J Syst Sci Syst Eng (Sep 2011) 20(3): 323-345
DOI: 10.1007/s11518-011-5172-z
ISSN: 1004-3756 (Paper) 1861-9576 (Online)
CN11-2983/N

RE-ENGINEERING TRANSFORMER MAINTENANCE PROCESSES TO IMPROVE CUSTOMIZED SERVICE DELIVERY

Amy J.C. TRAPPEY[1, 2] Yong SUN[3] Charles V. TRAPPEY[4] Lin MA[3]

[1]*Department of Industrial Engineering and Engineering Management, National Tsing Hua University, Taiwan, China,*
trappey@ie.nthu.edu.tw

[2]*Department of Industrial Engineering and Management, National Taipei University of Technology, Taiwan, China*
trappey@ntut.edu.tw

[3]*School of Engineering Systems, Queensland University of Technology, Australia*
y3.sun@qut.edu.au , l.ma@qut.edu.au (✉)

[4]*Department of Management Science, National Chiao Tung University, Taiwan, China*
trappey@faculty.nctu.edu.tw

Abstract

The outage of a transformer in a power generation system will generally result in a shutdown of the entire system. Consequentially, large amounts of revenue are lost to the plant owner with a substantial negative impact on the civil community and industrial customers. This paper analyzes the current maintenance practices (i.e., an as-is process model) of a transformer manufacturing company, which provides maintenance services to power generation plants and reports the major weaknesses in current business practices. The maintenance weaknesses include isolated processes and paper based information communication. These inefficient processes result in service delays, cost increases, and inappropriate responses to customers' specific requests and complaints. To improve the efficiency and flexibility of the entire transformer maintenance service system, an e-integration approach is implemented with three key tasks. First, the current business processes are re-engineered to provide an improved (to-be) business model. Then, we replace paper based documentation methods with an electronic filing system for efficient and cost-effective information exchange. Afterward, the improved process model is implemented as an Internet based system to enhance the interactions among the transformer manufacturer, end-users, and service contractors for customized maintenance services. The case study demonstrates that implementing the e-integration approach increases the efficiency and effectiveness of the customized maintenance services.

Keywords: Business Processes Reengineering (BPR), after-sales services, transformers, engineering asset maintenance, power industry

1. Introduction

Industrial transformers are critical engineering assets in power generation plants. A transformer converts electrical power and transforms voltage levels before and after power transmission. A breakdown of a transformer in a power generation system often causes a shutdown of the entire system, resulting in huge financial losses to the power generation plant and great inconvenience to public customers. Interruptions of power supply significantly affect people's daily lives and their trust in the national infrastructure. Therefore, any power generation plant must ensure that the transformers are reliable and well managed. Most transformers are maintained by the original manufacturers as contracted by after-sale services agreements. These services are provided either directly by the manufacturer's trained specialists or licensed contractors. Power plants expect high quality products with good after-sale maintenance services throughout the product life cycle. They necessarily require instant services from maintenance suppliers and most of the services must be customized for the given transformers and their conditions. Ongoing Preventive Maintenance (PM) is required to reduce the risk of sudden transformer failures (Trappey et al. 2009). After-sale service performance is critical to sustaining a competitive brand in the transformer market place. Bitner (1997) stresses that every business (manufacturing or non-manufacturing type) should be service oriented while Tien (2008) emphasizes that complex service systems should be integrated and adaptable across multi-disciplinary application fields. In the manufacturing sector, after-sales services impact revenues and competitive advantage. Thus, management's participation in the after-sales service process cannot be neglected (Gaiardelli et al. 2007).

