Maintenance Data Management System

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Abstract

For the effective management of manufacturing facilities throughout their life cycle, it is important to collect maintenance data and make use of them for operation and maintenance planning or design of new machines. However, it is seldom that the maintenance data are properly recorded and utilized in a systematic way. To solve these problems, we have proposed a maintenance data management system. In this paper, two major modules of the system are discussed. The first one is a malfunction data collection system which can navigate users to input malfunction cases in a proper format. The second one is a feedback data generation system which induces common causes implied in the malfunction cases by means of the attribute-oriented induction algorithm. An experimental system is applied to malfunction cases of machine tools for demonstrating its effectiveness.

Keywords: Maintenance data management, Failure analysis, Knowledge based system

1 INTRODUCTION

Although a lot of effort is devoted to enhancing reliability and maintainability in the facility design phase, occurrences of malfunctions in actual operations are almost inevitable. What is important is to learn from such experiences and to make use of them for improving design of new facilities as well as for the operation and maintenance planning of current facilities. Such activities are called MP (maintenance prevention) activities. Although MP activities are strongly dependent on human efforts, it is essential to have the support of information technologies for their extensive implementation. For this purpose, we have been developing a system for providing support to collect malfunction data, extract knowledge from them and feedback it to various phases of the facility life cycle. The system is intended to be an important part of a maintenance data management system, which is an integrated system for managing all data relevant to the facility life cycle maintenance.

In the following, we first discuss a framework of the maintenance data management system. Then systems for malfunction data collection and for generating feedback data by applying the knowledge discovery technique to malfunction cases are discussed. An experimental system is also presented to illustrate the effectiveness of the system.

2 MAINTENANCE DATA MANAGEMENT SYSTEM

To make best use of the functionality of a manufacturing facility throughout its life cycle, we have to manage all activities related to the facility maintenance in an effective way. For this purpose, it is essential to provide a system for managing all data relevant to the facility life cycle. We call such system a maintenance data management system.

In order to facilitate Plan-Do-Check-Action management cycles in the facility life cycle maintenance, it is important to evaluate various processes during the facility life cycle in advance, and to feed forward predicted information for the purpose of planning and control of operations and maintenance. Besides, it is important to collect empirical data obtained during actual operation, extract generally applicable knowledge from them, and feed it back for the purpose of the facility development as well as operations and maintenance. The maintenance data management system should support such twofold information flow as shown in Figure 1.

In order to feed forward the predicted information, we need a system for evaluating potential problems anticipated during the facility life cycle based on various models. For this purpose, we have developed the life cycle simulation system [5].

For facilitating feedback information flow, on the other hand, we need a system to collect empirical data and feedback them to various phases of the facility life cycle. It is important for such a system to provide support for collecting data in an appropriate format to make further computer processing possible. It should also provide the function of extracting useful knowledge from them, otherwise they tend to become just a pile of files. In the following, we will discuss how to realize such functions.

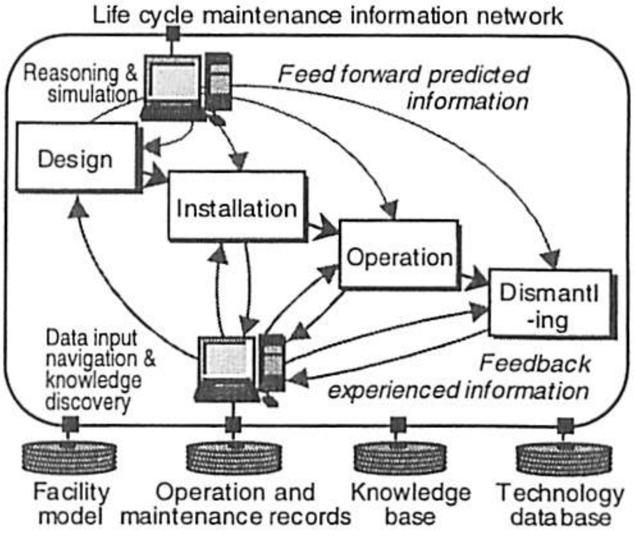


Figure 1: Maintenance data management system.

3 MALFUNCTION DATA COLLECTION SYSTEM

3.1 Requirements for the malfunction data collection system

Although malfunction data are recorded in many factories, it is seldom that they are effectively used for various maintenance activities. Based on the study conducted in an automobile parts manufacturing plant, we have found that the following points should be taken into consideration for designing the malfunction data collection system.

