ZERO-WAIT PIPELINE SCHEDULING BASED ON A NOVEL MULTI-LAYER ITERATIVE META-HEURISTIC ALGORITHM

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ABSTRACT: When performing production scheduling, manufacturing enterprises with complex production processes should optimize their scheduling plans as much as possible to achieve zero time waiting (zero-wait) pipeline scheduling. By using random variables to characterize some parameters, the Novel Multi-layer Iterative Meta-heuristic Algorithm (N-MIMA) can achieve global search when performing pipeline scheduling and effectively find out the dominant pipeline scheduling plan. This paper applied the N-MIMA to the problem of zero-wait pipeline scheduling, and the research results showed that, the zero-wait pipeline with setup time requires each factory to consider the processing completion time on each machine under the constraint of machine processing sequence. In addition, with the value function of prospect theory and the customer satisfaction function as evaluation indicators, this paper verified the effectiveness and robustness of the algorithm in solving zero-wait pipeline scheduling problems. The research in this paper provides an algorithm basis for realizing zero-wait pipeline scheduling.

KEYWORDS: production scheduling, Multi-layer Iterative Meta-heuristic Algorithm (MIMA), global search, zero-wait pipeline scheduling

1 INTRODUCTION

Most manufacturing enterprises have to deal with situations such as small production batches, short product life cycles, product model modifications, and frequent order and plan changes, etc. (Liao et al., 2019; Castro, 2017). Under such conditions, reasonable production planning and scheduling is extremely important, and producing the right products with the lowest cost within the right time has become the key to the success of manufacturing enterprises (Castro & Mostafaei, 2017; Chen et al., 2019). Due to the complex manufacturing techniques and the limited production capacity, the production process needs good production planning and scheduling schemes to balance the production load within a limited time; therefore, a tight production planning and scheduling scheme is the basis for enhancing the competitiveness of an enterprise (Zhang et al., 2018). Production planning generally deals with resource demand and rough distribution; it focuses on the balance between business plan and production capacity, and the time frame it considers is longer. Production scheduling mainly includes the specific arrangement of processing operations and the detailed arrangement of resource allocation, various constraints of the actual environment are involved; it focuses on the balance between equipment allocation and production materials, and the time frame it considers is shorter (Mastoras & Gross, 2018; Benoit et al., 2013).

Pipeline scheduling is also called the flow shop scheduling. It means that in a processing workshop, there are m machines, and each job must be processed by every machine (Mirhassani et al., 2011; Yang et al., 2003). The zero-wait pipeline scheduling is a common processing organization method for production workshops. In actual processing, it does not allow the existence of waiting time between two consecutive machines, so as to ensure that the jobs can pass through the assembly line without waiting for any machine (Zhang et al., 2017). The N-MIMA makes use of the characteristics of the distributed zero-wait pipeline scheduling problem with setup time and arrival time, in the process of solution generation, it only generates solutions that meet the allocation rule of earliest-completion factory and earliest-arrival workpiece, and at the same time, it intensively searches for high-quality solutions using a variable neighborhood search method (Fang et al., 2018; Liao et al., 2018). This paper studies the application of the N-MIMA in solving zero-wait pipeline scheduling problems, aiming to provide an algorithm basis for realizing zero-wait pipeline scheduling.
2 THE ZERO-WAIT PIPELINE SCHEDULING PROBLEM OF MANUFACTURING WORKSHOPS

