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DECISION-MAKING FOR METROLOGY SYSTEM SELECTION BASED ON FAILURE KNOWLEDGE MANAGEMENT

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ABSTRACT

Decision-making in relation to product quality is indispensable in order to reduce product development risk. Based on the identification of the deficiencies of Quality Function Deployment (QFD) and Failure Modes and Effects Analysis (FMEA), a novel decision-making method is presented that concentrates on a knowledge management network under various failure scenarios. An ontological expression of failure scenarios is presented together with a framework of failure knowledge network (FKN). A case study is provided according to the proposed decision-making procedure based on FKN. The methodology is applied in the Measurement Assisted Assembly (MAA) process to solve the problem of prioritizing the measurement characteristics. The mathematical model and algorithms of Analytic Network Process (ANP) are introduced into calculating the priority value of measurement characteristics, together with an optimization algorithm for combination between measurement targets and measurement systems. This paper provides a practical approach for improved decision-making in relation to quality control.

KEYWORDS

Decision-making in quality control, Failure knowledge management, Decision-making model, Analytic network process

1. INTRODUCTION

The inner and outer environments where the products are being designed and developed are complex and variable. Within such creative and uncertain surroundings, potential risks can never be fully avoided or mitigated (Jerrard et al. 2008). Therefore, risk assessments are required at critical decision-making points to keep product development at the possible lowest risk. Traditionally, the decision-making process is implemented qualitatively by experts of subject domain. Among the numerous research papers available in manufacturing system and process planning, most of them focus on the operations which are directly related to the processing phases (Chen and Ko 2009) and only a few discuss the decision-making and optimization in term of global quality control.

Failure knowledge can be employed as a quantitative methodology for decision-making in product quality. Different types of failures, which lead to the breakdown of certain functions, emerge in design, production and enterprise departments with respective possibilities of occurrence during the life cycle of similar products. The correlation degrees for each failure with different manufacturing characteristics, such as product functions, components, processes and organizations structure, are essential parts of failure knowledge.

By observing the knowledge network of failure scenarios, it is important to examine the perceived weight of manufacturing characteristics obtained from the market and customers and compare them with the overall consideration at the time of task launch. The decision-making related to product quality based on failure knowledge is composed of the following six tasks: (i) predicting and identifying risks and faults, (ii) analyzing the cause and mechanism of the past similar failures, (iii) presenting optional proposals, (iv) selecting the optimal scheme, (v) conducting the designated plan, and (vi) verifying the execution results.

In this paper, a quantitative approach for decision-making in product quality is proposed. An ontological expression of failure scenario is presented together with a framework of failure knowledge network (FKN). The decision-making process in product quality based on FKN is discussed in detail, followed by a case study carried out to verify the novel decision-making process.

2. LITERATURE REVIEW

The main reason why similar failure cases are repeated in practice is that the knowledge of past failures is not well captured and communicated to related people (Hatamura et al. 2003). In order to utilize the knowledge of past failure cases, an efficient and unified method has to be provided for communicating failure experience.

2.1. FAILURE EXPRESSIONS AND MANAGEMENT

Many organizations have constructed the databases that store failure information in addition to manuals, documents and procedures (Colding 2000). However, because of poor transferring of failure information to other parts of the organization, the failure knowledge is not effectively communicated and the same failures are repeated.

Failure Modes and Effects Analysis (FMEA) is a method that is used to identify and prioritize potential failures in products or processes, and has been widely applied to acquire and update failure knowledge within an organization (Dai et al. 2009a). The advantages and disadvantages of applying FMEA are extensively examined both in industry and academia. Conclusively speaking, the traditional FMEA uses three factors, Occurrence, Severity and Detection, to determine the Risk Priority Number (RPN), which is used to address and prioritize the potential failures rapidly. However, it has drawbacks such as the deficiencies in the relationship expressions between different failure components, so FMEA cannot be used as a technique for knowledge formulation. In order to address this deficiency of FMEA, failure scenario is introduced (Kmenta and Ishii 2000) and the ontological view of failure scenario is shown in Figure 1.