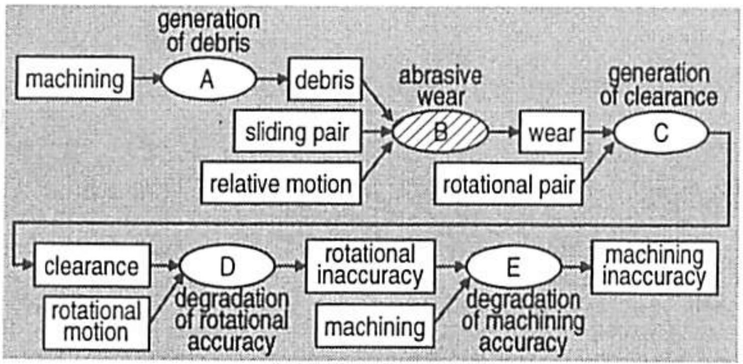
a) formats and terminology should be unified for enabling computers to process the data,

b) information about the structure and properties of the machine where the malfunction occurred should be represented in detail as well as the phenomena observed, because countermeasures are, in many cases, devised as modifications of the machine,

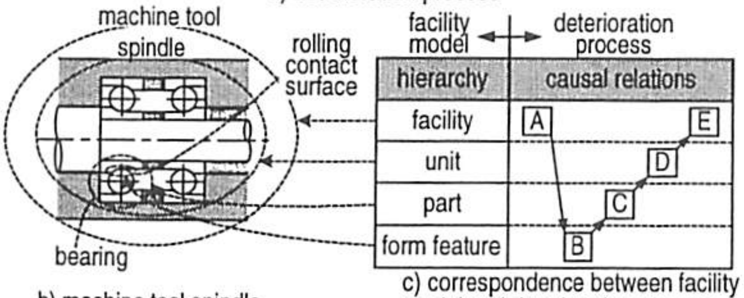
c) the level of detailedness of the description should be controlled, because cause-consequence relations depend on user's viewpoint in the hierarchical structure of the machine.

3.2 Representation of malfunction data

For unifying the format, malfunction data are represented in the form of a deterioration and failure process [3] in our system. It consists of mechanisms and causal factors. Mechanisms represent deterioration/failure mechanisms, such as fatigue, wear, and corrosion. The causal factors are conditions which induce mechanisms. There are cases where some of the causal factors are provided by certain mechanisms other than deterioration/failure mechanisms. Such mechanisms are called causal factor formation mechanisms. Since multiple mechanisms are usually related to a malfunction, malfunction cases are represented in terms of a chain of causal factors and mechanisms, which we call deterioration and failure processes. Figure 2 a) shows an example of the deterioration and failure process of a spindle gear box of a machine tool depicted in Figure 8 b). In this case, chips generated by cutting processes caused abrasive wear of a bearing which consequently led to machining inaccuracy. In the figure, the rectangles represent the causal factors, whereas the ovals represent the mechanisms.



a) deterioration process



b) machine tool spindle

c) correspondence between facility model and deterioration process

(A,B,C,D and E correspond to each mechanism of the deterioration process)

Figure 2: An example of the representation of malfunction cases.

In order to represent the information about the machine where the malfunction took place, we use a facility model which expresses the assembly structures of machines as well as properties of assembly items such as parts and units [1]. For indicating relationships between the facility model and the deterioration and failure process, each mechanism has a link to a corresponding assembly item of the facility model. Since the facility model represents the hierarchical structure of the facility, this link indicates which hierarchical level each failure or deterioration mechanism corresponds to as shown in Figure 8 c).

3.3 Malfunction data input navigation

The malfunction data collection system provides various functions for navigating the registration process of the malfunction data into the system. When the user specifies the location of the malfunction, the system shows a 3D image of the corresponding assembly using a 3D CAD system. At the same time, it retrieves the properties of the specified assembly from the facility model as possible causal factors, and displays candidates for mechanisms which could be induced by them using a mechanism database. Once the user specifies a part of the deterioration and failure process, the system provides candidates of mechanisms which could be induced by the current process, or could lead to one of the causal factors causing the current process. Providing candidates of mechanism in such a way is an effective means for unifying terminology in the malfunction data description.

The system also supports another input mode called case based input. The user can search through the database for a similar malfunction case, and modify it to represent the current malfunction, instead of specifying mechanisms one by one.

With regard to the level of detail in the description, the system recommends the user to describe a deterioration mechanism occurring at a form feature of a part which corresponds to the lowest level of the hierarchy of the facility model. Due to this function, malfunction cases can always be described from the level of fundamental causes.

