Study on Structural Complexity of Transmission Case Production Line

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Abstract: Complexity level is one of the factors that affect manufacturing system design and control, so study on complexity quantification is gaining more attention. A method that combined information entropy and system structure factor is introduced to measure the complexity of transmission case production line. The method can realize structural complexity comparison among various production lines that provide reference for manufacturing system design, and in practice systems designed with lower complexity level are controlled and managed more easily and accurately.

Introduction

In order to cope with increasingly fierce market competition, it is necessary for manufacturing enterprises to respond customer demand diversification and individuation timely, which makes manufacturing system becoming more and more complicated. So, effective complexity measurement study not only is convenient to capture control point for managers and provides basis and method to compare different system complexity for planners.

Research on complexity is gaining more and more attention in recent years and exists in any field. But due to different backgrounds, various methods are applied in specific manufacturing systems.

Classification of Manufacturing Complexity

Manufacturing system complexity refers to the state that is difficult to be understood, described, predicted, and controlled. It mainly studies on the how well the integration between manufacturing process and all links is. The higher the complexity of the system is, more uncertain and unpredictable the manufacturing system shows, more difficult the system control is.

Manufacturing system complexity can be divided into static complexity and dynamic complexity. Static complexity refers to the complexity that results from system structure and function, combination type, composition elements, and the relationship among various elements, such as the number of products, the number of machines etc. Static complexity does not change over time, that is to say static complexity depend on plant structure or design. Dynamic complexity refers to the complexity that is caused by uncertain events in systems, such as machine fault, quality issues. Comprehensive production and repair (TPM) and total quality management (TQM) can be considered as the measures to reduce system complexity [1].

Structural complexity belongs to internal complexity and structural complexity of transmission case is studied in this paper.

Measurement and Evaluation Methods of Manufacturing Complexity

Due to difficulty in complexity measurement, unanimous approval methods are not available until now. The most commonly used method is the information entropy theory presented by C.E.Shannon. The expression of static complexity $H(S)$ is shown as Eq. 1[2].

$$H(S)=-\sum_{i=1}^{M}\sum_{j=1}^{N}p_{ij}\log_2(p_{ij}) \tag{1}$$

Where: M-number of resources; N-the number of potential states of ith resource; P_{ij}- probability of state *j* occurring for *ith* resource.

The method is to use information content involving in the system and its structures to describe the structural complexity, and is widely accepted. But the application of this method also has its limitations. Firstly which elements are decided to describe the states of system structure and its components? Secondly usually this method assumes that the components of the system are independent, but in practice the components of the system are interrelated. So conditional probability should be applied to calculate probability of the states, which is more difficult to calculate when the system consists of plenty of elements.

Another method is to develop complexity evaluation index based on heuristic algorithm to evaluate systematic complexity, which considers the subjective factors of human.

For measuring and evaluating structural complexity, the advantage of information entropy method is more objective, and heuristic evaluation index system is more favorable for understanding the influence of system elements on the complexity. So Kuzgunkaya presented a new method that combined information entropy with heuristic evaluation index to evaluate system complexity. Here the new method is applied to measure and evaluate structural complexity transmission case production line[3].

Structural Complexity Evaluation of Automobile Transmission Case Production Line

Process steps of the automobile transmission case production line are rough milling, fine machining, drilling hole, and cleaning.

Blank experiences rough milling on two sets of special milling machine, and then fine machining, drilling hole, cleaning. The station of fine machining has three sets of machining centers, among which two sets of machining centers are the same type. The station of drilling hole has a set of radial drilling machine and the station of cleaning has a set of cleaning machine.

Combining information entropy and heuristic evaluation index develops complexity evaluation function that is shown as Eq. 2.

$$H(S) = w_1 H_M + w_2 H_B + w_3 H_{MHS} \quad (2)$$

Where: H_M-machine complexity; H_B-buffer complexity; H_{MHS}-material transfer complexity; w_1, w_2, w_3-weight of H_M, H_B, H_{MHS} respectively.

