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Design and implementation of a fuzzy inference system for supporting customer requirements

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Abstract

Efficient and effective response to the requirements of customers is a major performance indicator. Failure to satisfy customer requirements implies operational weaknesses in a company. These weaknesses will damage both the rights of customers and the reputation of the company. The traditional method of handling customer requirement for a machine tool manufacturer was dominated by manual process and subjective decision. In this study, we improved the operation process of handling customer requirement. The framework of a customer requirement information system (CRIS) for machine tool manufacturers was then analyzed, integrating rule-based fuzzy inference and expert systems, and a prototype system developed. The CRIS supports both customers and service personnel in providing a systematic way of fulfilling and analyzing customer requirements. The system was installed and operated in a machine tool manufacturer and the performance was found promising.

Keywords: Fuzzy inference; Expert systems; Customer requirements; Fault diagnosis; Integrated information system

1. Introduction

The machine tool sector consists of more than 1400 companies in Taiwan, with over 26,000 employees. This sector thus ranks fifth worldwide as far as manufacturing and export are concerned (Perng, Tsai, & Lin, 2003). The Taiwanese government thus prioritized this sector as one of 10 major industries for intensive development in the first decade of the new millennium. The machine tool sector faces extreme pressure from global competition and information technology change. The major pressure arises from the need for broad delivery of information to everyone who affects business processes with rapid time-to-market and low cost-of-ownership. To confront this challenge, the industry requires business intelligence, not just for a select few, but for everyone—employees, managers, partners, suppliers, customers, and constituents. Increasing demand and hands-on users are rendering the customary model of business intelligence applications, originated within departments and isolated from the enterprise, inefficient and ineffective. Information technologies are anticipated to transform this paradigm, introducing information-rich interactive capabilities to the e-business environment. Furthermore, globalization and information technology affect industries radically. Many companies have become increasingly aware of the significance of managing customer relationships. Concepts such as customer satisfaction, customer-orientation and service differentiation have become critical initiatives in developing the competitive advantages of a company.

However, the findings in Kalakota and Robinson (1999) show, developing a new customer costs more than six times the effort of keeping a present one. Hence, any demand of the existing customer needs to be treated more positively. Customer requirement management seeks to ascertain customer needs and solve or fulfill them. Accelerating response

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depends on a more advanced information system and the exploitation of a specific method.

In manufacturing industries, cases of utilizing information technology to promote performance are growing significantly. An example of this is the after-sale service management information system for the machine tool industry proposed by Tsai, Shuei, Perng, Lin, and Yao (2001). The system handles data generated from merchandise service, such as repair request and maintenance history. It is a management information system for customer requirement. However, their system is incapable of handling the requirements expressed by customer with vague semantics.

For most situations in machine tool manufactures, the customer requirements are handled by service personnel manually in different department with their subjective recognition and responses. However, this appears tedious when there are diverse customer needs and inconsistent departmental policy. For instance, due to insufficient technical knowledge and lack of awareness about machine specifications, customers may present requests with some inexact meanings. Our interview to major machine tool service managers also revealed that the most significant problems the companies encountered, i.e., customer requirement frequently received with verbally vague description and the customer service is not performed systematically. We noticed and recognized the practical difficulties in handling customer requirement, and thus developed a systematic means of handling them. The detailed analysis was shown in the sections of demand analysis and system analysis. Fuzzy inference and expert systems were utilized in this study to deal with events with fuzzy demands. When customer requirements are encountered, fuzzy inference is employed to clarify the unclear wordings. Expert systems are then used to infer the root causes of the problems, suggesting suitable solutions to those problems. Furthermore, this system also helps the customer service department to assess customer feedback, integrating it with after-sale service records. By analyzing the service records, product quality can be improved and the service improved.

Additionally, the future electronic trading environment will center on business networks or community-like business models. Alternatively, information technology enables digitalization of the supply chain. The significance of digitalization resides in synergy resulting from sophistication of external trade environments rather than any immediate benefit from computerization. Conversely, applying digitalization when the environment matures may already be too late (Tsai, Lu, Perng, Lin, & Chu, 2001). Therefore, the motivation to apply information technology to customer requirement management, and thus to develop an integrated customer requirement information system (CRIS) is to join the forces of all participants in the entire service process, enhancing prompt customer requirement handling.

This study analyzed and designed a CRIS for the machine tool industry. The implemented system was thereafter installed on an application server and functioned effectively at a local manufacturer. More specifically, the objectives were as follows: (1) using fuzzy inference to surmount ambiguous verbal description of requirements from a customer; (2) analyzing the information demands of CRIS and sequencing the integrated system framework based on fuzzy inference and expert systems; and (3) constructing a prototype of CRIS for the machine tool industry.

2. Literature review

The behavior of consumer requirements has been defined in many studies (Day, 1980; Hart, Heskett, & Sasser, 1990; Heskett, Jones, Loveman, Sasser, & Schlesinger, 1994; Jacoby & Jaccard, 1981; Joentgen, Mikenina, Weber, Zeugner, & Zimmermann, 1999; Lewis, 1982). There are two basic concepts: (1) The behavior of consumer demands is caused by dissatisfaction of the consumers. (2) The response to the behavior of consumer demands divides into two types: behavioral response and non-behavioral response. Behavioral responses include conveying the negative images to his/her friends and complaining directly to retailers, or to the third parties, such as the Consumer Protection Foundation. A non-behavioral response forgets the unsatisfactory experience without taking any further actions. Customer requirements management is a procedure adopted to solve customer requirements and establish customer confidence in a company. The industry uses requirement data to alter product, correct service weaknesses and thus enhance company reputation. Requirement data enables employees to immediately comprehend the customer requirements as problems are encountered. Because customer requirements are handled after the product or service is sold, requirements management is also called service remedy. Gronroos (1988) notes that the tactics of service remedy involve measures adopted when the supplier service fails.