4 FEEDBACK DATA GENERATION SYSTEM

4.1 Knowledge discovery in malfunction cases

One of the effective ways of utilizing malfunction records is to identify frequent malfunctions which include similar causal relations. For this purpose, we have developed a feedback data generation system using the technique of knowledge discovery. The system first groups similar malfunction cases according to the similarities between cases. For this purpose we use distances between concepts which are defined based on concept hierarchies. Then, the system tries to identify common causal relations implied in each group of malfunction cases by means of the attribute-oriented induction method [4].

4.2 Grouping similar malfunction data

Distance between malfunction cases - a measure of similarity

When evaluating similarities, we often direct our attention to a particular aspect, because, in many cases, a group of cases which are quite similar from a particular aspect provides more useful

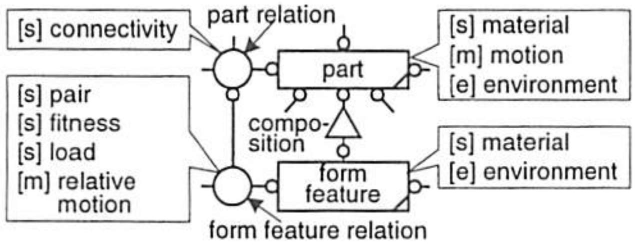


Figure 3: Attributes defined in the facility model.

knowledge than a group of cases which are similar on average from all aspects. In the system, therefore, similarities between malfunction cases are first evaluated from different aspects separately, then the results are combined according to the user's preference for weights on each aspect. Two major aspects, phenomenon and facility aspects, are considered in the system.

In the phenomenon aspect, the system considers mechanisms which appear on the cause side of the deterioration and failure process. They are deterioration mechanisms at the form feature level and those which contribute to the occurrence of these mechanisms. In the example of Figure 2 a), mechanism A and B are included in this aspect.

In the facility aspect, attributes defined in the facility model are taken into account. They are attributes of the form feature where the deterioration occurs, its parent part, and their relations shown in Figure 3. The facility aspect is further divided into three aspects according to the type of attributes: structural, motion and environmental aspects. Labels [s], [m] and [e] in Figure 3 indicate which aspect each attribute belongs to.

In each aspect, similarities are evaluated in terms of distances between concepts used for the description of mechanisms and attributes. The distances between concepts are measured based on the concept hierarchy. The concept hierarchies are hierarchical organizations of concepts. For example, Figure 4 shows a concept hierarchy of deterioration mechanisms. The higher the level goes in the hierarchy, the more general the concept becomes. The distance between two concepts a and b is defined based on the concept hierarchy in the following way.

$$D(\mathrm{a}, \mathrm{b}) = \begin{cases} 0 & \text{(if } a \text{ coincides with } b\text{)} \\ r/q & \text{(if } a \text{ and } b \text{ correspond when ascending the concept hierarchy by } r \text{ levels } (r =< q)\text{)} \\ 1 & \text{(otherwise)} \end{cases} \tag{1}$$

Let us consider the distance between malfunction case c_1 and c_2 in the phenomenon aspect first. Assuming that c_1 and c_2 include m and n mechanisms in the cause side of the deterioration and failure process which are expressed by concepts c_{1i} and c_{2j} (i =1, …, m, j =1, …, n), the distance between c_1 and c_2 in the phenomenon aspect $d_p(c_1, c_2)$ is defined as the minimum distance among those of all combinations of concepts c_{1i} and c_{2j}.

$$d_p(c_1, c_2) = \min \{D_p(c_{1i}, c_{2j})\} \tag{2}$$

With regard to the facility aspect, the system takes into account the attributes related to the form features which suffer from the deterioration mechanisms which provide the minimum distance in the evaluation from the phenomenon aspect. Assuming that k aspect in the facility aspect involves N_k attributes (k corresponds to structural, motion or environmental), the system calculates the distance between c_1 and c_2 in the k aspect, $d_{f.k}(c_1, c_2)$ by the following equation, which is the average value of the distances between concepts c_{1l} and c_{2l} (l =1, …, N_k) expressing attributes involved in the k aspect.

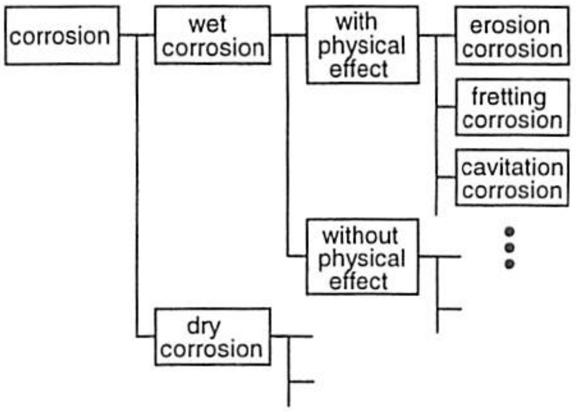


Figure 4: An example of concept hierarchies.

