

A decision support system for solving quality problems using case-based reasoning

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ABSTRACT *This study discusses an intelligent system designed to assist companies in decisions regarding the corrective and preventive action (CPA) process, the most fundamental component of quality-management systems. Without an effective CPA programme, problems will repeat themselves, continuous improvement will be difficult and it is unlikely that any of the other quality-system elements will work effectively. The system employs both case-based reasoning (CBR) and decision-support systems (DSS) components. The knowledge is represented as cases in the system, which can be reused to produce new solutions. The effectiveness of the proposed concept is demonstrated by applying the system to a CPA decision-making example.*

Introduction

Customer satisfaction results from a service provider's successful execution of a series of sequential activities. Customers can express varying levels of dissatisfaction, ranging from asking questions on problems to formal complaints, and these must be identified and analysed. Reworking and even fundamental correction can be required to address problems and prevent a recurrence. Correcting a mistake can involve direct costs several times higher than doing it right the first time, and the indirect costs in terms of frustration, loss of credibility, and damaged relationships can be even higher. From the perspective of the customer, whose satisfaction is the company's ultimate goal (Stavros & French, 1998), such costs are cumulative.

Quality standards such as ISO9001 (Paradis & Trubiano, 2002) require companies to keep quality records, and ensure that information regarding quality problems flows into a system of corrective and preventive action to:

- identify non-conformities and customer complaints;
- determine the cause of non-conformity;
- evaluate the situation for corrective and/or preventive action;
- determine and implement corrective and/or preventive action;
- record results; and
- review effectiveness of corrective and/or preventive action.

Although there have been advances in the design and implementation of decision-support systems, and profound changes in information technology (IT) capabilities, the

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provision of effective DSS for strategic decisions, such as preventive actions in a quality-management system (QMS), remains a challenge. There are several underlying issues.

- Corrective and preventive action (CPA) decision-making is an ill-structured process that can be drawn out over weeks; however, in urgent situations, rapid responses are required.
- CPA decision-making is a group effort involving cooperative problem solving, conflict resolution, negotiation, and consensus building.
- CPA involves multiple stakeholders, all of whom have different implicit assumptions that need to be made explicit.
- CPA decision-making is an evolutionary process that requires an accumulated knowledge of previous cases.
- CPA decisions can require a variety of analytical tools, ranging from simple cause-and-effect diagrams to complicated artificial intelligence (AI) tools.

The CPA decisions require an integrated information system that can handle the complete cycle of finding, analysing, solving and controlling the results for quality problems (Lari, 2002). The existing software does not provide this service. The majority of the available software applications are designed for auditing, documentation and administrative processes, rather than for solving quality problems, which require proper corrective and preventive actions (Hill, 1995; Hoover, 1998; Minner, 1997; Parr, 1997; Sarkar, 1998; Thondavadi & Mascon, 1999). Every year, *Quality Magazine* presents the latest software from manufacturers in the quality business (Hoover, 1998). A report indicates there are more than 440 software programs covering the analysis and design of experiments, benchmarking, document control, flow charting, gauge management, ISO9000, QS-9000, shape metrology, statistical quality control, technical drawing, and training (Badiru, 1995; Chase, 1998; Hoover, 1998). Khan & Hafiz (1999) have described a gauging absence of prerequisites (GAP) analysis expert system for ISO9000 implementation using an expert system shell called CRYSTAL 4. This expert system consists of several sections. The introduction is designed for new users who desire to implement ISO9000. The recommendation section suggests the type of ISO9000 to register with, in addition to selecting a registrar and registration. The GAP-analysis section, which is the core of this expert system, identifies the distance between the prerequisites and what actually exists in the present environment, so that successful implementation can be achieved.