To ensure high quality maintenance services, service processes must be effective and efficient to help manufacturers respond promptly to their customers' needs. Transformer maintenance and plant operation are coordinated through the service process to minimize transformer shutdown time and the corresponding negative consequences. Since transformer maintenance often requires the replacement of parts, components, and fluids, manufacturers are required to maintain and plan spare parts inventories based on maintenance frequency, suppliers' information, and cost data aggregated across all transformers in usage and under service agreement. The management and forecasting of spare parts and materials is considered an essential function of the product life cycle services platform. However, for traditional transformer manufacturers, the service processes are managed using paper driven systems. Customers, contractors, and manufacturers communicate repair requests and maintenance schedules via phone, fax, or e-mail. The maintenance service chain often lacks an integrated Internet platform to coordinate communication and data analysis processes. Using a paper driven system, a transformer manufacturer is less capable of tracking customer needs and less able to deliver fast, cost effective, high quality and highly customized services.

In order to respond to all customer requests quickly and increase customer satisfaction, transformer manufacturers should adopt innovative information technologies and advanced Business Process Reengineering (BPR) to advance their service performance. After investigating manufacturers of heavy equipment that traditionally rely on close and personal sales ties, Gaiardelli et al. (2007) indicated that the current trend was to build integrated sales maintenance information platforms to record, communicate, and plan customer service delivery. In order to develop agile and adoptable business and E-commerce applications which include systems and processes from multiple service providers, Jain & Reddy (2004) proposed a distributed architecture for the deployment of applications based on business components. Modern information technologies also benefit Engineering Asset Management (EAM). For example, e-Diagnostics and e-Maintenance have been proposed to provide the prompt diagnosis, repair and maintenance of equipment in the semiconductor industry (Hung et al. 2003).

BPR is an effective means to improve business processes and has been successfully applied in various industries. BPR emphasizes process simplicity and as noted by Hammer (1990), radical process simplification is an important way to reduce process times and costs. Organizations which change from hierarchical organizational structures to matrix structures are also implementing process oriented measurement goals (Zhang & Cao 2002). Based on the investigation of existing practices, Gursel et al. (2009) developed an integrated reference process model to improve the efficiency of lifecycle building performance. Using BPR technology to enhance EAM has also attracted the attention of researchers in recent years. After studying several EAM process representation problems, Ma et al. (2007) suggested a combination of existing business process representation methods to make models more intuitive, concise, and informative. Agreeing with this opinion, Sun et al. (2007) further indicated that EAM process modeling requires intuitive representation of its processes, fast implementation, effective process evaluation, and sound system integration ability. Even though several EAM modeling methodologies have been explored (Frolov et al. 2009) and the core EAM functions have been defined (Frolov et al. 2010), existing publications focus on EAM process modeling methodologies with little attention to process reengineering applied across a wider range of industrial sectors. The research remains at an early stage of development with many opportunities for innovation. For example, an effective method for improving transformer after-sale maintenance services has yet to be developed. To fill this gap, this paper presents an e-integration approach and studies its application in a transformer manufacturing company.

2. The Schema and Contents of the E-integration Approach

The basic concept in the e-integration approach is the combination of the Internet based information technologies and BPR. Figure 1 shows the schema of the e-integration approach across three task levels. The tasks include 1) reengineering the current business processes to provide improved (to-be) business models, 2) replacing paper based documentation methods with electronic filing systems for efficient and cost-effective information exchange, and 3) implementing the to-be process models with Internet based systems to enhance the interactions among the manufacturer, end-users, and contractors.

The application of the e-integration approach to improve transformer after-sale services is demonstrated via an industrial case study in the following sections.

3. Analysis of Current Practices

The business process models for after-sale maintenance services were defined using INCOME4, a system analysis tool with features that enable the evaluation of process efficiency and effectiveness (INCOME 2000). Using INCOME4, the processes are divided into 1) behavior models that describe the process (i.e., activities and their sequential relationships), 2) organization models which document the costs and responsibilities of departments and staff, including external contractors and customers, and 3) the definition of object models that represent data entities and relationships.