Machine Complexity

Machine complexity is expressed as Eq. 3:

$$H_M = \sum_{i=1}^{M}\sum_{j=1}^{N} X_{ij} a_{ij} \left[p_{ij} \log_2 \frac{1}{p_{ij}} + (1-p_{ij}) \log_2 \frac{1}{1-p_{ij}} \right] \quad (3)$$

Where: p_{ij}-reliability of *j* type machine for *i*th process; X_{ij}- number of *j* type machine for *i*th process; a_{ij}- complexity coefficient of *j* type machine for *i*th process; *N*-machine types of each process; *M*-number of all processes.

Complexity coefficient of machines is calculated as Eq. 4.

$$a_{ij} = \frac{\sum_{k=1}^{N} \frac{n_k}{n_{k\max}}}{N} \quad (4)$$

Taking the research enterprise for example, process types and machines of fine machining of transmission case are shown in Table 1.

Table 1 Type and Complexity Factor of Machine Structure

N	Structure type of machines	n_k	Structure factor of machines(maximum)
1	Basic structure	2	1fixed structure 2fixed module structure 3extensible and special equipment 4equipment that can increase module
2	Coordinate axis	3	Number of coordinate axis(5)
3	Principal axis	1	Number of principle axis(4)

4	Working head	1	Number of working head for machining
5	Cutting tools	0 60	Fixed cutter(100) Library of cutting tools(160)
6	Cutting tool management	2	0 cutting tool fixation

Table 3 Complexity Factors of Buffer for a Type of Product

N	Buffer type	n_k	Structure factor
1	Basic structure	4	1 manual 2 first in first out 3 last in first out 4 calibrated amout
2	Equipment technology	1	1 special roller 2 special turntable 3 random access system
3	Buffer amount	30	60

			1 manual replacement 2 automatic replacement
7	fixture	2	1 universal fixture 2 special fixture
8	buffer	2	0 no buffer 1 first in first out 2 equip with indexing table

According to the data of Table 1 and Eq. 4, complexity coefficient of fine machining A is shown as below:

$$a_{ij}=\frac{\frac{2}{4}+\frac{3}{5}+\frac{1}{4}+\frac{1}{4}+\frac{0}{100}+\frac{60}{160}+\frac{2}{2}+\frac{2}{2}+\frac{2}{2}}{9}=0.553$$

By the same token, complexity coefficients of the other machines can be calculated.

According to statistical production data, p_{ij} is available and machine complexity of every machine is calculated by using Eq. 3. Calculation results are shown as Table 2.

Table 2 Machine Complexity

	Machine A	Machine B	Milling machine	Drilling machine
Number	2	1	2	7
a_{ij}	0.553	0.525	0.24	0.29
p_{ij}	0.85	0.9	0.8	0.8
H_M		2.73		

Buffer Complexity

Buffer complexity is expressed by Eq. 5.

$$H_B=\sum_{i=1}^{M-1} b_i\left[p_{ine}\,log_2(1/p_{ine})+p_{ie}\,log_2(1/p_{ie})\right] \tag{5}$$

Where: p_{ie}-probability of none buffer; p_{ine}-probability of buffer is not zero,here, $p_{ine}+p_{ie}=1$; b_i-complexity coefficient of buffer; M-number of processes; k-product type; p_{ij}-probability of product type j machined in ith process.

Taking a type of product for example, complexity factors are shown as Table 3 and Calculation process of b_i is identical with machine complexity. The corresponding calculation results are shown as Table 4.

Table 4 Buffer Complexity

Number of process	4
b_j	0.61
p_{ie}	0.50
H_B	1.83

Table 5 Material Transfer Complexity

Number of process	7
m_t	0.20
P_{t1}	0.99
H_{MHS}	0.11

Material Transfer Complexity

Material transfer complexity is expressed as Eq. 6.

$$H_{MHS} = \sum_{t=1}^{T} m_t \left[p_t \log_2 \frac{1}{p_t} + (1-p_t)\log_2 \frac{1}{(1-p_t)} \right] \quad (6)$$

Where: p_t-reliability of material transfer; m_t-complexity coefficient of material transfer; T-number of material transporter.

Calculation result of material transfer complexity is shown as Table 5.

Supposing $w_1=w_2=w=1/3$, then:

$H(S)=(H_M+H_B+H_{MHS})/3=1.56$

Summary

The example of this paper showed that the new method that combined information entropy with heuristic evaluation index to evaluate system complexity is more understandable that make it more acceptable in production practice.

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