE RESEARCH

The paper is successfully conducting research on the application of Genetic Algorithm (GA) in the scheduling method of one dyeing plant. Addressing the issue of order lateness within the production environment, which includes various color restriction, machine resources capabilities and capacities, uncertain demand from customers, the primary objective is to minimize the total completion time of all orders which contributes to lowering the rate of late orders in the plant. The optimization result is an example of one-day scheduling using GA. With the reasonable computational time, demonstrates its ability to adapt to the current scheduling method of the company. The benefits of the approach not only saving time but the efficiently utilizes machine resources and tackles order sequencing problem, thereby enhancing the production efficiency.

However, there are still many potential directions for future research. As the current study focuses on scheduling applications under conditions of stable demand and certain machine operating conditions, future research could expand to address the challenges of dynamic environments in dyeing plants, thereby enhancing the flexibility of the model. Moreover, while this research tackles real-world situations, it has not been directly applied in a working environment. Thus, further research could integrate this scheduling approach into the planning systems of companies to verify the algorithm's effectiveness. Another avenue for future research could involve modifying the objective function, future modifications could target other objectives, such as minimizing the total number of late orders, optimizing the utilization of machine working hours, reducing the system's make span or aiming to reduce all the cost types that contribute to the production process.

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Ứng dụng giải thuật di truyền vào công việc điều độ đơn hàng của một công ty dệt may

Lê Đức Hạnh, Lê Đức Đạo và Ngô Xuân Minh

TÓM TẮT

Lập kế hoạch sản xuất luôn là một một vấn đề phức tạp đối với hầu hết các doanh nghiệp, vấn đề không chỉ dừng lại ở nội bộ doanh nghiệp, công ty có một hệ thống điều độ tốt có thể chiếm ưu thế cạnh tranh với các doanh nghiệp cùng ngành hàng. Ngành giày, đặc biệt là trong lĩnh vực phụ kiện cho sản xuất giày, cũng không phải là ngoại lệ. Để đáp lại những thách thức ấy, bài nghiên cứu này đề cập đến các vấn đề lập kế hoạch trong nhà máy nhuộm, đặc biệt là đối với sản xuất dây giày với nhiều hạn chế về màu sắc, nguồn lực máy và nhu cầu không ổn định. Với việc áp dụng Giải thuật Di Truyền (GA) tích hợp phương pháp lai chéo hai điểm, đột biến hoán vị và lựa chọn thế hệ k tournament, là những phương pháp thường dùng cho môi trường flow shop và jobshop, với mục đích tìm kiếm phân công công việc hiệu quả, tập trung vào giảm thiểu thời gian hoàn thành tất cả các lô hàng để giải quyết vấn đề trễ đơn hàng trong môi trường máy song song. Kết quả của mô hình mô tả lịch trình sản xuất trong một ngày, mang lại cái nhìn thực tế về lợi ích của GA. Nói tóm lại, nghiên cứu đóng góp những kết luận quan trọng cho lĩnh vực lập kế hoạch nhuộm dệt, đưa ra một giải pháp để nâng cao hiệu quả sản xuất, sử dụng nguồn lực và sắp xếp lịch trình hợp lý, đồng thời so sánh kết quả của GA với MILP và phương pháp hiện tại mà công ty đang sử dụng, cho thấy độ hiệu quả của GA khi áp dụng vào môi trường điều độ máy song song, với nguồn dữ liệu lớn về đơn hàng và phức tạp về tài nguyên máy móc.

Từ khóa: *thuật toán di truyền, máy song song, lập kế hoạch nhuộm, tổng thời gian hoàn thành*

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