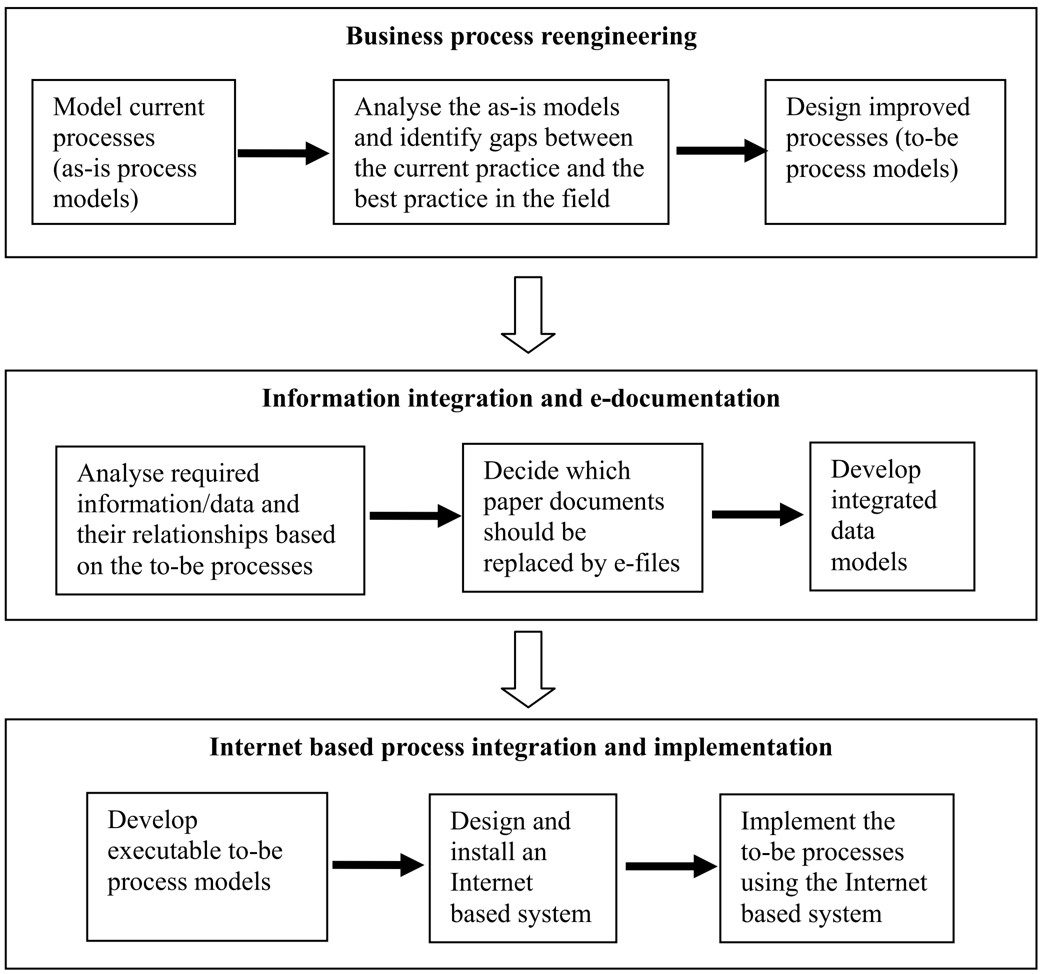

Figure 1 The e-integration approach with three task levels

3.1 As-is Behavior Models

Figure 2 and Tables 1 and 2 depict the as-is behavior model, the process activities, the drilled-down sub-processes, and the description of data entities. The entire as-is processes are paper base without Internet linkage and e-integrated information system support.