The pipeline scheduling problem has the characteristics of complicated, random, multiple constraints and multiple objectives (Li et al., 2016). With the development of just-in-time (JIT) production system, studies on the scheduling problems with ahead-of-schedule or beyond-headline costs are directly related to the cost-effectiveness (Shin et al., 2016; Cafaro et al., 2015). The zero-wait pipeline scheduling problems with sequence-related setup time and release time generally take minimized time cost as the objective, each workpiece must be processed on all machines without interruption, and their sequence-related setup time and release time must be processed clearly (Elmsary et al., 2019). Assume \( A = [j_1, j_2, \ldots, j_n] \) is the processing schedule or sequence of the workpieces, \( p_{ji} \) is the processing time of workpiece \( j_i \) on machine \( l \), \( sp_{ji} \) is the total processing time of workpiece \( j_i \) on all machines, \( ML_{ji,l} \) is the minimum delay time between the completion times of workpieces \( j_{i-1} \) and \( j_i \) on machine 1, \( L_{ji,1} \) is the minimum delay time between the start times of workpieces \( j_{i-1} \) and \( j_i \) on the first machine, \( S_{ji,l} \) is the sequence-related setup time between workpieces \( j_{i-1} \) and \( j_i \) on machine \( l \), set \( p_{ji,l} = 0 \), when \( l = 1, 2, 3, \ldots, m \). Then, \( ML_{ji,1} \) could be calculated:

\[
ML_{ji,1} = \max \{ S_{ji,1} + p_{ji,1} - p_{ji-1,2}, S_{ji-1,j_{i-1},2} + p_{ji,2}, l = 2, \max \{ ML_{ji,l-1} - p_{ji-1,2}, S_{ji-1,j_{i-1},2} + p_{ji,2}, l = 3, 4, \ldots, m \}
\]

where, \( L_{ji,1} \) could be calculated using the following formula:

\[
L_{ji,1} = ML_{ji,m} + sp_{ji} + sp_{ji}
\]

Fig. 1 Classification of scheduling problems

Figure 1 shows the classification of scheduling problems. Production scheduling includes single machine scheduling, parallel machine scheduling, flow shop scheduling, job shop scheduling, and open shop scheduling. The zero-wait flow shop scheduling problem is more complicated than other shop scheduling problems, and the start time and interval time of each flow line must be strictly controlled (Acevedo et al., 2017; Guan et al., 2020).

3 DISTRIBUTION ESTIMATION ALGORITHM FOR ZERO-WAIT PIPELINE SCHEDULING PROBLEMS

3.1 Estimation method for scheduling problems with setup time

Zero-wait pipeline scheduling is a special pipeline scheduling problem. The actual processing process is often restricted by processing technology or processing equipment, the processing process of jobs on all machines should be continual and uninterrupted, once the processing of a workpiece on a machine is completed, it must be immediately moved to another machine to continue the processing (Zhang and Xu, 2015; Peng et al., 2019). All processing processes have designated plans, and these plans need to consider the dispatching of workpieces in different factories and the dispatching of workpieces within a same factory at the same time. Different workpiece dispatching methods will lead to different scheduling results, and thus affecting the efficiency of the supply chain system (Nguyen & Lee, 2018).

The zero-wait pipeline with setup time requires each factory to consider their respective processing completion time on each machine under the constraint of machine sequence. According to the performance of different algorithms, local search algorithms are mostly adopted for pipeline problems. Since the ultimate quality of the solution is directly affected by the processing sequence of the factory that is the last one to complete the processing, and the local search is conducted cyclically, the algorithm works for every factory, and it needs to perform in-house insertion, in-house flip, and in-house exchange. Based on local search algorithm, the workshop scheduling performance was simulated, three factors were included, population size, proportion of dominant individuals, and learning rate. The images below show the trends of the parameters, Figure 2(a) is the population size, it can be seen that the both small-size population and large-size population cannot achieve certain search depth; Figure 2(b) shows the proportion of dominant individuals; only by selecting an appropriate control parameter value can higher proportion of dominant individuals be obtained; Figure 2(c) shows the learning rate; a higher proportion of dominant individuals will cause the learning rate to decline, resulting in premature convergence of the simulation process.
and is assembled into a product in a factory; all products are processed and assembled on a same assembly machine in a same assembly factory. Figure 3 shows the flow of distributed permutation. First, an initialized probability matrix is set, and the generation is set to 0; then, p individuals are generated by sampling the probability matrix, and perform local search to find the best individual, choose the best individual and update the matrix, if the stop condition is met, the distributed permutation is terminated.