Cristo (1997) discovered that the extent of customer satisfaction is inversely proportional to the response time. The longer the customer waiting time is, the more significant the inverse relationship. When customer requirements occur, appropriate and quick requirement management is of importance.

In related studies for the machine tool sector, Perng, Li, Tsai, and Lin (1996) and Tsai et al. (2001) targeted maintenance service systems. Their studies proposed some related frameworks, but the indistinct features of customer requirements were not discussed. Perng et al. (1996) claimed that the difficulty of maintenance service in practice encompasses: (1) training effect not significant, (2) repair process and material unrecorded in maintenance report and (3) component or material for early generation product not managed. Perng et al. (1996) also stated that building an information system for machine fault diagnosis raises many difficulties. First, due to the lack of engineering knowledge, maintenance information was not accumulated in practice. Second, the technology revolution leads to a short product cycle, resulting in greater difficulties with repair tasks. The maintenance tasks mainly rely on skilled technicians which take a long period of time to train. Ou (1997) discovered that the major customer complaint of international machine tool buyers related to the lack of quick response to their requests.

Zadeh, who first depicted fuzzy sets in 1965, advocated the application of fuzzy set theory in quantitative measures of the human thinking process (Zadeh, 1975). The practical application system of fuzzy control was developed in Europe. Chi and Zhang (1999) stated that fuzzy semantics handling was a widely applied methodology. Chen (2001) used fuzzy set theory to implement a circuitry framework of a rhetoric fuzzy controller.

Various applications of fuzzy inference can be found in the literature (Berkan & Trubatch, 1997; Chen & Pham, 2000; Ruan & Kerre, 2000). However, an integrated information system for dealing with customer requirement is not implemented. Javadpour and Knapp (2003) focused on the implementing a predictive neural network for use as an operator's aid in diagnosing faults with high prediction accuracy in an automated manufacturing environment. To evaluate the performance of the model, the network was assessed with both simulated time series and real time machine vibration data gathered in lab experiments. However, the fuzzy neural network approach was not applied to customer requirement. Joentgen et al. (1999) proposed a clustering-based dynamic method for early recognition of changes in a machine's state and thus for automatic fault detection. This recognition system requires less expert knowledge than traditional approaches. However, the collaborative approach ensuring efficient information sharing was not employed.

Expert systems are computer programs developed around the thinking processes of the expert and are capable of answering complicated questions. Many successful instances utilizing expert systems are available to handle customer requirement problems. For instance, Su (2000) proposed a malfunction recovery mechanism allowing maintenance personnel and decision makers to solve maintenance tasks cooperatively. Lin (1998) used expert system to detect machine breakdowns. Perng et al. (1996) applied neural network and expert systems to machine fault diagnosis. However, although the operation processes of expert systems were thoroughly discussed and a prototype system was constructed, requirements from customers still could not be handled. Liu and Chen (1995) developed a machine troubleshooting expert system through a fuzzy multiattribute decision-making approach. This system consists of five components and improves the efficiency of the diagnostic process. Fang (1995) proposed a method for on-line machine condition monitoring involving a fuzzy feature-state relationship matrices and expert system.

3. Demand analysis

To analyze the functional demand of a CRIS, and to fully augment system usability, managers from six machine tool manufacturers and sales agents were interviewed. All were managers working in the service departments of manufacturers ranked within the top 10 for sales figures from 1999 to 2003 in Taiwan.

3.1. The machine tool sector

The Taiwanese machine tool industry is one of the most potential industrial activities on the island. Machine tool enterprises must have reliable operational ability to attract international orders in the highly competitive global environment. Five major characteristics of the machine tool industry were isolated from the interview materials:

1. The machine tool industry has critically close relations with the aerospace industry, electronics, the automobile industry and defense. It plays an important supportive and cooperative role with other industries.
2. The machine tool industry, producing high precision machining tools, is technology intensive.
3. Demand for machine tools in market is dramatically influenced by economical cycles.
4. The number of components and range of materials is large. Enterprises frequently encounter urgent requests for changes of design.
5. While enterprises need to continuously invest on technology and human resources, the returns on investment are relatively low.

3.2. Essential elements of the interview

In-depth interviews were conducted to build up an information system for dealing with customer requirements so that most of the problems mentioned earlier could be solved. Six major companies were selected for analysis. The main analytical contents were as follows: (1) basic information about the interviewed company, (2) the company situation with regard to computer and networking usage, (3) the present process and condition of customer requirement handling and management and (4) the demand for a CRIS for machine tool service.

The interview conclusion was that the industry urgently needs an information system to handle customer requirement and enhance customer relationships. The interview material also uncovered many key factors and concerns for developing such a system. The most significant problems the companies faced are the customer requirement frequently received with verbally vague description and the customer service are not performed systematically. The operational practice, system analysis and system development in the study will now be discusses in detail.