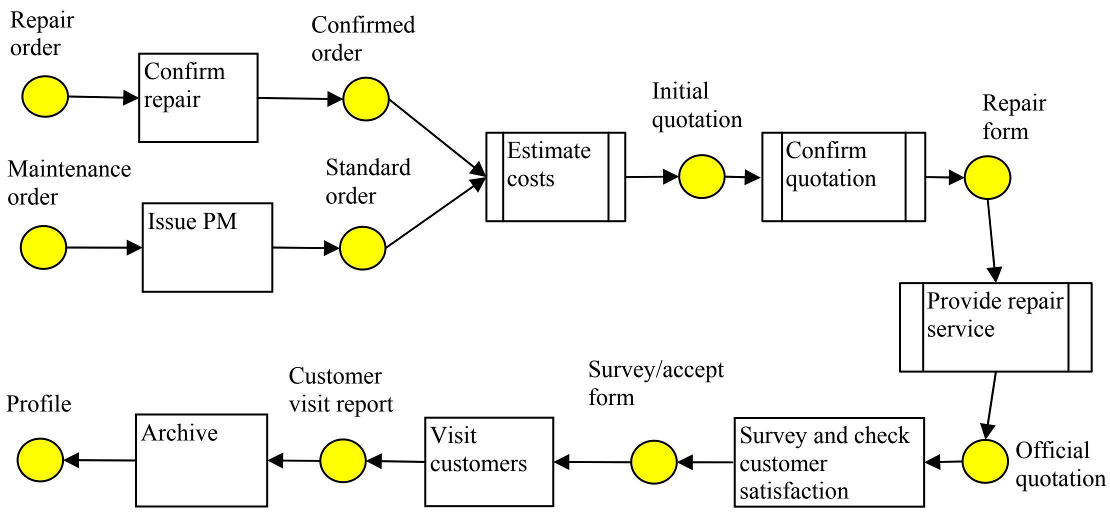

Figure 2 The as-is behavior model for current after-sales maintenance services

Table 1 Activity details for the as-is behavior model

Activity	Description
Confirm repair	After receiving a repair order from customers, technical staff confirm the order.
Issue PM	The technical staff issues a preventive maintenance (PM) order according to the contract PM regulations.
Estimate costs	The order received is sent to the procurement department for cost estimation. The procurement creates an initial quotation which is re-confirmed by the technical department.
Confirm quotation	The business department sends a quotation to the customer for confirmation. After receiving feedback from the customer, the order form is converted to a repair form. The trail of correspondence is maintained by the technical department that checks and saves documents. This activity can be expanded into sub-processes.
Provide repair services	The technical department contacts customers for service dates and schedules resources, and then provides repair services to the customers according to the schedule and contract procedure.
Survey and check CS	After completing the customer service, the business department follows up with a survey to measure the customer's satisfaction (CS).
Visit customers	The business department visits customers regularly to keep in touch and discuss needs.
Archive	IT staff archives the customer visit reports.

Table 2 Object details for the as-is behavior model

Object	Description
Repair order	Customer equipment repair demand.
Maintenance order	Customer equipment maintenance demand.
Confirmed order	Order confirmed by the quality assurance department.
Standard order	Order in standard format.
Initial quotation	Forms used by manufacturer before the official quotation is checked or negotiated.
Repair form	Forms checked by customer and sent to the maintenance department of the manufacturer for execution.
Official quotation	Quotation sent to customers
Survey/accept form	Survey form completed by customers to measure their service satisfaction.
Customer visit report	Reports which record customer's needs.
Profile	All orders, forms, and reports are saved in the customer project profile room.

3.2 Weaknesses of the Current Practices

After the analysis of the after-sale service processes, several inefficiencies were discovered. First, most data are written as paper notes and then saved in Excel spreadsheets. Duplicated data entry lacked systematic management overview and integration, leading to increased occurrences of errors and consequently higher service costs. Using paper documents often created communication barriers, disrupting the information flow between the manufacturer and customers. Second, the communications between departments were inefficient and lacked a common platform to view and check ongoing customer service cases. Following the as-is business processes, the company experienced difficulties in providing rapid responses to customers' requests and complaints. Third, only breakdown repairs and time regulated preventive maintenance (PM) services were carried out. Condition Based Maintenance (CBM) services, which are preferred by the modern power generation industry, were ignored. Lacking CBM services significantly weakens the manufacturer's competitive power. The best transformer after-sales maintenance services should include breakdown repairs, Time Based PM (TBPM) services, and CBM services.

