An Excellence Level Evaluation Model of Intelligent Manufacturing Unit

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***Abstract*—The construction of intelligent manufacturing unit is a process of gradual improvement. It is very important to define the current level of the unit. However, it is difficult to use one evaluation system to evaluate all units in an enterprise because of the difference of each unit. This paper took the product manufacturing unit as the research object, according to the production characteristics of products, manufacturing unit is divided into three different Excellence Grades: Meticulous, Lean and Excellent. Combined with the characteristics of the production and test process, the characteristic factors of the manufacturing process of products were extracted from the aspects of "man, machine, material, method, environment and testing", and the characteristic factors were decomposed and summarized to form an Excellent Process Grade evaluation model. Finally, the A.J.Klee method and Expert evaluation method were used to calculate the weight of factors at all levels and obtain the Excellence Level of manufacturing units.**

Keywords-cellular manufacturing; evaluation model; intelligent manufacturing; expert evaluation method

I. INTRODUCTION

Since the 21st century, with the rapid development of Internet, big data and other technologies, great changes have taken place in the Factory-method Pattern of all countries in the world [1]. With the advent of the 5G era, many Chinese factories have also begun to try to transform from "Made in China" to "Intelligent manufacturing in China"[2]. The intelligent manufacturing unit formed by the combination of intelligent manufacturing and cellular manufacturing is the most effective starting point for the implementation of intelligent manufacturing at present [3]. For a factory with multiple species and small batch manufacturing mode, building an intelligent manufacturing unit is an important means to increase output and improve quality. How to effectively guide the construction and evaluation of intelligent manufacturing units and find out the current shortcomings for factories has become an urgent problem for factories managers to solve.

This paper takes the manufacturing unit of an enterprise as the object. An enterprise contains many manufacturing units with different functions, and the differences between each unit are relatively large. At present, there are few studies on how to evaluate several units with large differences at the same time. This paper mainly studies and establishes a set of Excellent Process Grade evaluation model for products according to the requirements of manufacturing units and industry guidance documents, and analyzes the weight of each index by using the A.J.Klee method [4] and Expert evaluation method [5].

At present, there are many studies on systematic evaluation, such as Factor analysis, Analytic Hierarchy Process (AHP), Fuzzy Comprehensive Evaluation (FCE) [6][7], Entropy Value Method [8], AHP-TOPSIS [9], etc. Many of these methods are very effective in scientific research, but if different practical application scenarios are considered, some methods may not be very suitable. In actual operation, the simpler the system evaluation method, the higher the operability. At this point, AHP has lower requirements for theoretical foundation than other methods, but AHP has a large amount of data statistics when there are too many indicators [10][11]. An enterprise contains many different units, which can be roughly divided into three parts: manufacturing, detection and testing. The three parts have different focuses, and they all have unique evaluation indicators. It is difficult to evaluate them through a set of evaluation systems, and the number of units in the enterprise is large, it is obviously impractical to form a different evaluation system for each unit, so it is necessary to change the existing comprehensive evaluation system and try to evaluate all of the units at the same time.

Aiming at the existing problems, this paper proposes a systematic evaluation method which based on the A.J.Klee method to calculate the weight [12]. The method steps are as follows:

(1) Integrate all sub-elements of all evaluation objects.

(2) The importance of all sub-elements is determined by experts [13].

(3) When evaluating a unit, experts identify and remove sub-elements that are not relevant to the unit.

(4) Use the A.J.Klee method to determine the weight of each sub-element.

(5) Use the Expert evaluation method and combine the weights to calculate the score of each unit.

This paper is divided into the following four sections. Section 1 presents the background and motivation of this paper. Section 2 mainly establishes the Excellent Process Grade evaluation model for the production and test process of products, establishes the three-level evaluation model framework of "aspect, element, sub-element", and determines the weighting method of the sub-elements. Section 3 takes a machining unit in the enterprise as an example, combines the Expert evaluation method and the Excellent Process Grade evaluation model to determine the final score and level of the machining unit, and through the evaluation results to determine the current problems and

2693-9371/22/$31.00 ©2022 IEEE
DOI 10.1109/QRS-C57518.2022.00071

future improvement directions. Section 4 summarizes this work and looks forward to future research.

