Research on Reconfiguration Point Decision Method of Flexible Manufacturing Cell

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Abstract. When the dynamic environment, product process updates, machine failures, and unit processing functions or processing capabilities fail to meet the order requirements, you need to select the appropriate time node to reconfigure the cell. In this paper, the complexity of flexible manufacturing cell is represented by information entropy, and the cell complexity model is established. The model is combined with the cusp catastrophe theory to establish a flexible manufacturing cell reconfiguration decision model. The disaster point is the cell reconfiguration decision point. Finally, an example is given to analyze the validity and practicability of the choice of reconfiguration decision points.

Introduction

The flexible manufacturing cell production method is an advanced cell manufacturing production mode. The flexible manufacturing cell (FMC) is defined by Mac Carthy and Liu as "an FMS consisting of a single flexible machine sharing a common material processing device" [1]. Since FMC works effectively in a dynamic environment, in order to adapt to product process updates, meet higher product quality requirements or accelerate the application of innovative technologies, new devices, and new materials, flexible manufacturing cell need to make Refactoring decisions at the right time. When the FMC processing function or processing capability fails to meet the order requirements, if the reconfiguration is performed immediately, the normal result is a relatively high cost due to production downtime. System reconfiguration is more difficult and costly when there are a large number of delayed orders. The decision about reconfiguration time is a key step in FMC implementation [2].

Short-term factors may not require permanent reconfiguration of the system. However, medium or long-term factors may require reconfiguration of the system as they are more durable [3]. Smart et al. study the dynamic complexity of manufacturing systems based on improved information entropy theory; their main focus is to analyze the equipment and queue status in the production process, and elaborate the relationship between system complexity and system operation [4]. AM Farid and DC McFarlane measure the reconfiguration potential of manufacturing systems with production freedom as an indicator, using eight different production freedom measures as a variant of the three common element themes, reconfiguring production resources, processes or combinations [5]. S. H. Huang, G. X. Wang and Y. Yan proposed a decision-making method based on information entropy and cusp catastrophe theory for how to determine the timing of RMS reconstruction [6]. Therefore, this paper uses information entropy to represent the complexity of flexible manufacturing cells, and establishes a cell complexity model. This model combines cusp catastrophe theory to establish FMC reconfiguration decision model, and the disaster point is the reconfiguration decision point of FMC.
Complex Manufacturing Model of Flexible Manufacturing Cell Based on Information Entropy

The complexity of a flexible manufacturing cell includes positive complexity and negative complexity. Positive complexity means that the machine can operate normally, which helps the cell production to maintain a stable state; negative complexity means that the machine processing efficiency is low, the cost is high, or the production task cannot be completed normally, or it is in a shutdown state, and the stability of the cell is Negative Effects. The formula for information entropy is (1). Maintaining the Integrity of the Specifications

\[ E(C) = \sum_{i}^{n} p_{i} \log_{2} p_{i} \]  

Where C is the cell; \( p_{i} \) (i=1,2,3,…,n) is the probability that the i state in the cell occurs; E(C) is the information entropy of the element.

The flexible manufacturing cell contains a certain amount of machine, and the status of the automated transport vehicle, machine or transport vehicle includes processing, idle, adjustment, fault and unavailability. These states are attributed to three cases: operable/non-blocking, operable/blocking, and inoperative. These three conditions directly affect the complexity of the flexible manufacturing cell, and the machine complexity in each state. Complexity calculations, resulting in cell complexity.

The states included when the machine or transporter is operational/non-blocking are: process state and idle state. The complexity calculation formula is (2) and (3)

\[ E_{W} = -\sum_{j=1}^{n} \sum_{k=1}^{K} p_{jk}^{W} \log_{2} P_{jk}^{W} \]  

\[ E_{L} = -\sum_{j=1}^{n} p_{j}^{L} \log_{2} p_{j}^{L} \]  

Where \( E_{W} \) is the complexity in the processing state; \( E_{L} \) is the complexity in the idle state; j is the number of machines in the cell; K is the total type of the machined parts; \( P_{jk}^{W} \) is the probability that the jth machine is processing the Kth part while in the machining state; \( p_{j}^{L} \) is the idle probability of the jth machine when it is idle.

The state included when the machine or transporter is operable/blocking is: adjusted state. Then the complexity calculation formula is (4)

\[ E_{R} = -\sum_{j=1}^{n} p_{j}^{R} \log_{2} p_{j}^{R} \]  

\( E_{R} \) indicates the complexity when it is in the adjustment state; \( p_{j}^{R} \) is the adjustment probability of the jth machine when it is in the adjustment state.

When the machine or transport vehicle is in an inoperable/blocking condition including the blocked state and the fault state, the complexity calculation formula is (5) and (6)

\[ E_{B} = -\sum_{j=1}^{n} p_{j}^{B} \log_{2} p_{j}^{B} \]  

\[ E_{M} = -\sum_{j=1}^{n} p_{j}^{M} \log_{2} P_{j}^{M} \]  

Where \( E_{B} \) indicates the complexity in the blocked state; where \( E_{M} \) indicates the complexity in the fault state; \( p_{j}^{B} \) is the adjustment probability of the jth machine in the adjusted state; \( p_{j}^{M} \) is the jth machine in the fault state Probability of failure.

The unit complexity calculation formula is: (7)

\[ E(C) = \omega_{W} E_{W} + \omega_{R} E_{R} + \omega_{M} E_{M} + \omega_{L} E_{L} + \omega_{B} E_{B} \]  

Where \( \omega \) represents the weight of various state complexity, and E(C) is the cell complexity.
Cell Reconfiguration Point Decision Based on Cusp Catastrophe Theory

The trend of cusp catastrophe is shown in Figure 1. The shaded part is a very unstable area, and the route through the shadow part will go through two disasters. The flexible manufacturing unit needs to be reconfigured when it is unstable, that is, a new balance is achieved by the shadow portion, so that the unit capacity is increased and a new production cycle is entered.