Breakdown repairs are services provided when a transformer malfunctions. The service provider repairs the failed equipment and restores it back to a full operational state. Providing this type of maintenance is least preferred by the power industry since unplanned outages cause severe social and economic consequences. According to our investigations at a typical power plant, there can be a six month delay to replace a failed transformer with a new one. For TBPM services, transformers are regularly maintained based on their operational hours to reduce the probability of sudden failures.

When offering CBM services, a condition monitoring strategy is devised whereby service personnel install monitoring devises to transformers. Selected parameters that indicate transformer health conditions are measured and assessed either regularly or continuously. Once a combined indicator of the parameters of a transformer exceeds its predefined threshold, a PM action is executed to restore the transformer to a required operating level. Transformer owners prefer this type of service since it is the most cost-effective. Breakdown repairs, time based PM, and CBM, are listed by the Cooperative Research Centre for Infrastructure and Engineering Assets Management (CIEAM) as the primary maintenance strategies for engineering assets (CIEAM 2010).

Finally, customers were not consulted before issuing the PM order. The best transformer maintenance services must consider the customers' operational requirements which are dynamic. After-sale service processes should be incorporated with the customers' decision making processes. If contractors are hired to do repairs (a normal process for overseas customers), then these activities should also be analyzed and modeled.

4. Development of To-be Process Models

To improve the after-sale services of the company, the as-is processes have been re-engineered to to-be processes that eliminate weaknesses and bottlenecks of current operations. An online system was created to integrate all the processes into a matrix management platform. Organizational role players have authority to login to the system and readily access information, and communicate across the company. The manufacturer, customers, and contractors communicate with fewer delays and greater transparency which enhances the overall service performance.

4.1 To-be Behavior Models

The improved behavior model is depicted in Figure 3. The activities and data objects are described in Tables 3 and 4, respectively. Further, the main process model can be expanded into four detailed sub-processes including the condition monitoring (CM) sub-process (Figure 4), the PM confirmation sub-process (Figure 5), cost estimation sub-process (Figure 6), and, finally, the maintenance/repair service implementation sub-process (Figure 7). In order to implement the e-integration maintenance service platform, its interfaces and related functions, all activities and object entities of all sub-processes must be clearly defined for system design and analysis (SD/SA). For example, the CM sub-process activities and data objects are depicted in Tables 5 and 6.

The improved to-be process model involves many analysis and decision making processes. For example, the to-be condition monitoring sub-process model (Figure 4) is selected for an in-depth analysis. After the transformer owner agrees to implement CBM, the manufacturer needs to help the customer establish an effective condition monitoring strategy. To do so, the manufacturer and customer analyze the failure modes and effects of the transformers and their criticalities to decide which components and failure modes require monitoring. Transformers have different capacities and models and are complex electrical systems with many components. For instance, a generic oil-immersed power transformer with a capacity greater than three MVA has numerous major parts, including the core, windings, tank,

