Reliability Allocation Method of Production Line Based on Fuzzy Comprehensive Evaluation

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Abstract. A fuzzy comprehensive evaluation model was built to allocate the reliability of production line combined with the actual case studies. The production rate was converted to inherent availability in the calculation. Considering the buffer, we corrected the allocation index. Combined the opinion of relevant staff and experts, determined various types of factors and right weight that effect reliability of production line. Finally, simulated the production line and optimized allocation results. Provided allocation strategy to production lines.

Introduction

Currently，scholars gradually realized that we should prevent failures from the root, reliability allocation methods for CNC machine tools and systems are becoming increasingly mature. Internationally, it has accumulated a large number of academic achievements about reliability allocation methods of the system. Including genetic algorithms, dynamic programming, deterministic algorithms, etc.[1] Yang, etc[2] use these algorithms combine reliability allocation in pressurized water reactor systems; For series-parallel systems, Yalaoui[3] proposed Nonpolynomial Dynamic Programming; Mettas[4] developed Blocksim software program which can optimize reliability allocation method for large complex systems. ITEM company and Siemens AG have developed software on system reliability allocation. Enterprises can use the production site-related data complete the modeling and simulation of complex production line [5-7].

Major universities also developed software on reliability design, which mainly include: CARMES developed by CEPREI; ARMS developed by Kewill Venture technology company, that mainly used in system reliability design research of aerospace, shipbuilding, electronics and other industries[8].

Although methods for system reliability allocation have been more mature, the research for actual production lines are relatively few. Since structures of automated production lines are complex, dynamic performance is outstanding, it is difficult to get the correct allocation result while using a single method. Therefore, this article use statistic ,fuzzy mathematics and other related knowledge, give the final result taking the specific structure of production line and buffer into account. Finally , simulated the production line and optimized allocation results.

Reliability Allocation Model of Production line

Index of Reliability Allocation. There are multiple evaluation indexes of production line, which mainly include: overall equipment efficiency, allocation efficiency, production rate, output and so on. The production rate (K) is a key indicator widely recognized by companies, it is similar to the reliability inherent availability (A), there are slight differences in time division.

Production rate directly determines the output and efficiency of the production line, so most companies are pursuing high production rate. Production rate is decided by output, beat and configuration time, the specific relationship is shown as follows:

$$K = \frac{\text{take time} \times output}{\text{configuration time}} \tag{1}$$

If the production line is in the design stage, it is unable to count on its output, so we can not get accurate statistics of production rate. Inherent availability (A) can be used to instead production rate:

$$A = \frac{MTBF_s}{MTBF_s + MTTR_s} \tag{2}$$

$MTBF_s$ means time between failures of production line, $MTTR_s$ means time to repair of production line.

From what we have discussed above, inherent availability is determined by $MTBF_s$ and $MTTR_s$, production rate is determined by output and configuration time. While these periods have a certain overlap, thus we need to divide the entire additional time. Suppose the percentage of production time (excluding the non-operating time of equipment, loss of production time) is p_1, the percentage of configuration time is p_2, therefore, we can obtain the following equation：

$$K = \frac{MTBF_s \times p_1}{\left(MTBF_s + MTTR_s\right) \times p_2} \tag{3}$$

Factors of Reliability Allocation. Fuzzy Comprehensive Evaluation factors will directly affect the results of reliability allocation, therefore, after discussing with the business experts and staff, we decided to take frequency of failures, average repair time, equipment importance, equipment complexity, technical level and working environment as factors of Fuzzy Comprehensive Evaluation.

(1)Frequency of failures

For equipments that always fail, herein may see them as weaknesses in production line. The higher the score is , the lower reliability value should be.

(2)Average repair time

Average repair time means the length of time that production line can not work, in the condition of inherent availability is determined, the longer the repair time is, the lower the value is.

(3)Equipment importance

The more important, complicated process equipment assumes, its importance is higher.

(4)Equipment complexity

For complex production equipment, the assigned reliability indicators should be lower.

(5)Technical level

Researchers need to rely on market research, count production equipments that have high technical level and assign them a higher reliability index.