3.3. Practical operation process

The operational process was executed inefficiently in the following manner shown in Fig. 1. First, customer require-

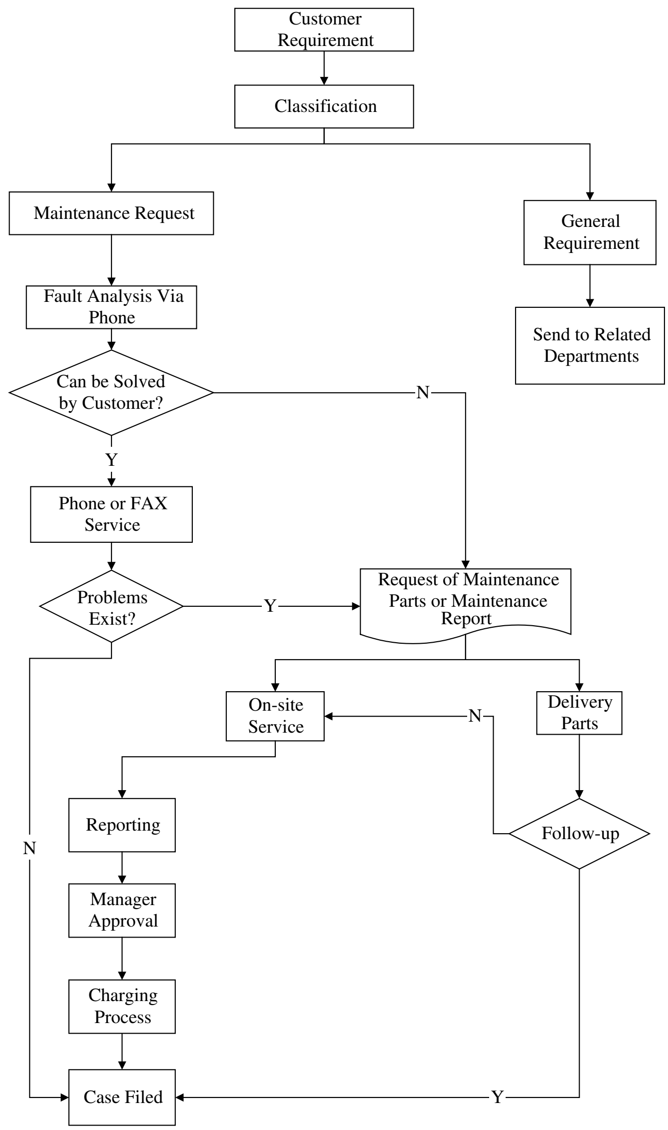


Fig. 1. Customer requirement handling process in practice.

ments were logged via phone, FAX or maintenance personnel. Basic customer information such as address, phone number and the machine model was recorded by either the service person in the call center or maintenance personnel. The requirement responses were then analyzed online or sequentially called/faxed back to the customer. The problem-solving hints or instructions were sent to the customer, and the problems were expected to be solved step by step by customers.

If the customers could not solve the problem by themselves, the maintenance personnel offered two further forms of service: (1) onsite service and (2) maintenance part delivery service. Before performing onsite service, service personnel needed to fill out a service request form. For those requirements able to be met by delivering parts for self-replacement, the service personnel followed up the situation to ensure the requirement was fulfilled. After service was completed, either onsite or by part delivery, the service personnel reported the process by filling out service records, including service reports, customer response sheets and part request forms. Those sheets or forms were then sent to the department manager for approval. If the requirements were made and fulfilled via phone or fax, the forms and sheets were omitted, that is, no any information was recorded. The process then went to billing, executed by the accounting department, for the service charge, man-hour charge and/or maintenance part charge. The inventory amount was also updated if the parts were checked out from stock.

4. System analysis and design

4.1. System analysis

The industry is not using CRISs to assist their service tasks or handle their service information, nor for further analysis of service information. The realization of the need of the industry stimulated the analysis and development of a CRIS. Developing a CRIS is largely an attempt to enable the sharing of enterprise resources, such as service information and manpower. With the aid of a CRIS, the customer service will be completed more efficiently. This will also help release customers from their inconvenient situation, consequently promoting customer royalty and increasing the customer satisfaction. To achieve this goal, an enterprise should provide a standard of operational procedure for maintenance service personnel to work by. Because different manufacturers usually develop very different processes, a standard procedure for customer requirements handling appears to be urgently needed. This investigation addresses the operational process, system analysis and system design for a CRIS.

4.2. System flow

Fig. 2 illustrates the CRIS process. The system is divided into two subsystems: general requirement handling and machine fault diagnosis. Customer problems first collected and classified. Service personnel directed the problem to the relevant subsystem triggering the handling process. For general requirements, the classification process is selected, fuzzy semantic treatment is instituted if needed, and the problem is recorded in the requirement recording system.

For machine fault related requirements, the machine fault diagnosis system will be activated if the ambiguity checking of the verbal expression from a customer is cleared. If the verbal expression is ambiguous, the fuzzy handling process will be activated.