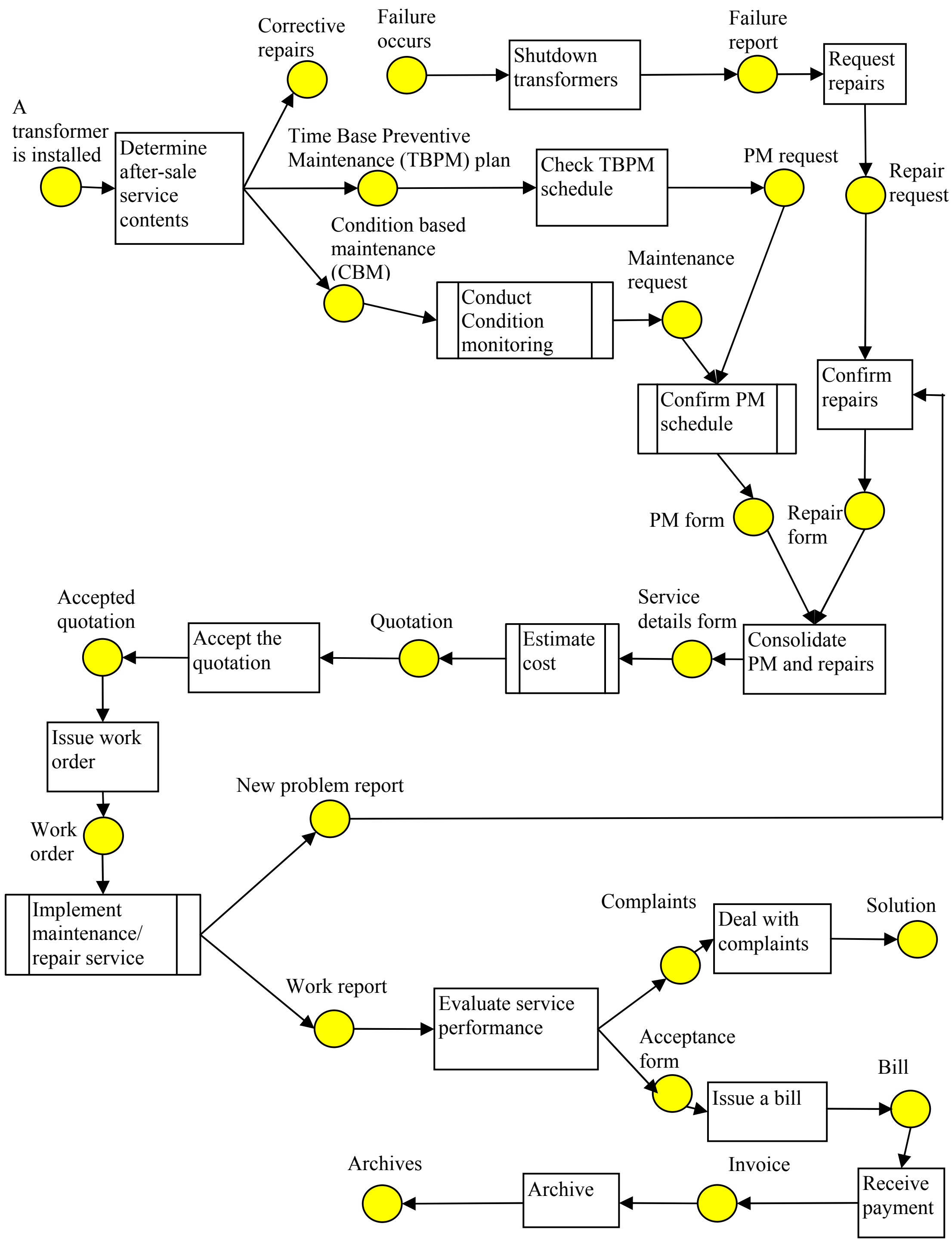

Figure 3 Improved to-be after-sales service behavior model

Table 3 Activity details for the to-be behavior model

Activity	Description
Determine after-sale service content	After a transformer is installed, the technical department and the business department work with the customer to decide after-sales maintenance service content. Normally the services will cover breakdown repairs, Time Based Preventive Maintenance (TBPM) services, and Condition Based Maintenance (CBM) services. The TBPM and CBM are planned based on manufacturer's experience, historical data, and customer's production requirements.
Shut down transformers	When the transformer malfunctions, the customer shuts it down immediately. A predesigned electronic failure report is filled out and sent by e-mail.
Request repairs	The customer's computer system automatically sends a repair request to the business department and the technical department, trigged by the completion of the failure report or by condition monitoring sensors.
Confirm repairs	After receiving the repair request, the technical department confirms failure details. When necessary, a site visit is scheduled.
Check TBPM schedule	The computer system automatically checks TBPM schedules and sends a reminder list to the business department and the technical department. Since the manufacturer has multiple customers, the list often includes multiple maintenance tasks. A specific PM request will be automatically sent to the customer via e-mail.
Conduct condition monitoring	Condition monitoring technology includes human inspection to monitor, assess, and predict the health conditions of the transformers. A PM action is scheduled if the working condition of the transformer reaches a predefined threshold. This activity includes multiple tasks and can be expanded to a sub-process.
Confirm PM schedule	After receiving the PM request, the customer confirms or modifies the maintenance date and content based on internal business requirements. Since this activity includes multiple tasks, the processes may be expanded to include sub-processes.
Consolidate PM and repairs	Upon PM and repair confirmation, the technical department consolidates multiple maintenance activities into one service visit.
Estimate cost	The consolidated service details are sent online to the technical department, the procurement department, and the financial department for cost estimation. Once the quotation is approved online by the manager of the company, it is then sent to the customer via e-mail for confirmation. The cost activity includes multiple tasks and may be expanded to include sub-processes.
Accept the quotation	The customer checks and sends back the confirmed quotation to the business department and the technical department.
Issue work order	The technical department creates a work order and the manager approves the work order. The approved work order is sent to the technical department and the procurement department online. When contractors are involved, the technical department sends relevant information to the contractors. Finally, an electronic work notice is sent to the customer by the technical department.