(6)Working environment

Most of the equipment are in the same external environment, but due to equipment have different processing technology, their processing environment are very different. In view of this, we make working environment an important index.

The Correction of Reliability Allocation Index While Considering Buffer. We can obtain frequency of failures and average repair time by historical data：

$$MTBF_s = \frac{1}{N_0}\sum_{i=1}^{n} t_i = \frac{\sum_{i=1}^{n} t_i}{\sum_{i=1}^{n} r_i} \tag{4}$$

t_i means the cumulative operating time of i-th production unit in the cycle;

r_i means the cumulative number of associated failures of i-th production unit in the cycle;

N_0means the cumulative number of associated failures of the production unit in the cycle;

n means Number of samples in the cycle;

In order to facilitate the calculation and considerate the role of buffer, suppose each time a failure occurs, WIP in buffer before faulty unit can supply half of maximum buffer time, there are:

$$t_{fi} = t_{ri} - t_{si}/2 \tag{5}$$

$$MTTR_s = \frac{\sum_{i=1}^{n} t_{fi}}{\sum_{i=1}^{n} r_{ri}} \tag{6}$$

t_{si} means maximum buffer time of i-th production unit;

$\mathrm{t_{ri}}$ means cumulative repair time of i-th production unit in the cycle(unit: h) ;

$\mathrm{r_{ri}}$ means the cumulative number of associated failures of i-th production unit in the cycle;

Fuzzy Comprehensive Evaluation Model. Reliability allocation method of production line with Fuzzy Comprehensive Evaluation can be divided into five steps:

(1) The establishment of factors set

A collection established by influential factors is called the factors set. These factors have considerable ambiguity in varying degrees. Establish relevant factors set has these factors: $U = \{u_1, u_2, \cdots, u_n\}$, where n is the number of influential factors.

(2) The establishment of weight set

The influence levels of various factors are different , we can obtain a weight set $\tilde{W} = (w_1, w_2, \cdots, w_n)$, the factors need normalization process.

(3) The establishment of evaluation set

Evaluation set $\tilde{V} = (v_1, v_2, \cdots, v_m)$ is obtained by dividing grade of each factors, m is the number of results. According to the opinions of experts, determine the evaluation results of each factor.

(4) The establishment of evaluation matrix

First, determine the membership degree of relative evaluation set judging from a single factor. Then determine the evaluation matrix $\tilde{R} = (r_{ij})_{n\times m}$ according to the established evaluation set and evaluation result of each single factor ,matrix factor r_{ij} means when selecting assessment factor u_i ,the membership degree of the assessment result v_j of evaluation set.

(5) The Fuzzy Comprehensive Evaluation

After getting the above set and matrix， in accordance with $\tilde{B} = \tilde{W} \circ \tilde{R}$， seeking evaluation index b_j. In the calculation of evaluation model, synthesis operator "$\circ$" has the following algorithm:

① Use $(+,\times)$ composite operator, have $b_j = \sum_{i=1}^{n} (w_i \cdot r_{ij})$

② Use $(\vee,\times)$ composite operator, have $b_j = \bigvee_{i=1}^{n} (w_i \cdot r_{ij})$

③ Use $(\vee,\oplus)$ composite operator, have $b_j = \bigoplus_{i=1}^{n} (w_i \wedge r_{ij})$

④ Use $(\vee,\wedge)$ composite operator, have $b_j = \bigvee_{i=1}^{n} (w_i \wedge r_{ij})$

It need normalization process after getting the fuzzy results. According to the ratio between weight and allocation index, obtain the following formula:

$$MTBF_i = \frac{\sum_{i=1}^{n} B_i}{B_i} \times MTBF_s \tag{7}$$

We can have allocate result $MTBF_i$ of each device in production line according to the above formula(unit: *h*).

Case Study

Reliability allocation results. An enterprise has a crankshaft production line, try to use reliability allocation method make production rate reach 85%, determine the reliability of each device. Wherein maximum time of each buffer is 30 minutes.