**Fig. 3 Flow of distributed permutation**

4 ZERO-WAIT PIPELINE SCHEDULING BASED ON N-MIMA

**Fig. 4 Uncertain events in processing process**

In a production system, there are many uncertain events, and the occurrence of these uncertain events will interfere with scheduling decision makers' cognition of the real-time production system, and it will affect the implementation of the determined scheduling plan. Figure 4 shows uncertain events in the processing process, including system uncertainty, process uncertainty, external environment uncertainty, and discrete uncertainty. Most production pipelines adopt the hybrid pipeline, and the various uncertain events in the environment of the hybrid zero-wait pipeline have higher requirements for production scheduling. The N-MIMA can use random variables to characterize some parameters, and can output the sensitivity
analysis of the scheduling, when performing pipeline scheduling, it can ensure to perform global search of the scheduling and effectively find out the dominant pipeline scheduling plan. This paper applies N-MIMA to simulate pipeline scheduling. In a hybrid zero-wait pipeline processing environment, assume the processing speeds of three processes are respectively $v_1$, $v_2$, and $v_3$, and the number of workpieces to be processed is $n$, the value of $n$ is set to 100; then, set the processing time and processing speed of each workpiece in the process set, sort and encode all the workpieces, according to the proportional relationship between the processing time of the workpiece set spent on process 1 and the processing speed of each process, the processing time of the workpiece set spent respectively on process 2 and 3 could be obtained. Figure 5 shows the changes of the distribution uniformity index of non-inferior solution in time windows of different time disturbance. Figures 5(a), 5(b) and 5(c) are respectively the machine disturbance time windows of [60, 90], [140, 170] and [150, 180]. In terms of the dispersion and diversity of the non-inferior solution and the proximity and coverage of the optimal solution, the N-MIMA shows its advantages.

The value function of prospect theory is a subjective function that can judge the subjective impression of decision makers. Figure 6 is the curve
of the value function of prospect theory, it can be clearly seen that the utility and profit shows a monotone increasing function. In the loss area, the sensitivity shows an increasing trend; and in the profit area, the sensitivity shows a decreasing trend; it can be seen that, in terms of same amount of loss and profit, the subjective impression brought by the loss is roughly the same with the subjective impression brought by the profit. Customer satisfaction is related to the delivery time of the product. Customers can bear certain delay in delivery, but their satisfaction will decline, and this requires that the manufacturing enterprises should lay emphasis on the satisfaction with punctual delivery when formulating and executing production plans and scheduling schemes, and reduce customer dissatisfaction caused by early or late delivery. Figure 7 shows the curve of customer satisfaction with delivery time, in the figure, point D is the right-on delivery time, and product delivery within a certain time period (T1, T2) before and after point D is acceptable. Based on N-MIMA, taking the prospect theory value function and customer satisfaction function as evaluation indicators is acceptable, that is, the N-MIMA is effective and robust.

5 CONCLUSION

Based on the N-MIMA, this paper explored its application in zero-wait pipeline scheduling problems, and verified the effectiveness and robustness of the algorithm.

(1) The actual processing process is often restricted by processing technology or processing equipment, the processing process of jobs on all machines should be continual and uninterrupted, once the processing of a workpiece on a machine is completed, it must be immediately moved to another machine to continue the processing.

(2) The N-MIMA can use random variables to characterize some parameters, and can output the sensitivity analysis of the scheduling, when performing pipeline scheduling, it can ensure to perform global search of the scheduling and effectively find out the dominant pipeline scheduling plan.

(3) The subjective impression brought by the loss is roughly the same with the subjective impression brought by the profit. Customers can bear certain delay in delivery. Based on N-MIMA, taking the prospect theory value function and customer satisfaction function as evaluation indicators is acceptable.

6 REFERENCES