Following processing the general requirement or machine fault diagnosis, system stores the requirement treatment details in the requirement recording system. Finally, the data in the requirement recording system are conveyed to the requirement analysis system for further evaluation. Some statistical computing was implemented in the prototype system, such as the defect rate, or requirement rate of

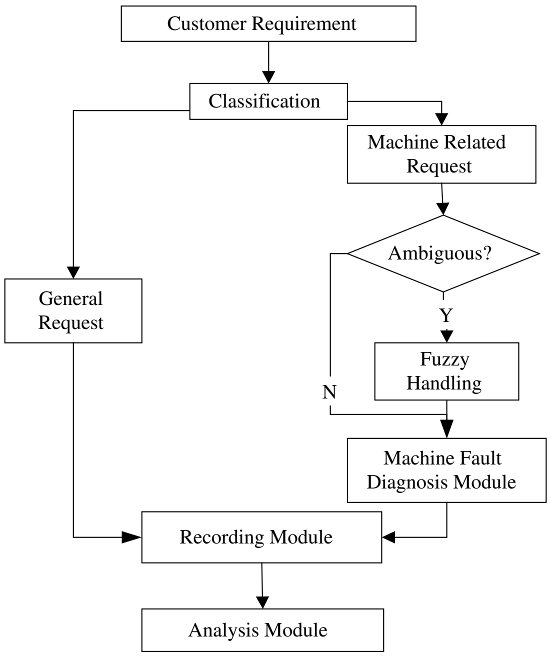


Fig. 2. System flow.

A0 CRIS
- A1 Requirement Classification System
  - A11 Human Related Complaint
  - A12 Machine Related Complaint
- A2 Fault Diagnosis System
  - A21 Fuzzy Reasoning System
  - A22 Expert System
  - A23 Rulebase Management System
- A3 Requirement Recording System
  - A31 Customer Tracking System
  - A32 Personnel Recording System
  - A33 Data Query System
- A4 Requirement Analysis System
  - A41 Breakdown Rating Analysis
  - A42 Maintenance Supplies Analysis
  - A43 Machine Performance Rating
  - A44 Personnel Performance Rating

Fig. 3. Framework of CRIS in IDEF0 structure.

a certain customer in a particular period of time. Statistical computing can be extended to many aspects, and is supportive of decision making.

Based on the proposed operational process and the functional demand of a CRIS, a system analysis was conducted with IDEF0, which is a structured system analysis tool. In the IDEF0 model, activities can be described by their inputs, outputs, controls, and mechanisms (ICOM). In addition, the description of activities can be recursively refined into greater and greater detail until the model is as descriptive as necessary for implementation (Bravoco & Yadav, 1985; Mayor, Benjamin, Bruce, & Painter, 1995; Perng et al., 2003; Ross, 1985).

A system analysis result was derived for efficient, economical and customized establishment of a CRIS. The result was further extended to the system design stage to constructing a prototype illustrating the feasibility of the system. Figs. 3 and 4 are two examples indicating the system processes depicted by IDEF0. The CRIS contains four subsystems, namely requirement classification system (RCS), fault diagnosis system (FDS), requirement recording system (RRS), and decision analysis system (DAS).

4.3. Fuzzy inference

This system incorporates fuzzy inference and rule-based expert systems. Fuzzy inference in this system refers to the use of computer programs to execute inference work resembling what humans do daily. Inputs and outputs are two basic elements in a system using fuzzy handling approaches. The input constitutes some ambiguous verbal semantics or unclear concepts for a specific event, such as the vague description of motor temperature or the leakage level of an oil pump. Following the fuzzy inference mechanism, the output can be a fuzzy set or a precise set of certain features. Fuzzy inference infers the results from the existing knowledge base. For after-sale service personnel, it is an important step to know about the customer requirement thoroughly when solving requirement problems. They usually spend considerable time finding out the truth of a customer's requirement, or the original customer intention. To conquer this problem, a method of synthetic fuzzy evaluation was adopted to construct the inference mechanism in this study.

Fig. 5 illustrates the framework of the fuzzy knowledge base and the relationship between elements. The fuzzy knowledge base comprises fuzzy concept base, fuzzy proposition base, fuzzy rule base and fuzzy strategy base.

4.3.1. Fuzzy concept base

This contains the terminology and relevant predicate of a verbal expression. Terminology is in the domain of the fuzzy set, possesses many pre-defined dismemberment values denoted by predicates.

4.3.2. Fuzzy proposition base

Membership functions accrue to the fuzzy proposition, which was induced from fuzzy concept base. There are numerous types of membership functions, such as S-shape, Z-shape, and Π-shape, all easily definable with equations and parameters. For example, if the general fuzzy set is expressed as

$$A = \{(x, \mu_A(x))\}, \quad x \in X$$

where μ denotes the membership function, and $(x, \mu_A(x))$ is a singleton, then a fuzzifier given by