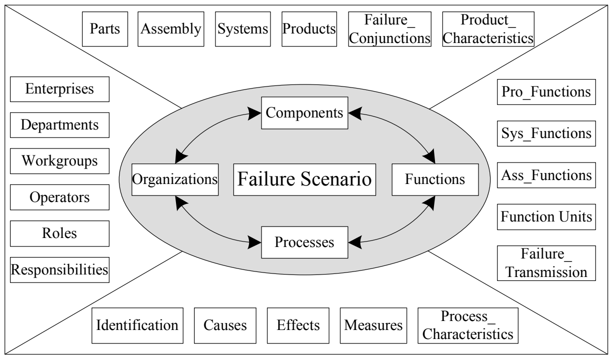

Figure 1 – Ontological view of a failure scenario

Failure scenarios of the mechanical products refer to any customer-perceived deviations from the ideal function of the product, including overload, impact, corrosion, fatigue, creep, rupture, deformation and cracking. There are four entities engaged in a failure scenario: functions, components, processes and organizations. The "component" entity is the carrier of the failure. The amount of failure types regarding one component is finite (Arunajadai et al. 2004), and different types of failures have conjunctions if they are related to the same component. The conjunctive failures are subject to certain variations of product characteristics, which play an important role in the occurrence of conjunctive failures. The "function" entity is used to record connections between the failure and functions. When the failure takes place, it is usually followed by a breakdown of the corresponding function, and other failures will occur if no corrective measure is adopted. On many occasions a function is interfered by different failures with respective probability, and the breakdown of this function can also give rise to many other failures. The "processes" entity is used to trace the chronological progression of the failure. A failure can be regarded as a unified process, through which input leads to output. As a developing failure becomes evident, its effects are firstly established, and the corrective actions will be taken after analyzing the causes that need to be addressed to deal with the event. The "organizations" entity should be regarded as a monitor to take care of the failure scenario. Each individual in the organization has different roles with different responsibilities during the failure process. Their respective actions and behaviours, as well as the failure status, are supervised and classified to construct and improve a quality system.

2.2. RELATIONSHIPS BETWEEN DECISION-MAKING AND KNOWLEDGE MANAGEMENT

Decision-making is one of the most common thinking activities and one of the most crucial processes of any business. It has been explained in many theoretical frameworks (Hammond et al. 1980 ; Kaplan and Schwartz 1977) in early researches carried during 1980’s and 1990’s. In the digital manufacturing environment, which is often referred to as the knowledge age (Stutt and Motta 1998), more and more decisions related to productivity highly dependent on decision makers’ experience and knowledge (Kidd 1994). Therefore, the decision-making techniques or decision-making support tools are in need to be developed to meet the timeliness and utility of the decision information that will be required by these people at all levels of the organization. The ‘…lack of knowledge is a major shortcoming of important business decisions’ (Wiig 1997).

To create, store, transfer and apply the large volume of knowledge within the business processes for the distributed manufacturing organizations, Knowledge Management (KM) has been proposed, referring as ‘a discipline and a managerial policy initiative that encapsulates the strategies, systems and processes that enable and simplify creation, capture, sharing, distribution and utilization of an organization’s knowledge’ (Oliver and Kandadi 1997). The detailed process of the knowledge management is shown in Figure 2. The main aspects of KM involve in the creation of value from an organization’s intangible assets and the information systems designed to facilitate the sharing and integration of knowledge (Alavi and Leidner 2001; Schultze and Leidner 2001). However, KM is still an immature discipline, mostly because a codified, generally accepted framework has not been established (K. Metaxiotis 2005; McDermott 1999).

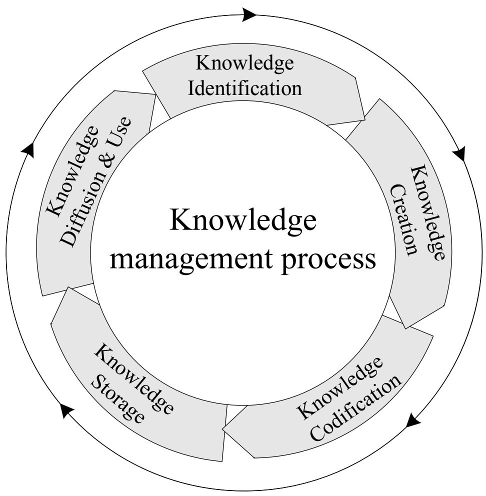

Figure 2 –Knowledge management process

Both of the KM and the decision-making activity during the product development process concern the representation and processing of knowledge by machines, human beings, organizations or societies (Borghoff and Pareschi 1997). The overall aim of the KM in decision-making is to ensure that the right knowledge is available in the right forms to the right entities at the right time for the right cost (Kotnour et al. 1997). The relationships between the decision-making and KM, therefore, can be concluded as that the decision-making is a knowledge intensive managing activity requiring knowledge as its raw materials. The proficiency and efficiency in KM is increasingly important to the competitiveness of the decision makers.