Implement maintenance and repair services	The technical department or contractors provide the approved service to the customer. This activity includes multiple tasks and may also be expanded to include sub-processes.
Evaluate service	After the service is completed, a survey is conducted to measure customer satisfaction.

performance	The customer completes an online survey form. On occasion, the business department may visit and interview the customer.
Complaint management	When a complaint is received, the related departments and the manager of the manufacturer analyse the complaint and derive solutions.
Issue a bill	After the customer is satisfied with the service, the financial department sends an electronic notice online to the customer for payment.
Receive payment	The financial department receives payment from the customer and issues a tax invoice to the customer.
Archive	The manufacturer's computer system archives the service data and electronic documents.

Table 4 The data objects for the to-be processes

Object	Description
A transformer is installed	A transformer is installed and asset ownership is transferred.
Corrective repairs	The corrective repair policy including information that can be shared by the customer and the manufacturer online.
Time Base Preventive Maintenance (TBPM) plan	The TBPM details including maintenance frequency (times), maintenance contents and procedure. The information can be shared by the customer and the manufacturer online.
Condition Based Maintenance (CBM)	The CBM policy including budget and targets for implementing CBM. The information can be shared by the customer and manufacturer online.
Failure occurs	When a transformer failure occurs, it is either discovered by the monitoring system or by physical service inspection. If it is detected by the condition monitoring system, the information is automatically shared by the customer and the manufacturer online.
Failure report	An electronic form from the customer records failure time and symptoms. The information is shared by the customer and the manufacturer online.
Repair request	A customer request for immediate repair service is automatically generated by the customer's computer system and sent to the manufacturer with the failure report.
PM request	An electronic form sent from the technical department to request a scheduled Preventive Maintenance (PM) service is automatically generated by the manufacturer's computer system and sent to the customer for conformation.
Maintenance request	An electronic form can be sent automatically from the technical department to request preventive maintenance services based on transformer operating conditions and scheduled maintenance. The form is generated by the manufacturer's computer system and sent to the customer for conformation online.
Repair form	Previously agreed upon repair details including repair time and required spares are included on the electronic form.
PM form	Previously agreed PM details including PM time, contents, and required spares are included on the electronic form. The information can be accessed online.
Service details form	PM content, repair content, and required spares are included on the electronic form. The information can be accessed online.