Doukidis (1989) has noted the increasing use of expert systems (ES) and artificial intelligence (AI) to incorporate 'intelligence' in conventional information systems. One of the AI paradigms that seem to be very promising for solving quality problems is case-based reasoning (CBR). CBR, as a subset of knowledge base systems (KBS), is an approach to problem solving that utilizes past experiences to solve new problems (Aamodt & Plaza, 1994; Kolodner, 1991, 1992, 1993; Watson & Mariar, 1994; Gentner, 1983; DARPA, 1991; Slade, 1991; Porter *et al.*, 1990; IEEE, 1992; Schank, 1982). In CBR technology, a *case* usually denotes a problem situation. A previously experienced situation that has been captured and learnt in a way that it can be reused in the solving of future problems is referred to as a *past case*. CBR systems provide decision support to managers through an interactive question-and-answer session.

CBR sprang from cognitive science research begun in the early 1980s by Roger Schank at Yale University AI Lab, in New Haven, Connecticut. The first case-based reasoner was the CYRUS system, developed by Janet Kolodner (Kolodner, 1983). CYRUS was basically a question-answering system with knowledge of various travels and meetings of former US Secretary of State Cyrus Vance. The case-memory model developed for this system later served

as a basis for several other case-based reasoning systems including MEDIATOR (Simpson, 1985), PERSUADER (Sycara, 1988), CHEF (Hammond, 1989), JULIA (Hinrichs, 1992), and CASEY (Koton, 1988). Another set of models was developed by Bruce Porter and his group (Porter & Bareiss, 1986). They initially addressed the machine-learning problem of concept learning for classification tasks. This led to the development of the PROTOS system, which emphasized the integration of general domain knowledge and specific case knowledge into a unified representation structure. The combination of cases with general domain knowledge was pushed further in GREBE (Branting, 1991), an application in the domain of law.

Another contribution to CBR has been the work by Edwina Rissland and her group. They were interested in the role of precedence reasoning in legal judgments (Rissland, 1983). Cases (precedents) were not used to produce a single answer, but to interpret a situation in court, and to produce and assess arguments for both parties. Other applications include: protein crystal growth (Jurisica *et al.*, 2001), supplier management (Choy & Lee, 2002), product configurator (Weil, 2000), task allocation (Choy & Lee, 2000), reactive scheduling (Srinivas & Patnaik, 1994), helping mechanics track down faults (Solomon 1998), automated customer support systems (Radosevich 1998), autoclave loading for heat treatment of composite materials (Hennessy & Hinkle, 1992), selection of the most appropriate mechanical equipment during construction of ships (Brown & Lewis, 1991), and many other areas (Kolodner, 1993; Aamodt & Plaza, 1994; Leake, 1996).

The use of CBR is increasing, and a number of development tools are now available that enable the rapid development of CBR applications (Althoff *et al.*, 1995). Several commercial companies offer shells for building CBR systems (Harmon, 1992; Aamodt & Plaza, 1994; Kolodner, 1993).

The objective of the present study is to outline the approach adopted in developing a support system for CPA decision-making in the car-design industry. This system integrates case-based reasoning (CBR) with decision-support systems. It must be emphasized that the model described in this paper is not a panacea for all the problems associated with effective CPA decision-making. The model attempts to overcome some of the problems that car designers have in formulating a CPA decision, and is designed to act as an aid for decision-making for other organizations in the formulation of decisions of this type.

Quality management in car-design industry

In a typical corrective-action process, four stages can be recognized (Paradis & Trubiano, 2002):

- identifying non-conformance through receipt of customer complaints and reports of product and process non-conformity;
- investigating the cause of non-conformity;
- determining the corrective action needed to eliminate the cause of the non-conformity; and
- applying controls to ensure corrective action is implemented and effective.

For preventive action, the process involves four similar elements:

- identifying potential causes of poor product quality through audit results, quality-management system records, service reports, and customer complaints;
- investigating potential causes of non-conformities;
- determining the preventive action needed to eliminate the causes of non-conformities; and

- controlling the process by reviewing changes with management, revising documents, training personnel, implementing changes, and applying controls to ensure preventive action is implemented and effective.