3. PROPOSED APPROACH

3.1. FAILURE KNOWLEDGE NETWORK

In order to manage and structure the failure knowledge network, research is required to deal with the connections between the system characteristics and the triggers, as well as the connections between the system characteristics and the results. Once the relationships have been identified and clarified, it is possible to view the failures, effects, causes, and actions in terms of characteristics, with a trigger leading to a result.

Generally, failure scenarios are induced by unexpected variations of certain manufacturing characteristics during the new product development (NPD), which includes design, processing, assembly and validation. For this reason, the relationship between failures and characteristics for both processes and products, as well as the experiences dealing with the similar failure processes, are the invaluable source of knowledge for NPD. The failure knowledge network (FKN) is comprised by the following five parts: (i) the connection between failures and product functions, (ii) the relationship between failures and product components, (iii) the correlation between failures and organizations, (iv) the association between failures and product processes, and (v) the conjunction among different failures.

Failure	Detection	Effect	Severity	Weight	Cause	Monitor	Reappearance	Operations	Efficiency	Precautions	…
q_1	d_1	t_1	s_1	w_1	c_1	m_1	r_1	o_1	e_1	p_1	
q_2	d_2	t_2	s_2	w_2	c_2	m_2	r_2	o_2	e_2	p_2	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
q_x	d_x	t_x	s_x	w_x	c_x	m_x	r_x	o_x	e_x	p_x	
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	
q_m	d_m	t_m	s_m	w_m	c_m	m_m	r_m	o_m	e_m	p_m	

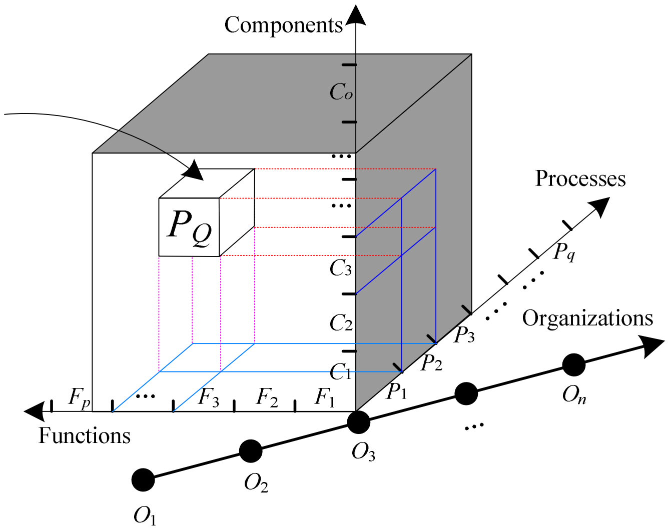

Figure 3 – A schematic of FKN

As shown in Figure 3, FKN can be described as a four-dimensional matrix, including components, functions, processes and organization. Each element in the matrix is a failure scenario and represents the related failures within the corresponding dimensions. The conventional factors of failures are embodied in the representation, including event, detection, effect, severity, solution weight, cause, monitor, reappearance, operation, efficiency and precaution. The indexes of the factors are provided by the subject matter experts and the engineers according to the degree of correlation between the corresponding characteristics and failures.

3.2. DECISION-MAKING MODEL BASED ON FAILURE KNOWLEDGE MANAGEMENT

Traditionally, quality function deployment (QFD) is employed in decision-making processes to quantitatively map the customer requirements to characteristics of design, processing, assembly and validation. This is known as a top-down approach, in which the qualitative requirements of customers are related to the quantitative weights of manufacturing characteristics during product development (Labodova 2004; Thornton 1999). A novel approach for QFD based on failure knowledge management is proposed in this paper, enabling the selection of the optimal schemes by analyzing the correlation between similar product failures and the relationships between the failures and the manufacturing characteristics.