II. Evaluation Model Construction

Before giving the assumptions of our model, we introduce the following notations and abbreviations which will be used in this paper.

NC	Numerical control
AHP	Analytic hierarchy process
R	Importance of the unit to be evaluated
K	*R* after benchmarking
W	Weight of the unit to be evaluated
CDMD	Capacity demand matching degree
CIR	Capacity improvement ratio
EQP	Equipment quality problems
ERC	Emergency response capability
AOTM	Advancement of turnover mode
OPM	Operation plan management
EUR	Equipment utilization ratio
DODM	Degree of detectability and measurability

A. Evaluation Indicator System

The framework diagram of the evaluation indicator system of product excellence process is shown in Figure 1.

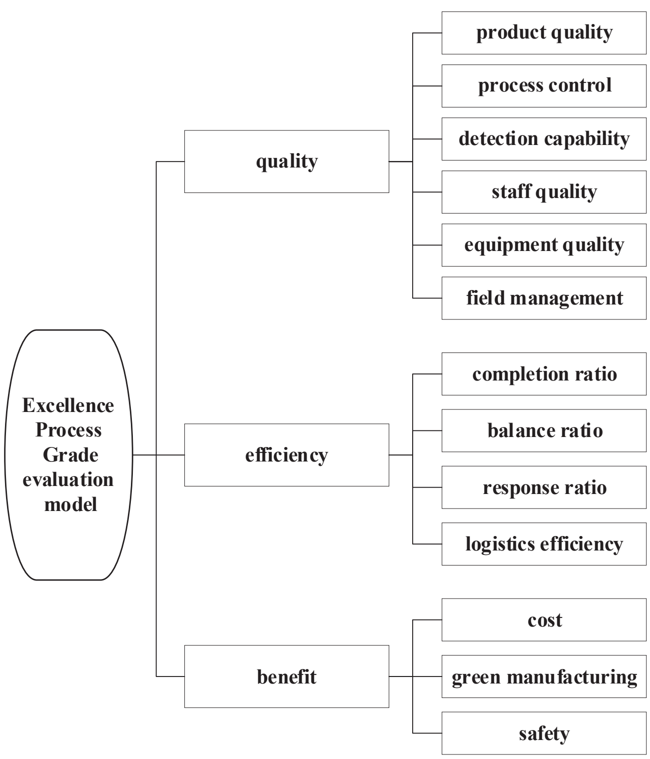

Figure 1. Indicator system diagram

The selection of the evaluation indicators for the excellent process of products mainly follows the principles of relative independence, objectivity, scientific, completeness and effectiveness [14].

The product Excellence Process Grade evaluation model is developed from three levels: aspect, element and sub-element. There are three aspects: quality, efficiency and benefit.

According to the manufacturing objectives and industry management requirements of product manufacturing enterprises, the product quality, process control, detection capability, staff quality, equipment quality, filed management, completion ratio, balance ratio, response ratio, logistics efficiency, cost, green manufacturing, and safety are subdivided according to the actual situation, so as to facilitate the later practical operation and analysis.

The quality aspect includes six elements: "product quality", "process control", "detection capability", "staff quality", "equipment quality" and "field management ".

- ➢ The product quality includes the first pass yield, pass ratio stability, scrap ratio and serious quality problems.
- ➢ The process control includes document management, state change control, operation standardization and human error prevention.
- ➢ The detection capability includes the DODM and the level of product intelligent detection.
- ➢ The staff quality includes personnel quality, human quality problems and team effectiveness.
- ➢ The equipment capability includes equipment automation level, NC program management, EQP and equipment operation status monitoring.
- ➢ The field environment includes 6S management and visual management

The efficiency aspect includes four elements: "completion ratio", "balance ratio", "response ratio" and "logistics efficiency".

- ➢ The completion ratio includes on-time completion ratio, OPM.
- ➢ The balance ratio includes CDMD, CIR.
- ➢ The response ratio includes flexibility, equipment failure ratio and ERC.
- ➢ The logistics efficiency includes rationality of layout and AOTM.

The benefit aspect includes three elements: "cost", "green manufacturing" and "safety".