In the car industry, product development involves four phases: *concept phase*, *definition phase*, *design phase* and *production phase* (Ichida, 1996). Car-design companies usually perform the first three phases, and the production phase is performed in the manufacturing environment. In the first phase, *concept design*, the main activities include: feasibility studies, formulating a development policy, and listing operational requirements. The second phase, the *definition* phase, includes the drafting of several scheduling proposals, making trade-offs, and defining system specifications. If the company uses subcontractors, they solicit bids at this stage. In the third phase, the *design* phase, activities include preparing a general design, preparing detailed designs, making prototypes, testing prototypes, and qualification testing. Finally, production-process design links the design activities to the production phase.

The structure of QMSs in research and development (R&D) organizations, and particularly in car design, is completely different from that in manufacturing environments. There is no single standard pattern of quality structure for everyone to follow. Each organization defines its quality-assurance system differently. For the purpose of this study, a car-designing company was selected as the prototype. In this company, the quality-assurance structure matches the product-development stages and includes seven assessment groups who control the quality at different stages in the design process. In addition to these groups, there are regular quality-assurance activities for the customer, the supplier, the parts and prototype manufacturer, and other functional areas. The specific roles of the assessment groups are briefly explained below.

- *First group. Assessment of the product definition.* This assessment group uses the functional definitions of the product given by the customer, different standards, and technical information to confirm the understanding of the company regarding the ordered product. The group uses written procedures and instructions to evaluate the proposed standards, methods, and tools. This falls within the *concept* phase.
- *Second group. Assessment of product definition and detailed technical specification of the product.* The second assessment is performed when the definition of the product is complete, the assemblies and subassemblies are defined, and the technical specifications and the platform of the product have been completely described. This is, again, a validation of the customer order. The 'House of Quality' is the tool for verification and validation. This falls within the *definition* phase.
- *Third group. Assessment of the 1:5 interior and exterior model.* The subject of the assessment at this stage is the exterior and interior of a 1:5 physical model of the car. This involves the evaluation of the related tape drawings, the documents concerning the exterior and interior design, and the technical documentation for the selected platform. The results are reported to the customer for validation. This falls within the *design* phase—prototype-making.
- *Fourth group. Assessment of 1:1 interior and exterior model.* At this stage, the manufacturing department has finished the 1:1 prototype model. The assessment is mostly performed on the model and control of calculations. This falls within the *design* phase—prototype-making.
- *Fifth group. Assessment of the parts design, drawings and Computer Aided-Design (CAD) data.* This group is responsible for assessing the quality of the outputs prepared up to this stage according to customer specifications and needs. These outputs include the

CAD data, two-dimensional (2-D) and three-dimensional (3-D) drawings, vehicle evaluation tests, and so on. This falls within the *design* phase—prototype-making.

- *Sixth group. Assessment of the prototype and cubic master model.* The cubic master model and prototype of the car are the subjects of this assessment. All the related checklists, tools, methods, documents and technical data are evaluated and compared with the desired specifications given by the customer and/or other related departments from different stages of the design process. This falls within the *design* phase—prototype-making.
- *Seventh group. Assessment of the test results.* A series of performance and durability tests are performed at this stage to ensure that the car meets all the requirements specified by the customer. At the end of this stage, all the documents and technical data are sent to the customer for final validation. This falls within the *design* phase—qualification-testing.

The concepts of the proposed CPA system for the selected prototype

Any type of information system for handling corrective and preventive actions should at least have the following capabilities (Lari, 2002).