Herein, the use of the analytic network process (ANP) (Satty 1996) is proposed in order to incorporate the dependency issues between the failures and manufacturing characteristics in a decision-making model. ANP differs from analytic hierarchy process (AHP) in that it allows the inner dependency within a cluster and outer dependencies among clusters. Based on the hierarchical structure, one can calculate the weights of manufacturing characteristics by using the ANP method. ANP provides a complete structure by which it is possible to find the interactions between the elements and the clusters from the problems, and then deduce the priority values and proportion value of each scheme. The ANP method includes two parts: (i) the control hierarchy, which refers to the network relationship of guideline and sub guideline, influencing the internal relationship of systems, (ii) the network hierarchy, which refers to the network relationship between elements and clusters.

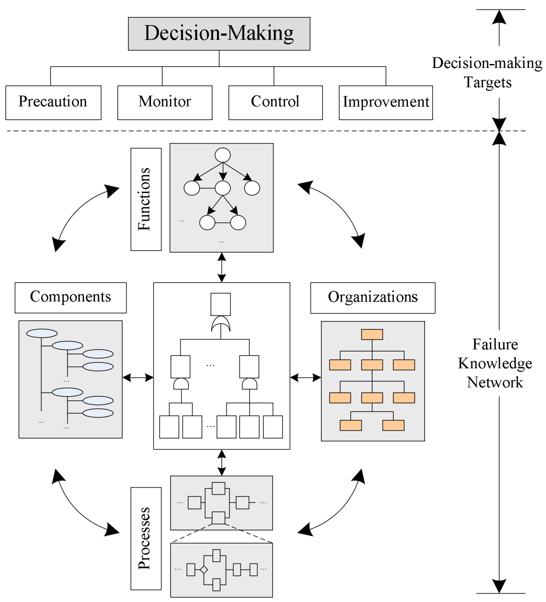

Figure 4 – Decision-making model

Figure 4 has shown the representation of the decision-making model, which is based on two parts: (i) the decision-making targets and (ii) the failure knowledge network (FKN). The decision-making targets include the precaution targets, the monitor targets, the control targets, and the improvement targets. The structure of FKN includes a cluster of failure scenarios and four extra manufacturing characteristics clusters, namely, functions, components, processes and organizations.

The first step of the decision-making methodology is to identify the failures and the corresponding characteristics. The second step is to determine the importance value of characteristics. In the third step, the body of the house will be filled by comparing the characteristics with respect to each target or characteristic. Finally, the interdependent priorities of the characteristics are obtained by analyzing the dependencies among the targets and characteristics. The supermatrix representation of decision-making model can be obtained as shown in Figure 5.

	G	*FS*	*F*	*C*	*P*	*S*
Goals (*G*)	W_{11}	W_{12}	W_{13}	W_{14}	W_{15}	W_{16}
Failure Scenarios (*FS*)	W_{21}	W_{22}	W_{23}	W_{24}	W_{25}	W_{26}
Functions (*F*)	W_{31}	W_{32}	W_{33}	W_{34}	W_{35}	W_{36}
Components (*C*)	W_{41}	W_{42}	W_{43}	W_{44}	W_{45}	W_{46}
Processes (*P*)	W_{51}	W_{52}	W_{53}	W_{54}	W_{55}	W_{56}
Organizations (*S*)	W_{61}	W_{62}	W_{63}	W_{64}	W_{65}	W_{66}

Figure 5 – Decision-making supermatrix

As shown in Figure 5, W_{11}, W_{22}, …, W_{66} are the inner dependency matrices of the targets and characteristics respectively. The other matrices are outer dependency matrices including the column eigenvectors with respect to each target or characteristic. The priority values and proportion values of each scheme can be obtained after multiplying the weighted supermatrix until its constringency.

3.3. OPTIMIZATION ALGORITHM

The final goal of metrology systems selection is to obtain an optimal arrangement between metrology tasks and metrology systems as well as to economically satisfy the customer requirements and engineering restrictions. Generally, there are more than one metrology systems that can be applied to accomplish the same inspection and verification task, and in turn one single metrology system has the ability to accomplish numerous inspection and verification tasks with different matching degrees (Singhal et al. 2007; Zhou and Zhao 2002).