Production line layout shown in Figure 1. Some equipment rarely fail, such as: online testing platform, quenching, tempering unit, etc. Therefore, this article does consider such equipment. Data of approximate production line are shown in table 1:

Table 1 failure data of approximate production line

Production equipment	number of failures	number of equipment	*MTBF /h*	*MTTR/ min*	*A*
Face Milling Machine	25	3	647	127	0.9967
Quality Centering Machine	13	4	950	102	0.9982
Double-pole CNC	35	4	612	145	0.9961
Milling CNC	66	3	250	226	0.9852
Link CNC Lathes	28	3	409	93	0.9962
Hole Machining CNC	44	4	451	98	0.9964
Rolling Machines	22	2	405	169	0.9931
CNC Turret Lathe	35	4	509	121	0.9961
Crankshaft Grinding	28	5	794	140	0.9971
CNC Cylindrical Grinder	66	4	335	129	0.9936
Gear Heating Machine	9	2	581	107	0.9969
Multifunction Machining Center	47	4	382	114	0.9951
Remove Weight Machine	21	3	525	120	0.9962
Balancing Machine	27	4	748	126	0.9972
Oil Duct Cleaning Machine	21	3	657	114	0.9971
Polishing Machine	99	3	182	88	0.9920
Final Cleaning Machine	30	2	396	128	0.9946
Manipulator	55	15	723	93	0.9979

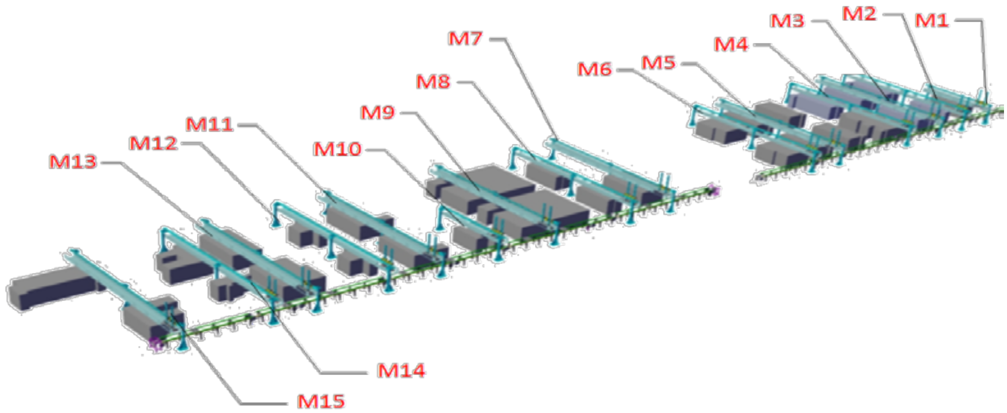

Fig. 1 Production line equipment layout (M1-M15 is production unit)

Since output in the cycle is unknown, turn indicators into the inherent availability. In a week, attendance time is 112 hour, additional time is shown as follows:

Table 2 Additional time

Time Categories	Specific Values
Break Time（in a week）	3.5 h
Education Time（in a week）	0.5 h
Security Management（in a week）	0.5 h
Trade Union Activities（in a week）	0.5 h
Production Samples（in a week）	0.5 h
Others （in a week）	0.5 h

P_1=90%，P_2=95% by calculation, the inherent availability A≈ 0.9 obtained by equation 3,this value is reliability allocation indicator of the crankshaft production line. $MTTR_s$ ≈2.585h obtained by equation 6. $MTBF_s$ ≈24h obtained by equation 2.

(1)Determine the factors and weight set

Factors and weight set is $\overset{\circ}{W} = (w_1, w_2, w_3, w_4, w_5, w_6) = (0.2,0.2,0.2,0.2,0.1,0.1)$ according to the opinion of scene operator and experts.

(2)The establishment of evaluation set

Range evaluation factors，specific division levels and standard are shown in Table3. Specific division results of importance, complexity, technical level and working environment are shown in Table4. This paper brings the suggestions of workers, maintenance staff, minister of equipment, data acquisition, etc together, obtained the final results shown in Table 5 after repeated calculation.