- It must have the capability to collect information about quality problems (non-conformities) through different sources (internally and externally).
- It must have the capability to store all the information about the problems, such as the characteristics, symptoms, symptomatic cure, cause, fix, corrective actions, and preventive actions. It is essential to separate informational processing from operational processing by creating a data warehouse. A data warehouse centralizes quality data that are scattered throughout disparate operational systems and makes them readily available for decision-support applications.
- It must have the capability to investigate the cause of non-conformity, and to determine the corrective and/or preventive actions needed to eliminate the cause of non-conformity. This is done through various man-machine solutions using different problem-solving tools, including intelligent knowledge-based systems and neural networks. An intelligent DSS with a defined interface with other modules is the core of the proposed system.
- It must have the capability to apply controls to ensure that corrective and preventive actions are implemented, to collect feedback on the effectiveness of solutions, and to control the process of change (including training and documentation).

The structure of such a proposed information system to support the CPA decisions includes three levels: the CPA Centre, the Sources of Non-conformities (external and internal), and the Quality Council. Each of these is considered below.

(1) CPA Centre level

The CPA Centre is the administration core of the whole corrective and preventive action system. It has several functions.

- Quality-problem records are received from different sources, including: the seven assessment groups (see above), quality audit, functional departments, customers, suppliers, vendors, and so on. The problems that are raised in any of the seven evaluation groups are discussed and, in most cases, the appropriate corrective and

preventive actions are determined within those groups. Regardless of the source of non-conformity, each finding requires a corrective action request (CAR)—that is, a web-based form that allows the request to be entered into the system in a predefined formatted input. Similar findings are grouped into one CAR. Internal end users submit the request via an Intranet, whereas external end users can submit via the Internet. The Internet is used as a tool to connect all the components of this system. Suppliers and customers have the chance to communicate with the company online.

- All the CAR information is entered in a log file. Findings are categorized according to the given instructions as: (i) major (systemic, critical)—a complete breakdown in an element of the QMS; or (ii) minor (isolated)—a single lapse in a requirement.
- A help desk manned by support quality assurance engineers provides service assistance, generally on two kinds of problems; those due to the user's not knowing how to perform a quality assurance task and those due to system failure of various kinds. Support staff are trained to recognize and fix certain kinds of common problems, but they do not generally engage in finding a failure's cause. Harder problems are sent to the Quality Council level (see below). The Quality Council uses different tools, depending on the nature of the problem. There is a guidance system for selecting the appropriate tool.
- The suggested solutions received from Quality Council are recorded and sent to the responsible departments for appropriate actions. The symptom, the symptomatic cure, the root causes, and the solutions are recorded in the database. The results of the process are communicated to all relevant personnel to ensure that the process becomes reinforced and ingrained in the operations.
- The CPA administration keeps track of the suggested solutions and the follow-ups. CARs are kept open as long as the root cause of the problem has not been found. A continuous follow-up is in place until all action items are closed and the results of the corrective actions are validated. The prescribed root-cause analyses should be completed and the results should be documented. Priority is placed on the response to the CAR and closure of the case.
- The database system is continuously updated.
- A monthly report is sent to top management for its evaluation, to be discussed in management review meetings.

(2) *Sources of non-conformities level*

This level is related to an online communication with the customer (internal and external), suppliers, vendors and departments in charge of implementation of corrective and preventive action. The prototyped company communicates with different parts manufacturers, dies manufacturers, and suppliers of materials for production of prototypes.

A dialogue-management module connects these sources to the CPA Centre level. The dialogue-management system is the hardware and software that provides the user interface for the system. It presents the process outputs to the users and collects the inputs to the system.

(3) *Quality council level*

This is the part of the system with the major problem-solving capability and tools. Problems collected at the CPA Centre level that require expertise for finding a solution are routed to this level. A specific intelligent decision-support system is designed to help the decision-

makers at this stage. There are three major components for this intelligent support system: (i) data management; (ii) model management; and (iii) knowledge management, as explained below.