- ➢ The cost includes cost control level, deviation of monthly cost ratio, unit man hour output and EUR.
- ➢ The green manufacturing includes energy saving and emission reduction.
- ➢ The safety includes operation safety and major safety accidents.

B. Sub-element division

In order to better reflect the characteristics of the three levels of Meticulous, Lean and Excellent[15], sub-elements are divided into the following three categories according to the evaluation objectives and requirements:

1) Veto type sub-element

The veto type sub-elements are the bottom line requirements for participating in the evaluating. If units fail to meet the requirements, they will be disqualified from participating in the evaluation and will be directly regarded as unqualified, including two sub elements: serious quality problems and major safety accidents.

2) Key type sub-element

This evaluation divides the unit into three levels: Meticulous, Lean and Excellent. Each level has corresponding key type sub-elements. If the requirements for key type sub-elements are not met, the unit cannot be evaluated as the corresponding level.

The meticulous level key type sub-element includes operation standardization. The lean level key type sub-elements include equipment automation level and rationality of layout. The excellent level includes equipment operation status monitoring and the level of product intelligent detection.

3) Guided type sub-element

Guided type sub elements refer to the elements that are used to score the problems in the production process and can provide a guiding evaluation for the construction of the unit through quantitative scores or qualitative descriptions. The guided type sub-elements include the remaining 28 sub elements.

C. *Indicator weighting method*

Common weighting methods include AHP, entropy method, A.J. Klee method, etc. Because the number of evaluation indicators involved in this paper is large, and the importance of indicators varies greatly, AHP and entropy method are not applicable, and because the importance of indicators can be quantitatively estimated according to the experience accumulated in the unit, the A.J. Klee method will perform better in this situation. Therefore, this paper uses the A.J. Klee method to determine the weight of each index. Next, introduce the steps of using the A.J. Klee method.

1) Sub-element sorting

Assume that the number of sub elements of an evaluation system is n, record these sub elements as $\{a_i\}, i = 1, 2, \ldots, n$, then let experts and enterprise managers determine the significance of each sub element and reorder the sub elements according to their significance, record as $\{a_{(i)}\}, i = 1, 2, \ldots, n$.

Table 1. Importance level and value

Relative importance	Valuation
Equally	1
Slightly	2
Strongly	3
Intensely	4
Extremely	5

2) Determine the importance of sub elements

Compare the sorted sub elements in pairs from front to back, and use numerical values to express their relative importance. The importance level and its valuation are shown in Table 1.

3) Importance R_i benchmarking

Assume that the results after benchmarking are K_i, based on the last sub-element, making $K_n = 1$, calculating the results of other sub-elements after benchmarking from bottom to top, and the formula is as follows.

$$\begin{cases} K_{i-1} = R_{i-1} \times K_i \\ K_n = 1 \end{cases}, i = 2, ..., n; \tag{1}$$

4) Normalization of K_i

Accumulating $K_i, i = 1, 2, ..., n$, and then K_i is divided by the accumulated result to obtain the weight W_i of each sub-element. The weight calculation formula is as follows.

$$W_i = \frac{K_i}{\sum_{i=1}^{n} K_i}, i = 1, 2, ..., n. \tag{2}$$

D. *Evaluation process*

In this section, the use process of evaluation model is described. The determined method is shown in the figure2.

