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Robustness Evaluation of Flexible Manufacturing System Considering the Static & Dynamic Manufacturing Environment

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***Abstract*—It is always the important and key research issue to estimate the robustness performance of flexible manufacturing system in the field of the advanced production management technology. A robustness evaluation method is proposed considering the static and dynamic manufacturing environment. The robustness is regarded as the combination of the scope of changes and the errors maintain capacity. Delphi method is introduced to decide the weights of the two single indexes. Finally a case study is used as an illustration to present the detailed evaluation procedure.**

Keywords—Robustness; Flexible Manufacturing System; Delphi Method; Indicators Architecture

I. INTRODUCTION *(HEADING 1)*

A robust manufacturing system aims at achieving scope of changes and responsiveness to the changing market needs, which brings innovative products to market very quickly, permit fast cost-effective responses to market and customer demands for new products and product features and support rapid product launches for previously unplanned products tailored to meet changing customer desires. It requires a manufacturing system to be capable of producing a variety of products efficiently, usually in small batches, and to be re-configurable to accommodate changes in the product-mix and product design.

The "robustness" is a statement about the ability to predict the satisfactory completion of a change activity. For a manufacturing system, the robustness is defined as its aptitude to preserve its specified properties against foreseen or unforeseen disturbances. Therefore controlling a robust manufacturing system consists in imposing a number of the control laws to achieve goals that meet the needs of the market, taking into account the disturbances which implicitly influence the prescribed exits.

Based on a survey and assessment of the various contemporary definitions, Durieux [1-2] summarize the following definition for the robustness of manufacturing systems:

- Robustness in terms of insensibility: in this case, a robust system is a system, for which performance will be relatively insensible to the variation of its environment.
- Robustness against a specified threshold: in this case, a robust system is a system which keeps an acceptable level of performance on a given number of environments.
- Robustness regarding a particular design solution: in this case, the behavior of each design solution is compare to the behavior of a particular solution which is optimal under a 'based environmental scenario'. The more robust solution will be the solution which is the best compromises regarding these particular solution according the entire considered environment.

Robust control and robustness evaluation are the classical proposition of the control science and engineering subject. But there is rare research on the robustness evaluation of manufacturing system because researchers cannot decide which indexes will be included in the key performance indicators architecture. Especially the physical equipments, shop floor layout, scope of changes are all the factors that affect the performance of robustness [3-6]. Therefore Evaluation of robustness is necessary for the strategic planning of determining how much robustness an manufacturing system currently possess, determining how much is needed, and then for assessing the gap and formulating a strategy for closing any perceived weaknesses.

In this paper, a robustness evaluation method is proposed considering the static and dynamic manufacturing environment. The robustness is regarded as the combination of the scope of changes and the errors maintain capacity. Delphi method is introduced to decide the weights of the two single indexes. Finally a case study is used as an illustration to present the detailed evaluation procedure.

II. INDICATORS ARCHITECTURE FOR ROBUSTNESS EVALUATION

A. *Static manufacturing environment*

In the static manufacturing environment, the customer demand and the physical equipments are fixed. So the range of changes depends on the numbers and functions of the physical equipments. If the users want to add the functions of the manufacturing system, the finance investment of physical equipments is necessary.

In this environment, the errors are very harmful because there is no the redundant equipment to replace the fault equipment.

Robustness represents the stability and rigidity of the manufacturing system, which means that the degree to unceasingly maintain the normal operation when the errors

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arise. The index will be quantified as the Error Maintenance Capacity (EMC).

The calculation processes are shown as follows:

(1) Calculate the error happen times Q_i and the successful maintenance times Q_i^{suc}

(2) Calculate the all the error happen times Q_{total}

$$Q_{total} = \sum_{i=1}^{n} Q_i \qquad (1)$$

(3) Calculate the happen probability of all the kinds or errors e_i^{fre}

$$e_i^{fre} = \frac{Q_i}{Q_{total}} \qquad (2)$$

(4) Define the error category and harm weight of every kind of errors

(5) Calculate the error maintenance capacity I_{EMC}.

$$I_{EMC} = \sum \omega_i^{imp} e_i^{fre} \frac{Q_i^{suc}}{Q_i} \qquad (3)$$

.

B. *Dynamic manufacturing environment*

In the dynamic manufacturing environment, robustness means the ranges that the manufacturing system can adopt the changes of customer demands, especially the changes are unpredictable. The index will be quantified as the scope of changes, which is nominated as I_{SoC}. The scope of changes (SoC) levels is judged as shown in Table 1. In the table, the scope of changes is clarified as seven levels and every level represents a range the manufacturing system can match the changes.

Function / Level	NC/DNC	CAD/CAM	Shop floor management	Monitor control	Manufacturing Cell reconfiguration	Automobile vehicles
1	▲					
2	▲	▲				
3	▲	▲	▲			
4	▲	▲	▲	▲		
5	▲	▲	▲	▲	▲	
6	▲	▲	▲	▲	▲	▲

III. IN DELPHI APPROACH

Before you begin to format your paper, first write and save the content as a separate text file. Keep your text and graphic files separate until after the text has been formatted and styled. Do not use hard tabs, and limit use of hard returns to only one return at the end of a paragraph. Do not add any kind of pagination anywhere in the paper. Do not number text heads-the template will do that for you.