- (a) *Data management.* The data management module contains a data warehouse that extracts data from internal and external databases. This is the database for all corrective and preventive action. The CPA Centre and the Quality Council use this database. It includes the user-provided description of the problem, problem-related information obtained during the fault recovery process, and the repair action performed to recover from the fault. In addition, reference materials such as the quality manual and standards, quality records generated by different processes, and the tracking information about non-conformities, solutions and follow-up are kept in this database. Other items in the database include: the technical information, such as 2D and 3D drawings, product definition, bill of materials, CAD (computer aided design) data, cubic master model data, prototype data, customer specifications, functional requirements, quality audit results, and benchmarks.
- (b) *Model management.* Both the seven assessment groups and the Quality Council use this component for analytical purposes. This module contains a variety of tools and models for analysis of the quality problems and for finding the proper solutions. It is composed of some planning tools such as QFD (Quality Function Deployment), FMEA (Fault Mode Effect Analysis), FTA (Fault Tree Analysis), and fatigue test models together with other quality control and data mining tools and models. Data mining tools are primarily used to generate preventive actions. Over time, as the number of database records increases, data mining tools—such as correlation or regression—can suggest specific solutions for a given set of quality problems. Some problems require simple data analysis tools, while some others require suggestion and optimization models. A simple ES assists the decision makers in the selection of proper tools. A model directory that catalogues and displays the models for use by several individuals in the organization is the other part of the model management system.

Figure 1 shows the components of the proposed system.

Due to the importance of the knowledge-management component of this system, this aspect is considered in greater detail below.

The knowledge management component of the system

Knowledge management relies on knowledge-based systems (KBSs). KBSs are computer programs that solve problems by emulating the problem-solving behaviour of human experts. Generating a KBS within a particular domain of knowledge involves capturing the knowledge and problem-solving logic and methodology regarding real-world problems associated with that domain. The application of KBS in quality-management decision-making has been very limited.

As discussed by Holsapple & Whinston (1996), an expert opportunity exists if such an activity involves reasoning for the purpose of: diagnosing the cause of a situation; prescribing a course of action; predicting what will happen; understanding what is happening; governing what is happening; and/or evaluating a happening. This component of the proposed system has a very important role. It includes both a rule-based knowledge base and a case-based knowledge base.