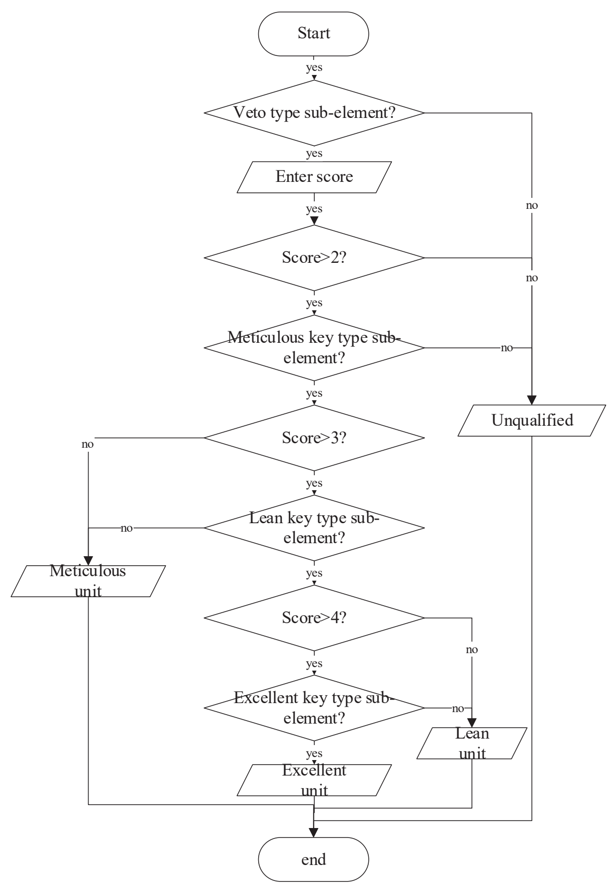

Figure 2. Grade evaluation process

1) Sort all sub-elements, than give importance to all sub-elements in combination with the opinions of experts

and managers.

2) When evaluating a specific unit, experts and managers shall select all sub-elements closely related to the unit, and calculate K_i and W_i.

3) Calculate the weighted scores of all sub-elements through expert evaluation method and weight.

4) After we get the weighted score, we need to determine which level the unit is currently in " Meticulous-Lean -Excellent".

III. NUMERICAL EXPERIMENT

This section uses the machining unit as a numerical experiment.

A. Determine the importance of all sub elements

All sub-elements are sorted as follows. "first pass yield, scrap ratio, pass ratio stability, document management, operation standardization, NC program management, CDMD, operation safety, emission reduction, on-time completion ratio, OPM, cost control level, unit man hour output, EUR, monthly cost ratio, team effectiveness, state change control, CIR, human error prevention, DODM, human quality problems, EQP, rationality of layout, 6S management, visual management, ERC, equipment failure ratio, AOTM, personnel quality, energy saving". R and K of each sub element are shown in Table 2.

Table 2. *R* and *K* of Sub-elements

Sub-element	R	K	Sub-elements	R	K
first pass yield	1	48	team effectiveness	1	4
scrap ratio	2	48	state change control	1	4
pass ratio stability	1	24	CIR	1	4
document management	1	24	human error prevention	1	4
operation standardization	1	24	DODM	1	4
NC program management	1	24	human quality problems	1	4
CDMD	1	24	EQP	1	4
operation safety	2	24	rationality of layout	1	4
emission reduction	1	12	6S management	1	4
on-time completion ratio	1	12	visual management	1	4
OPM	1	12	ERC	2	4
cost control level	1	12	equipment failure ratio	1	2
unit man hour output	1	12	AOTM	2	2
EUR	1	12	personnel quality	1	1
monthly cost ratio	3	12	energy saving	--	1

B. Score calculation

In this part, Experts select the relevant sub-elements of the machining unit, give the scores, and finally calculate the weighted score. The selected sub elements and calculated scores are shown in Table 3. The total score of machining unit is 4.2825.

C. Grade evaluation

First of all, the machining unit did not have serious quality problems or major safety accidents within the specified period, so we believe that the unit meets the basic requirements for participating in the excellent process grade evaluation. The evaluation score of the machining unit is 4.2825, which belongs to the range of "Excellent", then we analyze whether the unit meets the requirements of key type sub-elements.

We believe that the unit has a standard operation process. After training, employees can produce products with qualified quality and sufficient quantity according to the operation process, so this unit meets the requirements of Meticulous level.

The main production in the product manufacturing process can be realized through automatic equipment, and some specific operations require manual operation or participation, so this unit meets the requirements of Lean level.

This unit can collect all kinds of product quality inspection data in real time through intelligent inspection and other technical means, analyze, predict and evaluate product quality through real-time data, and provide improvement and decision-making for production process, so this unit meets the requirements of Excellent level.

The machining unit meets the requirements of veto type sub-element, key type sub-element and guided type sub-element scored 4.2 points, so this unit has reached the level of "excellent".