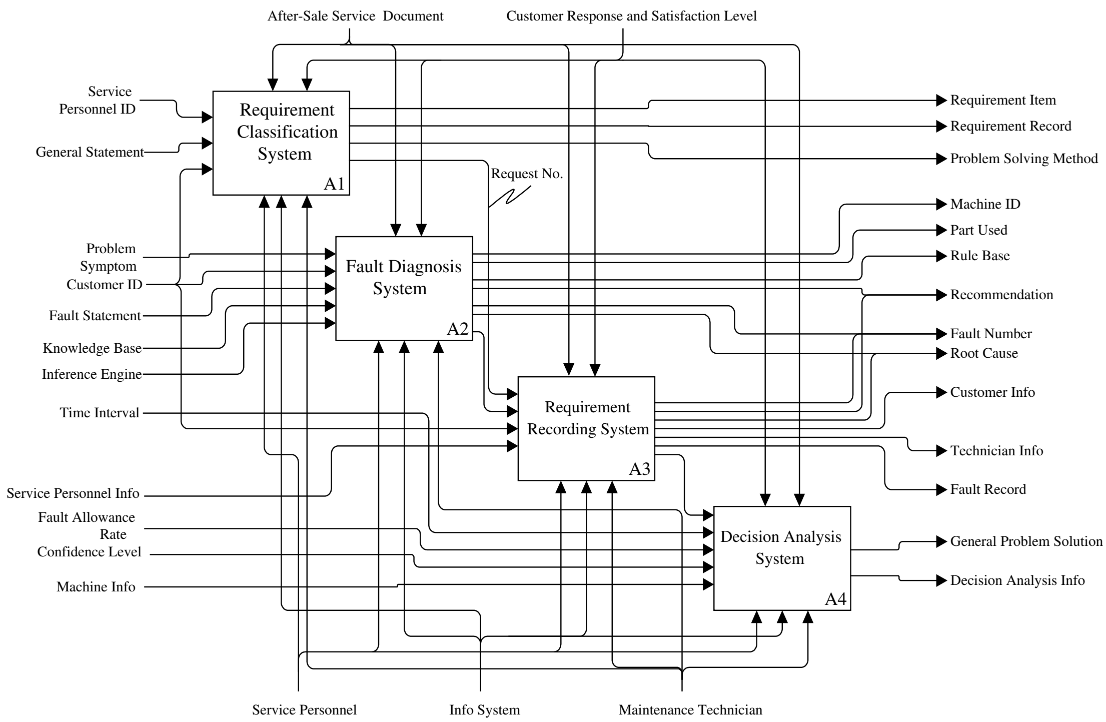


Fig. 4. System process depicted by IDEF0.

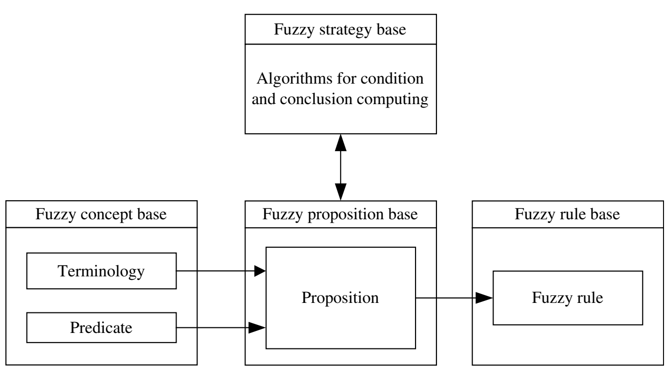


Fig. 5. Framework of fuzzy knowledge base.

$$\mu(x) = \frac{1}{1 + (x/K_2)^{-K_1}}, \quad x \in X$$

produces an S-shaped curvature. K_1 and K_2 are called the exponential and denominational fuzzifiers, respectively. By having controllable parameters such as K_1 and K_2, adaptive fuzzy algorithms can be developed.

4.3.3. Fuzzy rule base

The fuzzy proposition is then presented in IF–THEN format and constitutes the rule base. Specifically, a finite fuzzy logic implication statement in the rule base was described by a set of general fuzzy IF–THEN rules containing only the fuzzy logical AND operation, in the form "IF a_{11} is A_{11} AND … AND a_{1n} is A_{1n} THEN b_1 is B_1."

4.3.4. Fuzzy strategy base

This contains the algorithms for computing the condition part and the conclusion part. A proposition might encompass many conditions. An appropriate fitness of a rule had to be found so that the conclusion can be drawn. This is carried out by a process of implication. A membership function that defines the implication relation can be expressed in a number of ways. To illustrate the operation, we assume that we have the following simple conditional proposition (canonical rule):

IF X is A THEN Y is B

The implication relation is defined by

$$R(x, y) = \int_{x,y} \mu(x, y)/(x, y)$$

where linguistic/fuzzy variable X and Y take the value of A and B, respectively, and $\mu(x, y)$ is the membership function of the implication relation. The membership function is denoted by

$$\mu(x, y) = \mu_A(x) \wedge \mu_B(y)$$

The symbol $\wedge$ corresponds to intersection operation.

4.4. Numerical illustration

To demonstrate the operation of these elements, an example is given as follows:

The fuzzy concept base has a terminology of "oil leakage" with five terms of predicates, namely very few, few, fair, much, very much. The membership function for each

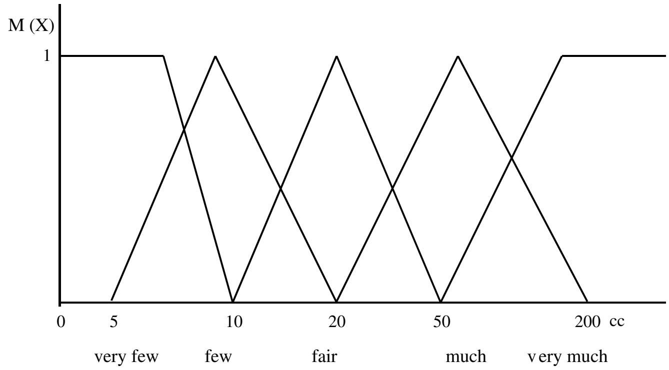


Fig. 6. Membership functions for oil leakage.

predicate level is provided in Fig. 6. In this example, "very few" is an X-shaped function, "very much" an S-shape, and Π-shape for the others.