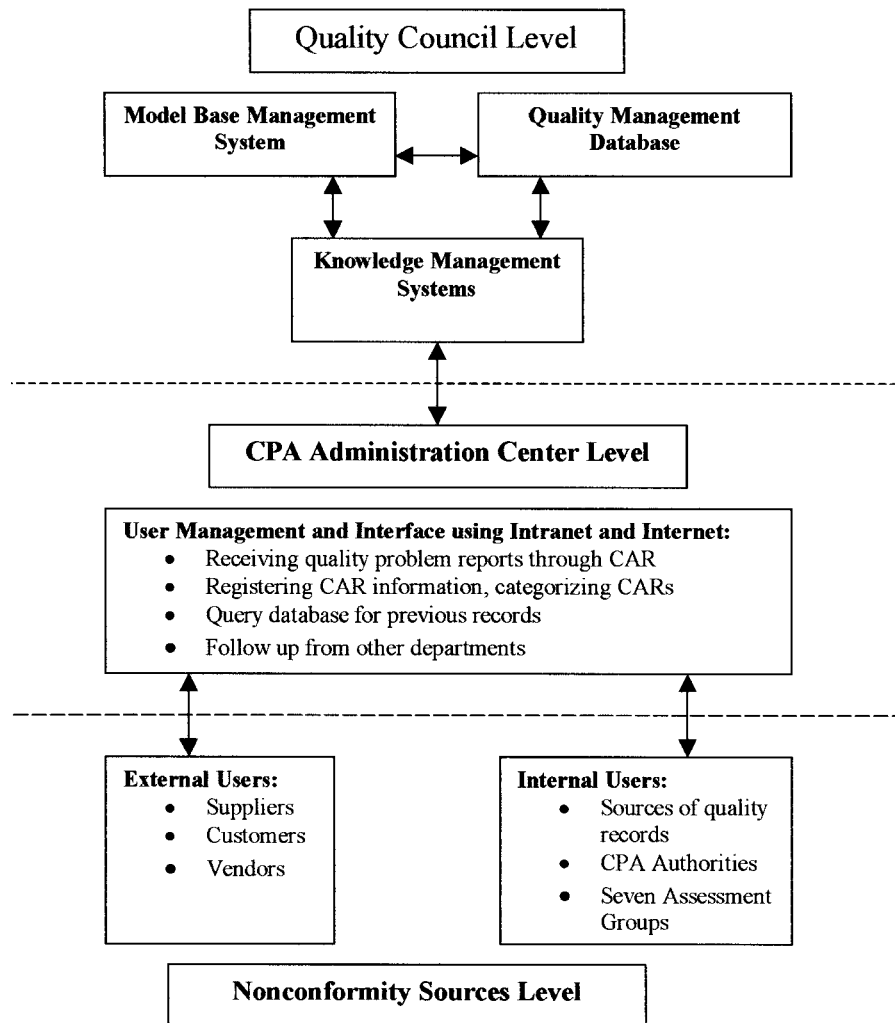


Figure 1. The major components of the proposed intelligent decision support for CPA.

The rule-based system is mostly used in the early stages of the product development process. The first and second assessment groups are the main users of the rule-based system. They use it for verification and validation of customer requirements. For other occasions, where the decomposition of experiences and generalization of their parts into rules is not possible, the CBR is used. For a CBR system to work effectively, important domain knowledge needs to be encoded in the case-indexing structure, as well as in the retrieval mechanism and in case adaptation (Richter, 1995). The Intelligent Decision Support System (IDSS) model shown in Fig. 1 consists of three levels of decision-making—(i) skill-based; (ii) case-based; and (iii) knowledge-based. These are described below.

- At the skill-based reasoning level, actions are carried out without the need for conscious reasoning. The current problem matches the same cases in memory. If a difference between the expected and real outcome is noted, control passes on to the case-based level.

- At the case-based reasoning level, the pattern of the problem is matched with the case pattern stored in the database or memory. If this succeeds, a particular case or a set of cases is applied. The database is consistent with the object-oriented paradigm and is implemented using a standard object-oriented language. If there is no case similar to the current problem, reasoning passes on to the knowledge-based level.
- At the knowledge-based reasoning level, problems are identified, analysed, and solved by combining expert knowledge. New cases are added to the database once a solution is evaluated, selected and implemented.

Aamodt & Plaza (1994) have described CBR as a cyclical process comprising the four 'Re's:

- *Retrieve* the most similar case(s).
- *Reuse* the case(s) to attempt to solve the problem.
- *Revise* the proposed solution if necessary.
- *Retain* the solution as part of a new case.

A new case (an initial description of a problem) is used to *retrieve* a case from the case base (a collection of previous cases). The retrieved case is combined with the new case (through *reuse*) into a solved case (a proposed solution to the initial problem). Through the *revision* process, this solution is tested for success and repaired if it has failed. During *retain*, useful experience is retained for future reuse and the case base is updated by a new learnt case or by modification of some existing cases. There is a further decomposition of four top-level steps (*retrieve, reuse, revise, retain*) with a task-oriented view in which each step is viewed as a task that the CBR reasoner has to achieve (Aamodt & Plaza, 1994).

For the purpose of the prototype system, it was decided that the system should be PC-based using an industry-standard database and that Visual Basic should be used as the main development environment. This allows rapid development of code, and external specialized libraries can be linked in for use by the main program. External libraries comprise a CBR library and a CBR shell. The system uses an MS ACCESS database as a back-end data store.

REMIND CBR Shell by Cognitive Systems (1992) is a generic tool, with fault diagnosis, data-mining prediction, and a classification capability that is used in this case. It provides facilities for rapid prototyping and deployment of CBR applications. It augments case representation with domain knowledge, which is very helpful in this type of situation. The system task flow is presented in Fig. 2.