![Figure 1. The trend of cusp catastrophe.](image)

The mathematical model of the cusp catastrophe theory is the formula (8)

\[
F(x) = x^4 + v_1 x^2 + v_2 x
\]  

(8)

Where \(F(x)\) is the latent function of system complexity, \(x\) is the state variable, and \(v_1\) and \(v_2\) are the control variables. The first derivative of formula (8) is formula (9)

\[
F'(x) = 4x^3 + 2v_1 x + v_2
\]  

(9)

Where \(v_1 = -\frac{\omega_B B + \omega_M M}{E_C}\) represents the ratio of negative complexity to cell complexity; \(v_2 = \frac{\omega W E_W}{E_C}\) represents the ratio of positive complexity to cell complexity. When \(F'(x) = 0\), that is, \(\Delta = 8v_1^2 + 27v_2^2 = 0\), the system is in a critical state, and any slight interference may cause the system to mutate and reconfigure; when \(\Delta > 0\), the complexity of the system is positive, that is, the system is in a stable production state; when \(\Delta < 0\), the complexity of the system becomes negative complexity, that is, the system state is unstable.

Case Analysis

This article takes a flexible manufacturing cell as an example. The cell consists of five machines, one for each machine: M1, M2, M3, M4, M5. The first sequence consists of six types of parts, each of which has 100 parts. The machining route of the parts is shown in Table 1. The processing time of the parts is shown in Table 2. After the first order is completed, the machine status statistics are shown in Table 3. According to the state result of Table 3, the calculated machine state probability table 4 is shown. According to the data in Table 4 and the formula in the second section, the calculation state complexity is shown in Table 5. The fault weight is 0.6 and the other weights are 0.1. The results are shown in Table 6.

Table 1. First processing routes.

| Part no. | Processing route |
|----------|-----------------|
| 01       | 1,3,4           |
| 02       | 1,4             |
| 03       | 2,4,3           |
| 04       | 2,3,5           |
| 05       | 3,4,5           |
| 06       | 2,3,4,5         |
Table 2. Processing time in minute.

| Part no. | M1 | M2 | M3 | M4 | M5 |
|---------|----|----|----|----|----|
| 01      | 1  | 2  | 1  |    |    |
| 02      | 2  |    |    |    |    |
| 03      |    |    |    |    |    |
| 04      | 2  | 1  |    | 1  |    |
| 05      |    |    | 1  | 2  |    |
| 06      | 1  | 2  | 1  | 3  |    |

Table 3. Machining state statistics.

| Machine state | M1 | M2 | M3 | M4 | M5 |
|---------------|----|----|----|----|----|
| machining     | 300| 400| 900| 600| 600|
| adjusting     | 100| 100| 100| 100| 100|
| Failure       | 100| 0  | 0  | 80 | 200|
| Idle          | 280| 350| 510| 500| 380|
| blocking      | 270| 490| 400| 470| 250|

Table 4. Machining state statistics.

| Machine state | M1 | M2 | M3 | M4 | M5 |
|---------------|----|----|----|----|----|
| machining     | 0.049| 0.066| 0.148| 0.099| 0.099|
| adjusting     | 0.016| 0.016| 0.016| 0.016| 0.016|
| Failure       | 0.016| 0   | 0   | 0.013| 0.033|
| Idle          | 0.046| 0.058| 0.084| 0.082| 0.063|
| blocking      | 0.044| 0.080| 0.066| 0.077| 0.041|

Table 5. Machining state statistics.

| Machine state | M1 | M2 | M3 | M4 | M5 |
|---------------|----|----|----|----|----|
| machining     | 0.213| 0.259| 0.408| 0.33| 0.33|
| adjusting     | 0.095| 0.095| 0.095| 0.095| 0.095|
| Failure       | 0.095| 0  | 0  | 0.081| 0.162|
| Idle          | 0.204| 0.238| 0.300| 0.296| 0.251|
| blocking      | 0.198| 0.292| 0.259| 0.285| 0.189|

Table 6. Machining state statistics.

| Machine state | Machining $E_W$ | Adjusting $E_I$ | Failure $E_R$ | Idle $E_B$ | Blocking $E_M$ |
|---------------|-----------------|-----------------|--------------|-------------|----------------|
| Weight        | 0.1             | 0.1             | 0.6          | 0.1         | 0.1            |
| Complexity    | 1.54            | 0.475           | 0.338        | 1.289       | 1.223          |

According to the table, the value of the control variable is calculated as $v_1=0.383$, $v_2=0.235$, $\Delta=1.04>0$, which means that the existing flexible manufacturing cell is relatively stable, and there is no need to reconfigure the cell. When the new order increases, the machine status changes. Repeat the above calculation steps. If $\Delta<0$ occurs, the unit status is unstable and the unit needs to be reconfigured.

**Conclusion**

In this paper, the decision making of flexible manufacturing cell reconfiguration decision points is studied. The information entropy is used to represent the complexity of flexible manufacturing cell. The cell complexity model is established. The model is combined with the cusp catastrophe theory to establish a flexible manufacturing cell reconfiguration decision model. The disaster point is the decision point of cell reconfiguration. The analysis of the example shows that using the information entropy to calculate the cell complexity and the reconfiguration decision point derived from the cusp catastrophe theory makes the FMC maintain a fast corresponding ability.
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