The Delphi method is a systematic, interactive forecasting method which relies on a panel of independent experts. The carefully selected experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the correct answer. Finally, the process is stopped after a pre-defined stop criterion and the mean or median scores of the final rounds determine the results [7-11].

Fowles describes the following ten steps for the Delphi method [12]:

- Formation of a team to undertake and monitor a Delphi on a given subject.
- Selection of one or more panels to participate in the exercise. Customarily, the panelists are experts in the area to be investigated.
- Development of the first round Delphi questionnaire
- Testing the questionnaire for proper wording (e.g., ambiguities, vagueness)
- Transmission of the first questionnaires to the panelists
- Analysis of the first round responses
- Preparation of the second round questionnaires (and possible testing)
- Transmission of the second round questionnaires to the panelists
- Analysis of the second round responses (Steps 7 to 9 are reiterated as long as desired or necessary to achieve stability in the results.)
- Preparation of a report by the analysis team to present the conclusions of the exercise

IV. CASE STUDY .

(1) Experiment environment

The layout and equipments list of the experiment environment are shown as Figure 1 and Table 2.

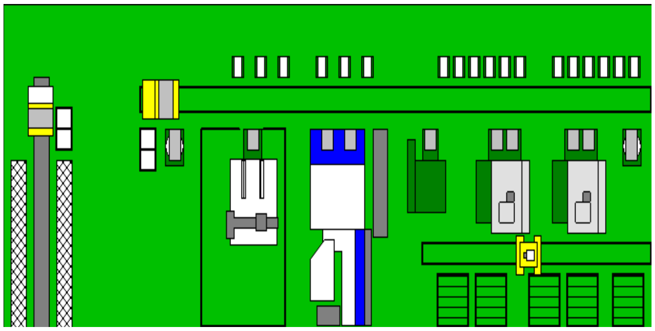

Figure 1 Layout of the experiment environment

Table 2. The equipment list of experiment system

Type	Quantity	Code
Vertical machining center	2	OMA/OMB
Horizontal machining centre	1	MCH
AGV	1	AGV
Depot station	1	LUL
Washing station	1	WAS
Measure machine	1	CMM
Buffers	18	BUF
Tool magazine	1	CEN
Robot	1	ROB

Based on the statistic results, error category and times analysis are shown as Table 3 and error level and harm weight are shown as Table 4 respectively.

Table 3. Error category and times analysis

Category of errors	Error times	Successful maintenance times
Man-Made	35	32
Equipment	28	24
Design	45	39
Manufacturing	19	16
Material	17	14
Disturb	8	4

Table 4. Error category and harm weight

Category of errors	Error level	Harm weight
Man-Made	Ⅵ	1
Equipment	Ⅰ	6
Design	Ⅳ	3
Manufacturing	Ⅲ	4
Material	Ⅱ	5
Disturb	Ⅴ	2

Table 5. The judgment matrix of all experts

Experts	EMC	scope of changes	Sum
EP1	0.415	0.585	1
EP2	0.415	0.585	1
EP3	0.416	0.584	1
EP4	0.417	0.583	1
EP5	0.417	0.583	1
EP6	0.415	0.585	1
EP7	0.415	0.585	1
EP8	0.415	0.585	1
EP9	0.413	0.587	1
mean	0.415	0.585	1
Standard deviation	0.0012	0.0011	
upper C. I.	0.416	0.586	
Lower C. I.	0.413	0.583	

Table 6 Robustness level based on robustness score

Robust level	Index value	Robustness performance
Ⅰ	(0.9，1.0)	Very good
Ⅱ	(0.8，0.9)	good
Ⅲ	(0.6，0.8)	Not bad
Ⅳ	(0.4，0.6)	Bad
Ⅴ	(0，0.4)	Very bad

(2) EMC calculation

According to the equation 1-3, the EMC of the experiment system is calculated as 2.862

(3) Scope of changes calculation

After the detailed investigation, the scope of changes of the experiment system is judged as the sixth level.

(4) Normalization

Because the EMC and scope of changes have different dimension, the normalized function is introduced to the combination of these indexes. The final value of the EMC and scope of changes are 0.897 and 0.865 respectively

(5) results of the weighs assigned

According to the steps of the Delphi method, the judge matrix and the weights assigned to EMC and scope of changes are shown as Table 5.

(5) Final result calculation

Therefore, the final result of robustness is:

$$\text{Robustness}=0.415 \bullet I_{EMC} + 0.585 \bullet I_{SoC} = 0.878$$

According to the Robustness level definition policy shown as the Table 6, the robustness performance of the flexible manufacturing system is good.

V. Conclusions

In this paper, a robustness evaluation method is proposed considering the static and dynamic manufacturing environment. The robustness is regarded as the combinations of the errors maintain capacity and scope of changes. Delphi method is introduced to decide the weights of the two single indexes. Finally a case study is used as an illustration to present the detailed evaluation procedure.

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