The cases are structured in terms of the following features: (i) *major* (systemic, critical)—a complete breakdown in an element of the QMS; and (ii) *minor* (isolated)—a single lapse of a requirement; (iii) vehicle class; (iv) nature of the problem and whether it is a conceptual or physical problem; (v) car design development phase; (vi) product section, such as body, engine, suspension, transmission etc; (vii) sub-section of the product section, such as doors, bumper etc; and (viii) carryover versus in-plant parts. In addition, the symptom, the symptomatic cure, the apparent cause, the fix, the corrective action, the root-cause, and other organizational information are used for further classifications. A sample of a prototypical case is shown in Fig. 3.

The indexing is done based on: (i) conceptual categories of cases defined by an expert; (ii) inductively derived discriminations guided by a qualitative model of a domain; (iii) abstract-derived features defined by expert-supplied heuristics; (iv) abstractions over symbolic values; and (v) expert-supplied assessment of importance. It has a decision tree traversal retrieval algorithm. The organization of cases is by clustering shared common characteristics and/or flat memory. The matching process is based on nearest neighbour, and the adaptation

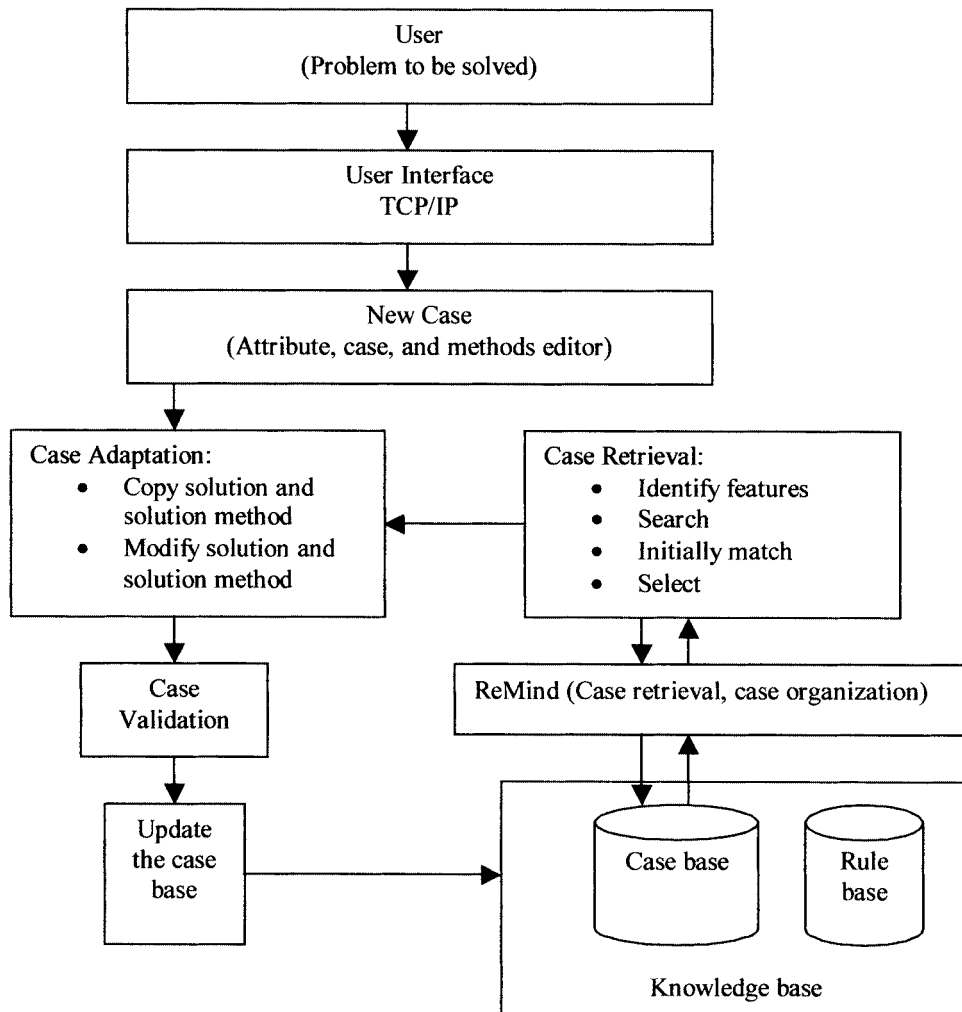


Figure 2. System task flow.