The requirements were received from a customer and stated as "We have a problem of the oil pump. It leaks seriously and is not working. The temperature of the pump is as high as 280 °F. The leakage is about 60 c.c." The system will fuzzify the input by searching the fuzzy proposition base and determining two predicates as the following:

1. Pump temperature, x denoted in Fahrenheit, is *high*:

$$T = \begin{cases} \frac{x-200}{150}, & 200 < x \leqslant 350 \\ \frac{500-x}{150}, & 350 < x \leqslant 500 \end{cases}$$

2. Volume of oil leakage, y denoted in c.c., is *much*:

$$L = \begin{cases} \frac{y-20}{30}, & 20 < x \leqslant 50 \\ \frac{200-y}{150}, & 50 < x \leqslant 200 \end{cases}$$

The system then searched the fuzzy rule base to retrieving related rules. Two rules were found as follows:

1. Rule 112: IF *pump temperature* is *high* AND *oil leakage* is *much* THEN *oil pump is broken.*
2. Rule 213: IF *oil leakage* is *much* AND *motor noise* is *high* THEN *parking ring is damaged* OR *pipe screw is loose.*

Rule 112 contains two predicates of the requirement statement, *much* and *high*. The implication computation of H and L was then performed in the fuzzy strategy base:

$$T \times L = R(x, y) = \int \mu_T(x) \wedge \mu_L(y)/(x, y)$$

yielding product of 0.86667.

Rule 213 contains one predicate of the requirements statement. The computational result of membership is 0. The THEN operator performs a mapping-like function. After comparing those two rules, rule 112 was adopted to infer the root cause of the problem and achieve the result of "oil pump is broken."

4.5. Expert systems

Expert systems are capable of acquiring, analyzing, and processing knowledge and experience in certain professional fields. The knowledge is presented in the format of IF–THEN and stored in the knowledge base. The mechanism processing the knowledge is called the inference engine. It is employed to produce a conclusion for some conditions. An expert system primarily consists of a knowledge base, an inference engine, and an interface. The CRIS was designed by integrating the three components.

The knowledge base stores the facts and rules in two categories: machine faults and general customer requirements. The presentation of knowledge can be one, or hybrid, of the following: Rule Base, Semantic Network, Object-Attribute-Value, Frame Base and Logic Base. The approach of this investigation uses IF–THEN rule to present the knowledge, forming a knowledge base. Because the rule validity is uncertain, or the problem statement of a customer might be ambiguous, or the problem itself has many possible solutions, the uncertainties become more difficult to deal with problems. An inference engine was therefore constructed to ascertain the root causes and store them into the knowledge base.

The expert system contains 158 rules in total. The examples are as follows:

Rule 11:
IF machine type is VS-50
  and injection failure
  and oil temperature is high
  and mold is malfunctioning
  and object intrusion failure
  and inlet pipe not heated up to settings
THEN outer steel pipe is broken or loosened

Rule 22:
IF machine type is VS-90
  and loud noise
  and radial vibration of motor support fails to reduce
  and injection precision has decreased
  and machine variation has increased
THEN ball screw is curved

The function of the inference engine is to use various inference algorithms to propose root causes by comparing with facts and rules in the knowledge base. The inference process will produce new facts and rules, which will be stored in the knowledge base. As the knowledge base accumulates, the uncertainty difficulty can be minimized.

The process of coordinating inference engine and knowledge base is illustrated with an example shown below.

The following problems for a machine, type VS-90, occurred: (1) mold is not easily aligned; (2) injection parts spread on the floor; (3) dimensions of injection parts is apparently not identical; (4) radial vibration of motor supports cannot be reduced and (5) machine is operating with loud noise. The operator, a user at the customer site, or the service personnel at the manufacturing site, enter those settings into the CRIS by selecting appropriate predicates under an appropriate terminology. The system searches the rule base, retrieving four rules (rule 5, 14, 22 and 37). Through the forward-inference mechanism and with the help of the knowledge base, the inference engine will further identify the root causes. The inference process is depicted in the following:

1. Fact I: the mold is not easily aligned
   Fact II: injection parts spread on the floor
   Rule 5: IF mold is not easily aligned AND injection parts spread on the floor THEN machine base is vibrating.
   Fact inferred (Fact V): machine base is vibrating.
2. Fact VIII: loud noise
   Fact V: machine base is vibrating
   Rule 37: IF loud noise AND machine base vibrating THEN machine is vibrating dramatically.
   Fact inferred (Fact VII): machine base is vibrating dramatically.
3. Fact III: dimension of injection parts are apparently not identical
   Rule 14: IF dimension of injection parts appears not to be identical THEN operation fails to maintain precision.
   Fact inferred (Fact VI): low operation precision.
4. Fact VIII: loud noise
   Fact IV: dimension of injection parts apparently not identical
   Fact VI: low injection precision
   Fact VII: machine vibrating dramatically
   Rule 22: IF loud noise AND radial vibration of motor supports not reduced AND low injection precision AND machine vibrating dramatically THEN ball screw is curved.