$$d_{f.k}(c_1, c_2) = \sum_{l=1}^{N_k} D_{f.k}(c_{1l}, c_{2l}) \,/\, N_k \tag{3}$$

Taking all aspects defined above into account, the distance between malfunction cases c_1 and c_2 is calculated by the following equation.

$$\begin{aligned} d(c_1, c_2) = {} & \alpha\, d_p(c_1, c_2) + \beta\, d_{f.structral}(c_1, c_2) \\ & + \gamma\, d_{f.motion}(c_1, c_2) + \varepsilon\, d_{f.environment}(c_1, c_2) \end{aligned} \tag{4}$$

where α, β, γ and ε are weights for the distances of each aspect. By controlling these weights, we can search the malfunction data from various points of view.

Clustering malfunction data

For grouping similar malfunction cases, we have applied a leader algorithm [2] which is one of clustering techniques using the distance defined in Equation (4). The system first assigns two cases for the leaders which are furthest with each other. Then the case furthest from them is searched. If it is further than the threshold, then it becomes a new leader, otherwise it belongs to the closest existing leader. This operation is iterated until all cases are grouped.

4.3 Identification of common causal relations

For identifying common causal relations from the sets of

Table 1: An example of grouped similar cases.

No.	factor	mecha-nism	location	relative motion	motion
1	metallic powder	abrasive wear 3	collet sleeve & chuck	exist	linear
2	chip	abrasive wear 10	center & chuck holder	exist	linear
3	vibration	fretting wear 2	collet chuck & sleeve	exist	rotation
4	chip	abrasive wear 10	chuck holder & center	exist	rotation

Table 2: Generalized cases obtained from Table 1.

No.	factor	mecha-nism	location	relative motion	motion
1	foreign substance	abrasive wear 3	chuck unit	exist	linear
2	foreign substance	abrasive wear 10	chuck unit	exist	linear
3	improper state	fretting wear 2	chuck unit	exist	rotation
4	foreign substance	abrasive wear 10	chuck unit	exist	rotation

similar cases, we adopted attribute-oriented induction method which is one of the data discovery techniques. In this method, concepts used in expressing the attributes of each case are generalized so as to obtain a set of cases which have common values in a certain part of their attributes. Then, rules are induced from them taking these attributes with common values into account. Let's consider the malfunction cases indicated in Table 1. By generalizing the values of the attributes: causal factor, mechanism, and location, we can obtain Table 2. In this case, malfunction case 1, 2 and 4 have same values for 'factor', 'mechanism', 'location' and 'relative motion'. Thus, the following rule can be deduced from these three cases.

$$((\text{unit} = \text{chuck}) \wedge (\text{relative motion} = \text{exist}) \wedge (\text{factor} = \text{foreign matter})) \rightarrow (\text{mechanism} = \text{wear}) \qquad (5)$$

5 EXPERIMENTAL SYSTEM

The experimental system has been developed using a relational database system (Access®) and 3D CAD system (Solid Edge™) running on Windows NT®. The system is applied to the malfunction cases of machine tools in an automobile parts manufacturing plant. Figure 9 shows an example of a input window of the malfunction data collection system. In this example, a malfunction which occurred at a bearing of a spindle unit in a lathe was being registered. In the right side of the window, 3D models of the specified part as well as its neighboring parts are automatically displayed when the user specified the part. In the left side of the window, causal factors retrieved from the facility model and mechanisms with resultant phenomena which could be induced by these factors are displayed as candidates for choices.

These malfunction cases are processed by the feedback data generation system. It grouped malfunction cases of the same type of lathes and extracted such knowledge that 'a part in a chuck unit which has relative motion could suffer from seizer due to foreign matter'.

6 DISCUSSION

By combining the facility model with the deterioration and failure process, we can realize a powerful framework for describing the malfunction cases of the facilities. Although it is not feasible to prepare a facility model only for the maintenance purpose, we can expect that most facilities will be designed using the 3D CAD system in the near future.

With regard to the feedback data generation, we could demonstrate the possibility of application of knowledge discovery techniques. However, there are still several issues to be solved. Preparing appropriate concept hierarchies for each concept necessary to describe the malfunction cases is not an easy task. It takes time to collect extensive domain knowledge. For extracting knowledge for generating feedback data, it is necessary to control several parameters such as the threshold of distances in clustering operations and ascending levels of the concept hierarchies in the generalization process. We need further study to obtain an appropriate guideline for setting these parameters. When applying attribute-oriented induction method, the current system takes into account only one mechanism which is used in the calculation of the distance in the clustering operation. For inducing knowledge regarding consecutive mechanisms such as when 'a spindle bearing is corroded by cutting fluid invaded through the clearance of a seal which is generated by wear due to cutting chips', we need to extend our algorithm.