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(Case 3
  (problem_features
    (vehicle_class.Passenger)(problem_nature.Conceptual)
    (development_phase.Ptototype)(product_section.Body)
    (sub_product.FrontRightSash)(part_type.Carryover)
    (problem_description.Gap))

(CPA_plan (corrective_action
  (CPA_corrective_plan ((change.bodysideAngle)(prototype)))
  
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Figure 3. Part of a prototypical case.

method is special-purpose expert-supplied heuristics. The expertise is encoded implicitly in cases rather than explicitly in rules or modelled on the problem domain.

Results and conclusion

This paper introduces an intelligent decision-support system to manage corrective and preventive action decisions in a quality-management system.

Having an intelligent DSS, such as the one proposed in this paper, will benefit a QMS in numerous ways by: (i) increasing productivity; (ii) decreasing decision-making time; (iii) integrating several expert opinions; (iv) working with incomplete or uncertain information; (v) providing training; (vi) enhancing problem-solving and decision-making processes; (vii) solving complex problems by using past problem-solving experiences and cases to solve new ones; (viii) integrating the data, knowledge, and models required for a sound corrective and preventive-action decision system; (ix) helping experts to select the proper tools for problem analysis, and (x) the knowledge-based system provides the junior engineers access to the senior engineers' problem-solving expertise.

The proposed intelligent system with its several components (database, model base and knowledge base) can help decision-making at different levels of organization. The decisions can range from simple queries to the use of complicated tools. In this system, the resources of traditional information systems are combined with the vast reach of the Web and connect critical business elements of the system directly to customers, employees and suppliers via Intranets, Extranets and via the Web. By connecting the traditional information technology systems to the Web, this system becomes an e-business application that makes it easier to do the things we already do.

The proposed system has been tested in a prototype situation in a car designer. The information from the past five years has been used to build different components of this system. Even so, these data were still not enough for data-mining or related activities. Due to the nature of the activities and the type of quality problems recorded in the past five years, both rule-based and case-based approaches should be used. Case-based reasoning systems are preferred over rule-based systems if rules are inadequate to express the richness of the domain knowledge. This is frequently the case when expertise deals largely with exceptions rather than the rule. Ideally, CBR systems are best suited for domains that are experience-rich but knowledge-poor (Chi *et al.*, 1991).

There were many limitations to this study. Quality assurance in this type of organization has its own structure and distinctive complications. Unlike production processes, the car-design process is not a fast data-generating process. The operation moves very smoothly, but is a very time-consuming process. As a result, sufficient data for complete validation of the system take some time to be generated, checked for quality, and compared with the standards. The data that have been entered into the database mostly relate to the past few years of operations. Building the knowledge-based system was very difficult due to improper documentation of records and incomplete data. Both rule-based and case-based knowledge systems have been developed. However, their use is still very limited because the CPA centre has not encountered many serious quality problems. Some of the experts who worked on the problems in the past are no longer with the organization, and their expertise was therefore not available for use in the current study.

The measures used to benchmark the prototype were related to the results from past experiences. Based on these results, the prototype appears to be promising. Most of the non-conformities received by the CPA Centre were related to a misinterpretation of standards and to operators not following written instructions. A couple of serious problems reported

by customers were routed through the new system, and all were handled expeditiously. There are many potential areas of development and improvement, including different interfaces between components and adding more knowledge to the case-based system.

Finally, further potential development of this tool lies in the possible use of its capabilities as a generic tool for other types of enterprises. The structure of the system, as explained in Fig. 1, can be used for other industries. However, the content of database, model base, and the knowledge base should be changed according to the particular application.

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