APPLICATION OF HIGH-ORDER MARKOV DECISION MODEL IN THE OPTIMAL SCHEDULING OF RAW MATERIALS IN PRODUCTION WORKSHOP

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ABSTRACT: During the operation of production workshop, the scheduling process of raw materials directly affects the economic benefits of the production workshop, and the high-order Markov decision model can well describe the time series characteristics. In the actual process, the optimal scheduling of raw materials in the production workshop is uncertain and affected by many factors. This paper introduces the high-order Markov decision model to explore its application in the optimal scheduling of raw materials in the production workshop. The research results show that: the cost of raw materials is greatly affected by the scheduling scheme, and the cost of raw materials must be taken into consideration in the process of optimal scheduling. Based on the production of workpieces in an actual production workshop in Zhengzhou city, China, this paper applies the high-order Markov decision model to the scheduling of raw materials in a multi-resource workshop, and finds out that there is a certain scheme that can make the coordination degree, the influence degree of comprehensive efficiency, and the influence degree of comprehensive qualified rate of the optimal scheduling of raw materials at a relatively high level. This research provides a theoretical basis for improving the core production competitiveness of manufacturing workshops.

KEYWORDS: Production workshop, raw materials, high-order Markov decision model, optimal scheduling, scheduling scheme

1 INTRODUCTION

China is a major country for the manufacturing industry around the world, and the manufacturing industry is developing towards the direction of internationalization and globalization. New materials, new energy, and advanced technologies and management methods are emerging constantly as well. Moreover, customers are showing more diversified and personalized requirements for the products (Mao et al., 2012), and the traditional large batch production lines are gradually shifting to the production modes such as production in small-and-medium batches, large-scale customization, and lean production, etc. This process has posed great challenges to the supply and scheduling of raw materials (Nanduri and Saavedra-Antolínez, 2013). With the transformation of production lines, traditional raw material scheduling methods cannot guarantee to achieve the optimal or satisfactory scheduling scheme, resulting in the waste of resources. Furthermore, uncertain factors increase the difficulty of workshop scheduling; even in manufacturing companies with advanced technology and equipment, the scheduling methods based on past experience can hardly exert the superiority of the system (Polotski et al., 2015). According to the types and quantities of resource constraints, the scheduling of raw materials in production workshop can be divided into single resource scheduling and multi-resource scheduling; the scheduling of raw materials in production workshop has the characteristics of diverse scheduling objectives, uncertain scheduling environments, and complex problem solving (Chipoyera, 2016).

The Markov model is a random process commonly used in data mining, which uses a kind of state transition matrix to describe the states’ interdependent relations and transition process (De Bonis et al., 2016; Hu and Zhang, 2018; Xing et al., 2019). The Markov process is a theory that describes the current state and studies the interdependent relations of the states. Using this theory, the transition between states can be estimated so as to establish the state transition probability matrix (Gao & Guo, 2013). When establishing models for the optimal scheduling of
raw materials in production workshop, we need to know that the models under each mechanism are only affected by the current environment, but in reality, the models are affected by more environments; higher-order Markov model can describe the environment and the characteristics of time series, so it can make the predictions more reasonably (Das et al., 2014, Keneally et al., 2016). The optimal scheduling of raw materials in the production workshop is uncertain; it is affected by many factors. Introducing higher-order Markov model into the design of scheduling will provide new ideas and methods for production scheduling, based on this, this paper introduces the high-order Markov model and explores its application in the optimal scheduling of raw materials in production workshop, in the hopes of providing a theoretical basis for improving the core production competitiveness of the manufacturing workshop.

2 HIGH-ORDER MARKOV DECISION MODEL

The core of the high-order Markov decision model is the set of all kinds of random states, it uses state transition matrix to describe the states’ interdependent relations and transition process (Hayatle et al., 2013). During the entire decision-making process, the data of the Markov matrix is only related to the current data and has nothing to do with other data, that is, it has no aftereffect (Jia et al., 2001). For the higher-order Markov decision model, each additional delay adds an additional parameter to the model, considering a time series \(\{X_t, t\in\mathbb{N}\}\), where \(\mathbb{N}\) is a positive integer and \(\mathbb{N}\in\{1, 2, \ldots, m\}\). Then, the model is expressed as:

\[
P[X_t] = \{X_t = j_t \mid X_{t-1} = j_{t-1}, \ldots, X_{t-l} = j_l\} = \sum_{l=1}^{\infty} \theta_l q_{j_tj_l} (1)
\]

where, \(\theta_1 + \cdots + \theta_l = 1\), and \(0 \leq \sum_{l=1}^{\infty} \theta_l q_{j_tj_l} \leq 1\).

For higher-order Markov decision models, the commonly-used evaluation and prediction processes include structure prediction, common factor variance measurement, redundancy measurement, and the model’s goodness of fit (Cao and Zhang, 2008). In this paper, the optimal scheduling of raw materials in the production workshop belongs to the model’s goodness of fit, which mainly predicts the endogenous observable variables through the exogenous latent variables. Figure 1 shows the prediction relation and fitting measures of high-order Markov decision model. The goodness of fit of the entire model includes the entire prediction process of the high-order Markov decision model.