Table 3. *W* and Weight Score of sub-elements

Sub-element	K	W	Score	Weighted Score
first pass yield	48	0.1491	5	0.7453
scrap ratio	48	0.1491	5	0.7453
pass ratio stability	24	0.0745	5	0.3727
document management	24	0.0745	4	0.2981
operation standardization	24	0.0745	4	0.2981
NC program management	24	0.0745	4	0.2981
CDMD	24	0.0745	4	0.2981
operation safety	24	0.0745	5	0.3727
emission reduction	12	0.0373	2	0.0745
on-time completion ratio	12	0.0373	4	0.1491
OPM	12	0.0373	4	0.1491
monthly cost ratio	12	0.0373	3	0.1118
state change control	4	0.0124	4	0.0497
human error prevention	4	0.0124	3	0.0373
DODM	4	0.0124	4	0.0497
human quality problems	4	0.0124	3	0.0373
EQP	4	0.0124	4	0.0497
rationality of layout	4	0.0124	3	0.0373
6S management	4	0.0124	4	0.0497
equipment failure ratio	2	0.0062	4	0.0248
AOTM	2	0.0062	3	0.0186
personnel quality	1	0.0031	3	0.0093
energy saving	1	0.0031	2	0.0062

D. Result analysis

We add the weights of the three aspects of quality, efficiency and benefit respectively, and analyze which one is the most important aspect of the enterprise. The results are shown in Table 4.

Through calculation, we can obtain that the total weights of the three aspects of quality, efficiency and benefit are: 0.6737, 0.1739, 0.1522. We can notice that the enterprise currently pays special attention to quality, but not enough attention to efficiency and benefit. If an enterprise wants to develop continuously, it must pay attention to efficiency and benefit while paying attention to quality.

Then we determine the current deficiencies of the enterprise according to the scores of each sub-element. From Table 3, we can clearly see that the current energy saving and emission reduction of the enterprise is not enough, and the weight of emission reduction is relatively large in all sub-elements. Therefore, in order to build a better manufacturing unit, it is possible to consider improving emission reduction. The manufacturing unit performed better on sub-elements with higher weights and scored less on sub-elements with lower weights. There is still a lot of room for improvement.

Table4. The weight of each aspect

element	Sub-element	*W*	Weighted Score
Quality	first pass yield	0.1491	0.7453
	scrap ratio	0.1491	0.7453
	pass ratio stability	0.0745	0.3727
	document management	0.0745	0.2981
	state change control	0.0124	0.0497
	operation standardization	0.0745	0.2981
	human error prevention	0.0124	0.0373
	DODM	0.0124	0.0497
	personnel quality	0.0031	0.0093
	human quality problems	0.0124	0.0373
	NC program management	0.0745	0.2981
	EQP	0.0124	0.0497
	6S management	0.0124	0.0497
Efficiency	on-time completion ratio	0.0373	0.1491
	OPM	0.0373	0.1491
	CDMD	0.0745	0.2981
	equipment failure ratio	0.0062	0.0248
	rationality of layout	0.0124	0.0373
	AOTM	0.0062	0.0186
Benefit	monthly cost ratio	0.0373	0.1118
	energy saving	0.0031	0.0062
	emission reduction	0.0373	0.0745
	operation safety	0.0745	0.3727

IV. CONCLUSIONS

In this paper, the combination of the A.J. Klee method and the expert evaluation method is used to determine the weight and score of each sub-element in the manufacturing unit, and an excellent grade evaluation model is established. Aiming at the problem that it is impossible to determine the level of the unit based on the score only when distinguishing the unit level, three different types of sub-elements are proposed to correctly divide the level of the unit. The use of the evaluation model and the evaluation process are demonstrated through the case of a manufacturing unit.

In this evaluation, there may be similar problems that the on-time completion ratio of the downstream unit is affected due to the untimely delivery of materials from the upstream unit. In the future, the evaluation of units should consider the relationship between each unit to avoid affecting the evaluated unit due to other units.

ACKNOWLEDGMENT

The authors gratefully acknowledge the financial supports for this research from the National Natural Science Foundation of China (Nos. 71871181, 72271200) and the Key R&D Program of Shaanxi Province (2022KW-15, 2021ZDLGY12-03, 2021ZDLGY10-06).

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