In the metrology systems selection and optimization process, there are two types of constraints between inspection and verification tasks and metrology systems: (i) all inspection and verification tasks must be accomplished, and (ii) the capacity limits of metrology system can not be exceeded. Regarding to the above constraints, it is pre-assumed that there are m metrology systems that can be applied to assure n tasks. For this kind of complexity in optimal planning process, multiple tasks optimization may be involved. Other constraint factors such as time, cost and priority must also be taken into account in the product development stages. Weighted zero-one goal programming (WZOGP) is a feasible method to optimize the matching process, and the general mathematical model is presented as follows.

$$\min \quad \sum_{x=1}^{r}(\omega_x \cdot (\sum_{z=1}^{t} d_{xz} \cdot (1-\frac{w_{xz}}{W}))) \quad (1)$$

wherein:

$$W = \max_{\substack{1<x<r \\ 1<z<t}}(w_{xz}),$$

$$d_{xz} = 0 \ \ or \ 1,$$

$$\sum_{x=1}^{r} d_{xz} = 1,\ z = 1, 2, \dots\ t. \text{ and}$$

$$\sum_{x=1}^{r}\sum_{z=1}^{t} r_{xz}^{k} \cdot d_{xz} \le R_k,\ k = 1, 2, \dots\ m.$$

In Formula (1), ω_x is the weight of task T_x (i =1,2, …, r), w_{xz} is the matching degree between task T_x and metrology system MS_z. d_{xz} is a "0 or 1" variable, wherein d_{ij} =1 means the quality system MS_j (j =1,2, …, n) is selected to implement task T_i. R_k represents the ***k***th resource restriction (including time, cost etc.), and r_{xz}^{k} is the amount which resource R_k will be needed when utilizing metrology system MS_z to implement tasks T_x. The optimization of metrology systems selection for inspection and verification tasks can be obtained by employing WZOGP. Modification of the mapping result can be made by the designers and engineers based on the result of further simulations and evaluations in the digital environment.

4. EXPERIMENTATION AND CASE STUDY

To verify the decision-making model proposed in previous section, a simple artifact has been created using the popular CAD/CAM modelling software. As shown in Figure 6, it is a rectangular block, on the top face of which two vertical holes are slotted symmetrically, as well as a shwallow groove is cut in the centre. The design characteristics of the artifact is derived and simplified from the diesel engine blocks, which will be measured on Coordinate Measurement Machines (CMMs) for the purpose of 6-Sigma Quality Control in Measurement Assisted Assembly (MAA) process.

In order to determine the weights and values of Measurement Characteristics (MCs) in the Decision-Making Model, all the kinds of information required to construct a complete measurement specification has been loaded on the CAD model in Figure 6, including its design specifications and related tolerance features.

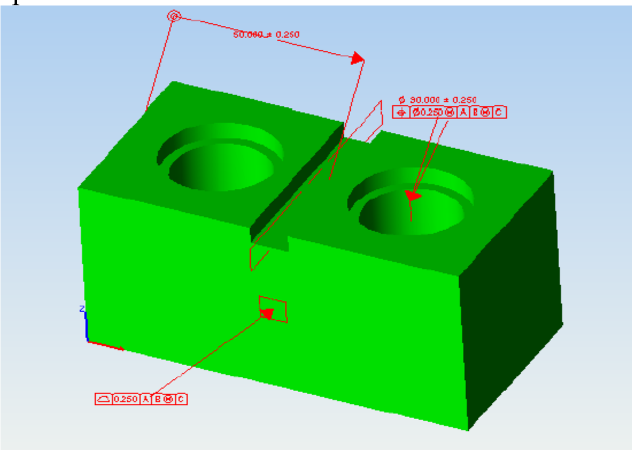

Figure 6 – The tolerance features to represent Measurement Characteristics

In the case study, the decision-making target is to prioritize the MCs of the part and select appropriate metrology system to satisfy the customer requirements and engineering restrictions economically. To generate the decision-making supermatrix, four of the design specifications and related tolerance features have been picked as the presentation of the *MC*s, which are MC_1 = "cylindricity", MC_2 = "location of the slotted hole", MC_3 = "location of the cut groove" and MC_4 = "the diameter of the bigger round step on top of the slotted hole". The weight of each characteristic has to be decided before executing the metrology resource planning activities(Dai et al. 2009b). Hence, the decision-making model is employed to express and codify the relationship between the *MC*s and failure scenarios.