![Redundancy measure](image)

**Fig. 1** Prediction relation and fitting measures of high-order Markov decision model

3 INTELLIGENT OPTIMIZATION TECHNOLOGY FOR RAW MATERIAL SCHEDULING IN PRODUCTION WORKSHOP

3.1 Technical framework for intelligent optimization of raw material scheduling in production workshop

The optimal scheduling of raw materials in production workshop is a complex system engineering project. Unlike the traditional raw material scheduling in the workshop, most of the current production workshops are batch production workshops, and the process of raw material scheduling is much more complicated than that of the traditional single-job scheduling (Kárny, 2016). For the products to be produced in batches, after they are divided into multiple batches, each batch is processed by proper technical processes that are selected according to the allocation situation of the raw materials, so as to achieve the purpose of reducing the production costs and shortening the completion time (He et al., 2002). With the changing of the market environment, the subjects of market competition are changing as well, resulting in that the core competitiveness of the enterprises is experiencing important transformation, and the optimization of scheduling is becoming an important part of the core competitiveness. The cost of raw materials is greatly affected by the scheduling scheme, so we must take the cost of raw materials into consideration during the process of scheduling optimization. In the process of batch production, a product often requires multiple processing steps and various types of raw materials, and the direct sequence and amount of the of the raw materials are closely related, therefore, we must consider all these aspects comprehensively in the scheduling process.

Figure 2 shows the current situation of intelligent scheduling of raw materials in the production workshop. The raw material optimization scheduling in the batch production process is divided into two processes: single-source workshop raw material scheduling and multi-resource workshop raw material scheduling; and the
The production workshop issues the raw material strip allocated by the raw material plant to carry out the workshop demand for picking and performing reclaiming and reclaiming operations, taking the equipment load as the optimization objective, and taking the energy consumption and pollutant emission as the optimization objectives, etc.; while the multi-objective optimization of multi-resource workshop raw material scheduling includes the optimization processes such as time indicator, cost indicator and other indicators.

Fig. 2 Current situation of intelligent scheduling of raw materials in production workshop

3.2 Basic theory and key technologies in the intelligent optimization technology framework for raw material scheduling

According to the objectives of intelligent optimization of raw material scheduling, we can use some algorithms to search for the optimal scheduling scheme of the raw materials. Theoretically, existing algorithms only have one solution for the scheduling of single-resource workshop, and the optimal scheduling process of the raw materials can be obtained through the optimal scheduling solution. While for the multi-objective workshop, there are multiple optimization objectives, so its optimization solutions are a set of optimal solutions; for different indicators selected for the evaluation, even for the same scheduling algorithm, its scheduling models may have certain changes. Figure 3 is the execution flow of the raw material scheduling tasks. The production workshop issues the raw material operation demands, the raw material warehouse allocates the material strips for the material-picking operation, and checks whether there are conflicts in the raw material supply equipment; in the case of no conflict, it performs the tasks of material-picking and raw material delivery.

The production environment is full of changes, including changes in orders, machine failures, or rush orders. Changes in any link will cause major adjustments to the raw material scheduling systems. Figure 4 is the scheduling and allocation process of raw materials when inserting rush-orders. First, the rush-order tasks are input into the database, and the raw material warehouse extracts the urgent tasks from the database; then after the production workshop completes the ongoing tasks, the rush-orders are prioritized, and the allocation sequence of the raw materials for the rush-orders is prioritized as well, while the allocation sequence of the raw materials for other products is postponed.

Fig. 3 Flow of raw material scheduling tasks
The distribution network of raw materials in the production workshop is a strategic production planning problem. In order to make the raw material scheduling scheme in accordance with the actual production situation, this paper takes the change of production time as the dynamic operation efficiency to explore the change of the dynamic operation efficiency of raw material scheduling optimization over time. Figure 5 shows the coordination degree of the high-order Markov decision model, through the exogenous observation variable evaluation scheme (production time), the exogenous latent variable evaluation scheme and the exogenous observation variable data are obtained; combing the data with the path coefficient, we can get the influence degree of the endogenous latent variables (allocation of raw materials), thereby obtaining the coordination degree based on the high-order Markov decision model. The scheduling of raw materials occurs in the production lines of product batches, the loading and unloading of raw materials are the necessary operations required for the production of each product. The compactness of the entire scheduling process is directly related to the overall optimization objective of the production workshop.