Table 1
Facts summary

Facts	
I	Mold not easily aligned
II	Injection parts spread on the floor
III	Dimension of injection parts apparently not identical
IV	Radial vibration of motor supports not reduced
V	Machine base vibrating
VI	Low injection precision
VII	Machine vibrating dramatically
VIII	Loud noise

Table 3
Fact–Rule inference processes

Facts	Rules	
I,II,III,IV,VIII	5	I,II → V
I,II,III,IV,V,VIII	37	V,VIII → VII
I,II,III,IV,V,VII,VIII	14	III → VI
I,II,III,IV,V,VI,VII, VIII	22	IV,VI,VII,VIII → Root cause

Root cause inferred: ball screw is curved.

Tables 1–3 summarize the inference processes.

4.6. System architecture

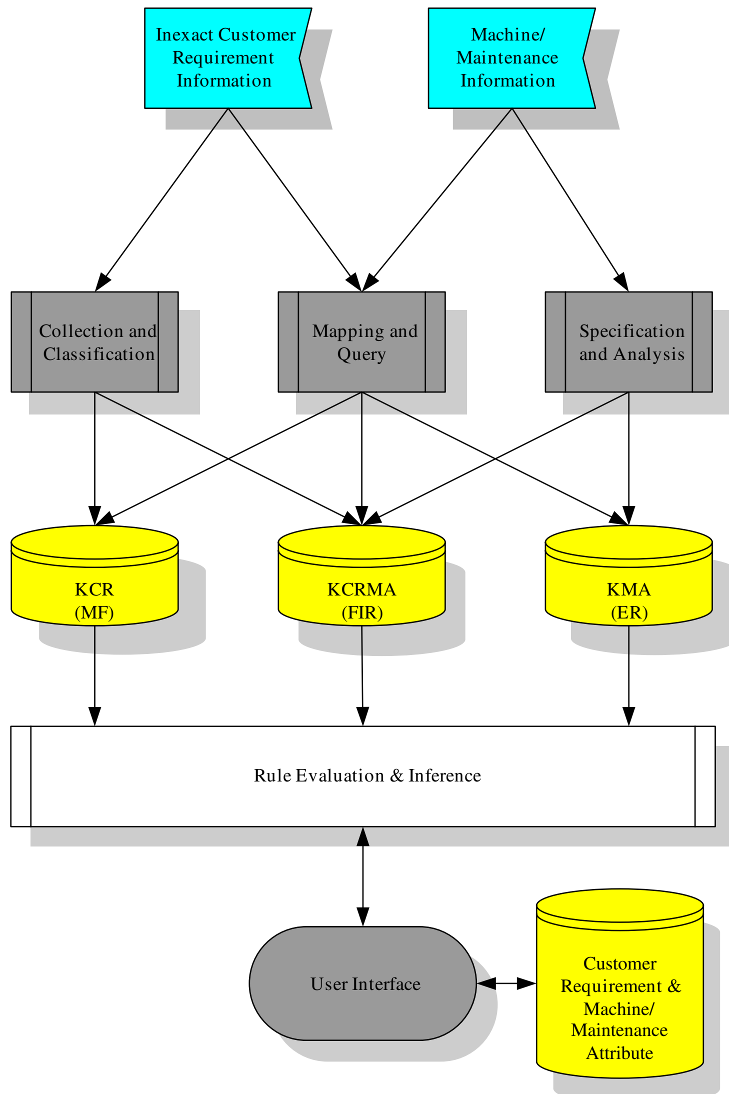
The CRIS performs many activities to handle customer requirement, such as information collection, classification, fuzzification, rule evaluation, inference, aggregation and defuzzification as depicted in Fig. 7. The processes result in crisp target values for handling customer requirement or root causes of machine faults. When requirement information has been collected and the customer information gathered, the system activates the classification module to group the request. When a set of customer requirements has been identified as a machine-related requirement, the attributes are first treated according to the term sets (sets of linguistic variables) of the relevant terminology and transformed by the fuzzy set hedges as appropriate to fully elaborate the maintenance attributes, as has been depicted in the previous section in this study. This process was applied to all the ambiguously described customer requirements. Processes of expert systems were also triggered to diagnose the machine faults with the aid of the knowledge base and inference engine. Using the inferred fact, an intact fuzzy rule base was developed, to capture the customer requirement knowledge and experience, defining the relationship between customer requirements and machine diagnosis characteristics. The knowledge base for machine fault diagnosis was constructed by domain experts and was updated by the system. The system is capable of processing customer requirements and providing proper recommendations to the specific requirement. The preset diagnosis module and recommendation database make this possible.

4.7. System implementation

The prototype system was developed by many software packages: Access, Visual Basic, and Active Server Pages

Table 2
Rules summary

Rules	
5	IF mold is not easily aligned AND injection parts spread on the floor THEN machine base is vibrating
37	IF loud noise AND machine base vibrating THEN machine is vibrating dramatically
14	IF dimension of injection parts appears not to be identical THEN operation fails to maintain precision
22	IF loud noise AND radial vibration of motor supports not reduced AND low injection precision AND machine vibrating dramatically THEN ball screw is curved



KCR: Knowledge about Customer Requirement
KMA: Knowledge about Machine Attributes
KCRMA: Knowledge about the relationship between Customer Requirement and Machine Attributes
MF: Membership Functions
ER: Expert System Rules
FIR: Fuzzy Inference Rules/Propositions

Fig. 7. Architecture of fuzzy inference system.