Four *MC*s are set as cluster *MC*, and two dominant failure scenarios, which are F_1 = "overheating" and F_2 = "detonation", are selected as *FS* cluster. From the hierarchical structure, cluster *FS* is the control level whilst cluster *MC* is regarded as the network level. By extracting information from the FKN, one can obtain the pairwise comparison matrix A, B and C, and then evaluate its eigenvectors to group into the supermatrix *SM* in Figure 7.

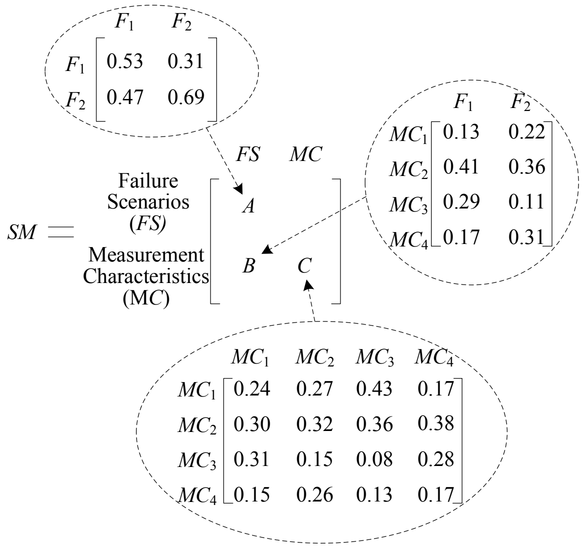

Figure 7 – Supermatrix structure Decision-making in MAA

To group the supermatrix *SM*, one needs to firstly transform it into a weighted supermatrix. The constringent supermatrix (shown in Figure 8) is obtained after multiplying the weighted supermatrix until its constringency, and it can show the weight of each *MC*. The following procedures of measurement planning can be conducted thereafter.

$$\begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0.28 & 0.28 & 0.28 & 0.28 & 0.28 & 0.28 \\ 0.33 & 0.33 & 0.33 & 0.33 & 0.33 & 0.33 \\ 0.20 & 0.20 & 0.20 & 0.20 & 0.20 & 0.20 \\ 0.19 & 0.19 & 0.19 & 0.19 & 0.19 & 0.19 \end{bmatrix}$$

Figure 8 – Decision-making supermatrix in MAA

In order to implement those quality aims in the product inspection process, seven metrology systems, including five laser trackers and two laser radars, are ready to be deployed. The usage cost c_z and capacity limits R_z of each metrology system MS_z are listed in Table 1. Assuming that the total budget for this project is £2000. The economical optimization for metrology system selection, then, has to be applied.

Table 1- The usage cost and capacity limits of each metrology system

	1	2	3	4	5	6	7
c_Z	£200	£300	£500	£1600	£300	£1000	£500
R_Z	1	1	1	2	1	2	3

According to the constraint factors, including cost, processing time and capacity limits of the metrology operations, WZOGP is applied as described in section 3.3. Finally, the measurement system selection result has been determined, as shown in Figure 9.

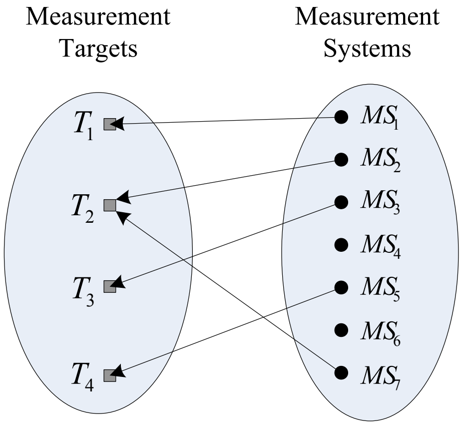

Figure 9 – Result of metrology system selection

5. CONCLUSION

This study shows that the knowledge from past failures of similar products is very useful for decision-making in relation to product quality control. This research has set up a failure knowledge based framework for decision-making in product quality control, and embodies its materialization to calculate the priority and lower the risk of manufacturing characteristics during new product development. The methodologies developed include: (i) identifying relationship between the failure scenarios and manufacturing characteristics, (ii) defining failure knowledge network according to the quantitative factor obtained, and (iii) employing the ANP method to deduce the priority and proportion of each scheme. Future research includes the construction of an IT-assistant system, which can assist to conduct decision-making by utilizing the failure knowledge management.

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