4.2 Actual application of the model

In a production workshop, for a same kind of workpieces, different processing procedures are completed on different equipment, but the processing time and the complexity of the workpieces are different, and the processing time is set by the program of the equipment. To explore the feasibility of applying high-order Markov decision model in the production workshop, this paper adopts the actual workpiece processing procedures in a production workshop in Zhengzhou city, China as the example; and assumes that the processing sequence of each kind of workpiece is determinate, and there is no sequence constraint between the procedures of different kinds of workpieces. For each kind of workpieces, the same processing procedure can only be performed on certain equipment. Table 1 shows the procedures and complexity of the production of the workpieces. The production workshop produces four types of products, and the processing procedures of these products are different.
Table 1. Procedures and complexity of the production of workpieces

<table>
<thead>
<tr>
<th>Workpiece</th>
<th>Working procedure</th>
<th>Production time/d</th>
<th>Workpiece quantity</th>
<th>Time/min</th>
<th>Complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>22</td>
<td>164</td>
<td>11.03</td>
<td>0.82</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>19.12</td>
<td>0.88</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>5.93</td>
<td>0.78</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>28</td>
<td>95</td>
<td>5.09</td>
<td>0.80</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>11.46</td>
<td>0.85</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>21.03</td>
<td>0.92</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>18</td>
<td>34</td>
<td>6.23</td>
<td>0.49</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>9.91</td>
<td>0.53</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>45</td>
<td>198</td>
<td>9.34</td>
<td>0.68</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td></td>
<td></td>
<td>13.30</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>22.79</td>
<td>0.78</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>29.81</td>
<td>0.83</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td></td>
<td></td>
<td>16.53</td>
<td>0.74</td>
</tr>
</tbody>
</table>

Fig. 6 Types of raw materials required for each process (1-1 in the figure represents the first process of workpiece No.1)

Figure 6 shows the types of raw materials required for each process (1-1 in the figure represents the first process of workpiece No. 1). It can be seen that, for each processing procedure of different workpieces, the required raw materials are quite different; some procedures only require one kind of raw material, while some procedures may require as many as six types of raw materials. However, the sequence of the supply of each material is determinate. Figure 7 shows the start time and duration of the raw materials in each process. It can be seen that there are also large differences in the start time and duration of the raw materials in each process, which also brings great difficulty for the connection of the scheduling processes of raw materials. The results of the multi-resource workshop raw material scheduling calculated based on the high-order Markov decision model are shown in Table 2. Due to the diversity of the processes and the allocation situation of the equipment, seven results were obtained and we found that the third scheme perform better in the coordination degree, the influence degree of comprehensive efficiency, and influence degree of comprehensive qualification rate.

Table 2. Results of high-order Markov decision model

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Coordination degree</th>
<th>Maximum completion time/d</th>
<th>Comprehensive efficiency influence degree</th>
<th>Comprehensive fatigue influence degree</th>
<th>Comprehensive qualification rate influence degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.57</td>
<td>36.8</td>
<td>6.93</td>
<td>7.53</td>
<td>15.8</td>
</tr>
<tr>
<td>2</td>
<td>0.59</td>
<td>32.4</td>
<td>7.72</td>
<td>7.71</td>
<td>16.48</td>
</tr>
<tr>
<td>3</td>
<td>0.69</td>
<td>30.6</td>
<td>7.74</td>
<td>7.0</td>
<td>16.94</td>
</tr>
<tr>
<td>4</td>
<td>0.71</td>
<td>33.5</td>
<td>7.61</td>
<td>7.62</td>
<td>17.05</td>
</tr>
<tr>
<td>5</td>
<td>0.72</td>
<td>40.9</td>
<td>7.87</td>
<td>7.77</td>
<td>16.18</td>
</tr>
<tr>
<td>6</td>
<td>0.72</td>
<td>43.4</td>
<td>7.52</td>
<td>7.50</td>
<td>16.57</td>
</tr>
<tr>
<td>7</td>
<td>0.72</td>
<td>58</td>
<td>7.44</td>
<td>7.44</td>
<td>16.53</td>
</tr>
</tbody>
</table>
5 CONCLUSIONS

This paper introduced the high-order Markov decision model to explore its application in the optimal scheduling of raw materials in the production workshop. The specific conclusions are as follows:

(1) The optimal scheduling of raw materials in production workshop resulted in the important changes in the core competitiveness of enterprises, the process of scheduling optimization had become an important part of their core competitiveness; the cost of the raw materials is greatly affected by the scheduling scheme, so the cost of raw materials must be taken into consideration in the process of the optimal scheduling.

(2) For different indicators selected for the evaluation, even for the same scheduling algorithm, its scheduling models may have certain changes. The production workshop issues the raw material operation demands, the raw material warehouse allocates the material strips for the material-picking operation, and checks whether there are conflicts in the raw material supply equipment; in the case of no conflict, it performs the tasks of material-picking and raw material delivery.

(3) From the results of the multi-resource workshop raw material scheduling calculated based on the high-order Markov decision model, we found that there is a certain scheme that performs better in the coordination degree, the influence degree of comprehensive efficiency, and influence degree of comprehensive qualification rate. So, applying the high-order Markov decision model in the optimal scheduling of raw materials in production workshop is feasible.

6 ACKNOWLEDGEMENTS

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7 REFERENCES