Table 3 Division Standard of Membership Range of Each Factor

Divided grade	Frequent of failure		Time to repair	
	Description	Membership range	Description	Membership range
1	A lot	More than 16	Very long	More than 210min
2	More	13-16	Long	150-210min
3	General	9-12	General	90-150min
4	Less	5-8	Short	30-90min
5	Seldom	0-4	Very short	0-30min

Table 4 Membership Range of Each Factor

Divided grade	Importance		Complexity	
	Description	Membership range	Description	Membership range
1	Very low	[8-10]	Very high	[8-10]
2	Low	[6-8)	High	[6-8)
3	General	[4-6)	General	[4-6)
4	High	[2-4)	Low	[2-4)
5	Very high	[0-2)	Very low	[0-2)
Divided grade	Technical level		Machining environment	
	Description	Membership range	Description	Membership range
1	Very low	[8-10]	Very bad	[8-10]
2	Lower	[6-8)	Bad	[6-8)
3	General	[4-6)	General	[4-6)
4	Higher	[2-4)	Good	[2-4)
5	Very high	[0-2)	Very good	[0-2)

Table 5. Scoring Results of Factors

number	Machine name	Importance	Complexity	Technical level	Machining environment
1	Manipulator 1	5	2	2	2
2	Face Milling Machine	4	5	4	4
3	Manipulator 2	3	2	2	2
…	…	…	…	…	…
38	Manipulator 15	2	2	2	2
39	Polishing Machine	4	3	6	8
40	Final Cleaning Machine	4	4	3	3

（3）The establishment of evaluation set

Establish evaluation matrix $\overset{\circ}{R}_i$（i=1，2，3，…，40），and $\overset{\circ}{R}_i = (r_{ij})_{6\times5}$. According to $\overset{\circ}{B}_i = \overset{\circ}{W} \circ \overset{\circ}{R}_i$, calculated evaluation index $\overset{\circ}{B}_i$. This article select $(+,\times)$ synthesis operator, get the weighted rank of the production equipment. Each rating reviews set is$\widetilde{V}$=（10，8，6，4，2）.Get the corresponding evaluation results through B=$\widetilde{B_i}\circ\widetilde{V}^T$. According to the formula 7 , we may have allocation results of various production equipment:

$MTBF_i$=（1170 ，849 ，1303 ，1019 ，822 ，1303 ， 822 ，1303 ，633，822 ，1303 ，865 ，865 ，1303 ，793 ，1170 ，740 ，1303 ，849 ，849 ，1303 ，862 ，1381 ，703 ，951 ， 951 ，1303 ，762 ， 1303 ，703 ，703 ， 1303 ，910 ， 872 ，1303 ，1373 ，980 ，1381 ，721 ，849）

Simulation and Optimization. We use Plantsimulation software predict the inherent availability of production line:

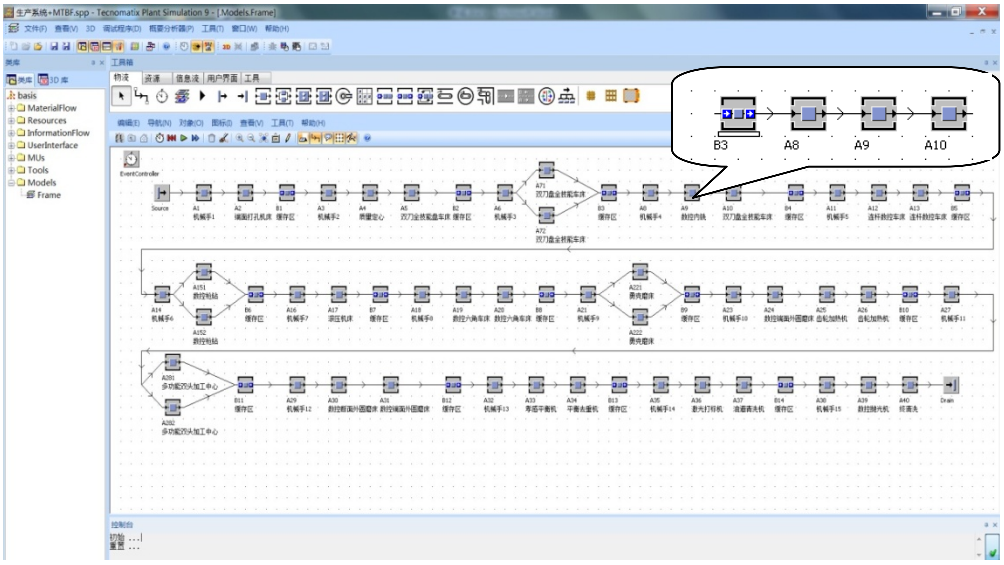

Fig. 1 Simulation of crankshaft production line

From simulation results, inherent availability is greater than 90%,production rate is greater than 85%. This paper addresses optimization problems for the equipment which have great differences between the target MTBF and practical MTBF(via discussion, the subtracted is greater than 400 hours), the specific content are shown in Table 6:

Table 6 the target value contrast to current level

Machine name	Target value （h）	Track record value （h）	Subtracted value （h）
Link CNC Lathes	865	409	456
Polishing Machine	721	182	539
Final Cleaning Machine	849	396	453

For equipment in Table 6, we can select the appropriate redundancy optimization method. In the case of not affect the production rhythm, ensure the normal operation of the system. In the view of above results, we can take MTBF of system as reliability of unit, index of single device as individual reliability, get related redundancy number:

Table 7 Number of equipment redundancy

Machine name	Number of redundancy	Optimized $MTBF$ (h)
Link CNC Lathes	1	818
Polishing Machine	2	536
Final Cleaning Machine	1	792

Redundant equipment also increase the cost. Thus, according to the actual need of manufacturers, we can increase or decrease the redundant equipment.

Conclusion

In this paper, a method of system reliability allocation applied to the actual production line, and binding the effect of buffer, amended the allocation indicators. It has great significance to companies. Through research, draw the following conclusions:

(1) Turn output rate indicator into inherent availability, taking the role of buffer into account, get MTBF of the equipment.

(2) Use Plantsimulation software verify the result of allocation, and further suggest improvements. Use passive redundant design to equipment that unable to meet the requirement.

Due to time constraints, this study failed to resolve some of the problems. In order to fully take the role of buffer into account, we need record the number of workpiece and location of the buffer while each time a failure occurs, facilitate further study.

References

[1] Da Silva L. G .W，Pereira R A F，Mantovani J.R .S. Optimized Allocation of Sectionalizing Switches and Control and Protection Devices for Reliability Indices Improvement in Distribution Systems[C] ， IEEE/PES Transmission &Distribution Conference & Exposition: Latin America，2004:1-6.

[2] Yang J E，Hwang M J，Sung T Y，et al. Application of Genetic Algorithm for Reliability Allocation in Nuclear Power Plants[J]. Reliability Engineering and System Safety，1999，65: 229 - 238.

[3] Yalaoui J E，Chadtelet E，Chu C B.A New Dynamic Programming Method for Reliability &Redundancy Allocation in a Parallel-Series System [J]. IEEETransactions on Reliability2005，54(2): 254 - 262.

[4] Adamantios M. Reliability Allocation and Optimization for Complex Systems [C]//Proceedings Annual Reliability and Maintainability，2000:216-222.

[5] Yin P Y，Yu S S，Wang P P，et al. Task Allocation for Maximizing Reliability of a Distributed System Using Hybrid Particle Swarm Optimization[J]. The Journal of Systems and Software，2007(80):724 - 735.

[6] Huang C Y，Lo J H，Kuo S Y，et al. Optimal Allocation of Testing-Resource Considering Cost，Reliability， and Testing-Effort[C]//Proceedings of the 10th IEEE Pacific Rim International Symposium on Dependable Computing，2004.

[7] Chen T C. IAs Based Approach for Reliability Redundancy Allocation Problems [J]. Applied Mathematics and Computation，2006(182): 1556 - 1567.

[8] Xiao Tianyuan，Fan Wenhui. Modeling and Simulation of Discrete Event System [M]. Electronic Industry Press，2011.8：254-255.