(ASP). Access helped design the database. Visual Basic was used to construct the user interface, while ASP facilitated connection and modification of the system database, integrating the whole system. The prototype of CRIS is running on a web server in a local machine tool manufacturer. After test activity and system refinement, the performance of the system is promising.

4.7.1. System operation configuration

The CRIS is configured for installation at the manufacturing site. It is installed in a web server running database applications. The system users are primarily customers and maintenance personnel of the machine tool manufacturer. The CRIS database is updated while the system receives commands from remote sites, such as sales agents, maintenance centers or authorized end customers. It also responds to the managers of the manufacturers while they perform inquiries such as machine performance analysis or statistical analysis of customer requirement.

4.7.2. Design of database

The design of database for the prototype system is mainly based on relational database with Access. The setting of primary keys and database normalization are inevitable for implementing a database application system successfully.

The primary key is a field that uniquely describes each record. In the Requirement Classification System, for

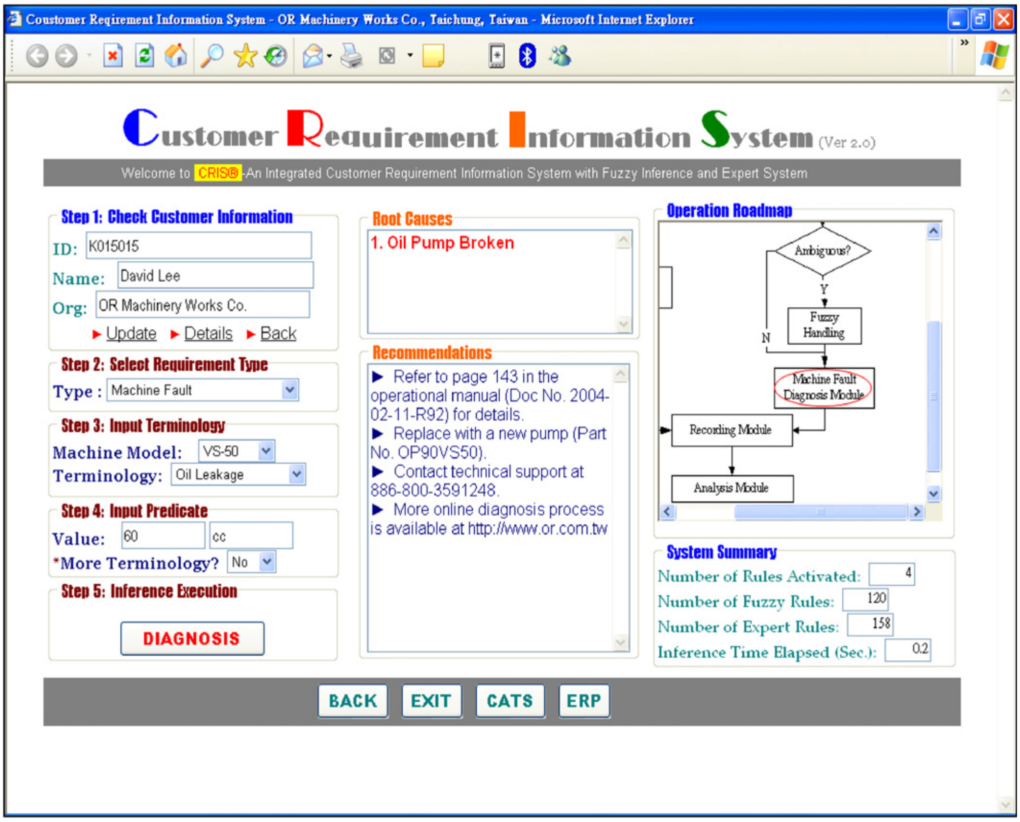


Fig. 8. Design of system interface.

instance, the customer ID number is set to be the primary key in the data table storing customer information. The content of this field is unique and generated by the system automatically. There are seven major tables used in the CRIS database including customer table, requirement table, personnel table, components table, fuzzy rule base related tables, knowledgebase related tables, and expert system related tables. Primary keys are associated with a field in other tables according to a specific relation.

4.7.3. Design of interface

The system interface was designed on the basis of system usability. It allows users to input data by clicking on a tag and making their choice directly from the list. Fig. 8 presents a display image for fuzzy handling of a customer requirement.

5. Conclusion

Requirement handling activities play an important role in after-sale service within the machine tool industry. After-sale service is a critical factor in maintaining customer royalty. During recent years, the development of information systems has assisted the companies in solving many managerial problems, to keep business running efficiently. It is useful and valuable to use information systems to handle customer requirement problems. This study proposes and develops an information system for customer requirement handling in the machine tool industry.

Fuzzy inference and expert systems are utilized in this study. When a customer requirement is encountered, fuzzy inference is adopted to articulate the unclear parts of requirement wordings. CRIS employs expert systems to infer the root causes of problems and to suggest an appropriate solution to those problems.

Furthermore, this system also helps the customer service department to analyze customer feedback and integrate it with after-sale service records. By analyzing the service records, product quality can be improved and the service can be enhanced.

Recent advances in information technology, companies have provided an opportunity for significant improvement in customer requirement handling. However, several important issues still need to be adequately addressed by future work. The system developed in this study also needs more refinement. Further work will direct to enhancing inference capacity of the expert system and performing more functional analysis from the database.

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