7 CONCLUSION

In this paper, we have discussed two major modules of the maintenance data management system which support the collection of malfunction cases and generation of feedback data used in various phases of the facility life cycle. The malfunction data collection system assists maintenance personnel to record the malfunction cases using the facility model and the mechanism database. With this system, malfunction data can be represented in terms of the unified format and terminology, which enables further computer processing. The feedback data generation system groups similar malfunction cases taking multiple aspects into account using the clustering method. Then it induces rules representing common causal relations implied in the cases involved in the group. The experimental system is applied to the malfunction cases of machine tools in an automobile manufacturing plant for demonstrating its effectiveness.

References

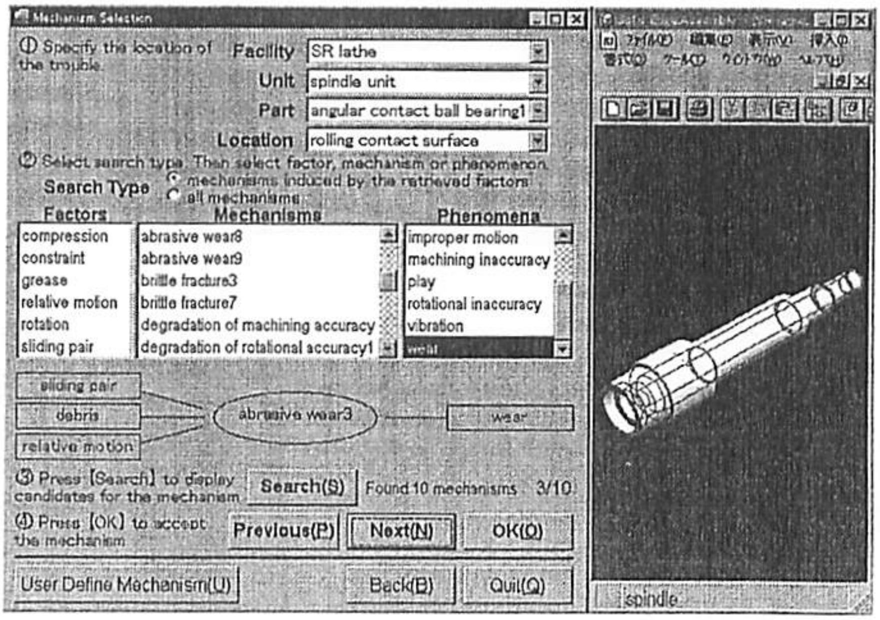
[1] Cai, Y., Cercone, N., Han, J., 1990, Attribute-oriented Induction in Relational Databases, in Piatetsky-Shapiro, G., Frawley, W. J., Eds. Knowledge Discovery in Databases, AAAI/MIT: 213-228.

[2] Hartigan, J. A., 1975, Clustering Algorithms, John Wiley & Sons: 74-83.

[3] Takata, S., Yamaoka, N., Asama, H., Hiraoka, H., 1994, Model Based Evaluation of Component Deterioration, Proceeding of RECY'94: 168-180.

[4] Takata, S., Hiraoka, H., Asama, H., Yamaoka, N., Saito, D., 1995, Facility Model for Life Cycle Maintenance System, Annals of the CIRP, 44/1: 117-121.

[5] Takata, S., Yamada, A., Kohda, T., Asama, H., 1998, Life Cycle Simulation Applied to a Robot Manipulator - An Example of Aging Simulation of Manufacturing Facilities -, Annals of the CIRP, 47/1: 397-400.



① Specify the location of the trouble.

Facility: SR lathe

Unit: spindle unit

Part: angular contact ball bearing1

Location: rolling contact surface

② Select search type. Then select factor, mechanism or phenomenon.

Search Type: ● mechanisms induced by the retrieved factors ○ all mechanisms

Factors	Mechanisms	Phenomena
compression	abrasive wear8	improper motion
constraint	abrasive wear9	machining inaccuracy
grease	brittle fracture3	play
relative motion	brittle fracture7	rotational inaccuracy
rotation	degradation of machining accuracy	vibration
sliding pair	degradation of rotational accuracy1	wear

sliding pair, debris, relative motion — abrasive wear3 — wear

③ Press [Search] to display candidates for the mechanism

Found 10 mechanisms 3/10

④ Press [OK] to accept the mechanism

Figure 5: An example of the input window of the malfunction data collection system