Quotation	An electronic form recording cost details is generated by the manufacture and sent to the customer online.
Accepted quotation	A quotation form signed by the customer.
Work order	An electronic form that records transformer problems, required repair or maintenance actions, spares, and personnel required to perform the services. The form may be accessed online by the technical department, the procurement department and the customer, but each is limited to viewing authorised content.
New problem report	An electronic form used for the maintenance personnel to record and report new problems which are discovered during the maintenance or repair. The personnel may record the problems using paper first and then enter the data into the manufacturer's computer system. The information is shared by the customer and the manufacturer online.
Work report	After the service is completed and accepted by the customer, the maintenance personnel transfer repair data into the manufacturer's computer system.
Complaints	Complaints from the customer are recorded using an online survey form and the complaints are sent to the manufacturer electronically. If the business department visits and interviews the customer, the complaints are first recorded using paper and then entered into the manufacturer's computer system.
Solutions	Solutions from the manufacture for resolving the complaints are recorded and are referenced with a time stamp of the complaint as a performance metric.
Acceptance form	An electronic form used by the customer to notify the acceptance of the service and may be included as part of the survey form.
Bill	An electronic form from the financial department to notify the customer to pay for the service.
Invoice	A tax invoice is sent to the customer to acknowledge the payment. There are two formats, one is an electronic form sent to the customer online and the other is a paper copy which is sent via traditional mail.
Archives	A collection of documents and data regarding the service.

coolers, oil, fans, pumps, bushings, conservators, tap-changers and secondary systems. These components have various failure modes which can be classified into thermal failures, dielectric failures, mechanical failures and general degradation. These failure modes are caused by a variety of factors. Lapworth and McGrail (1998) summarised that the important factors to consider include design weaknesses, pre-existing defects, abnormal system conditions, ageing, service loading and time scale for fault development. The working environment is also an important factor. Different failure modes may or may not result in the same consequences to a customer. Therefore, the critical components and failure modes to be monitored must be identified based on the customer's business demands.

After the first step, the manufacture helps the customer decide which parameters should be monitored for selected components and failure modes. A single failure mode may be detected by multiple parameters. For example, degradation in the core can be detected by the changes in its noise and insulation resistance. On the other hand, different failure modes may be indicated by parameters such as dissolved gases.

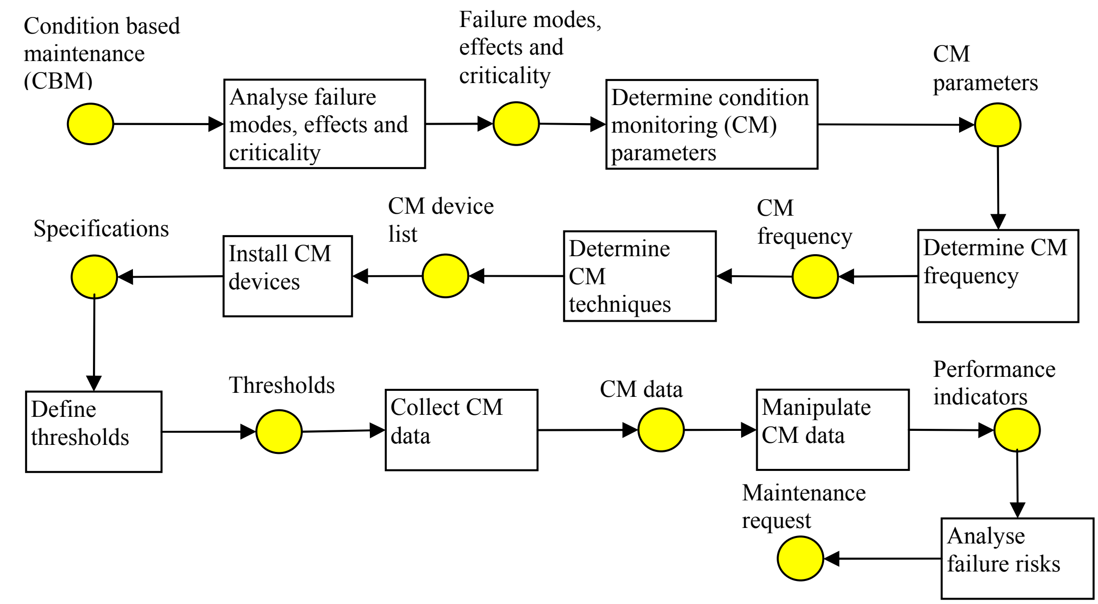

Figure 4 The improved to-be CM sub-process model

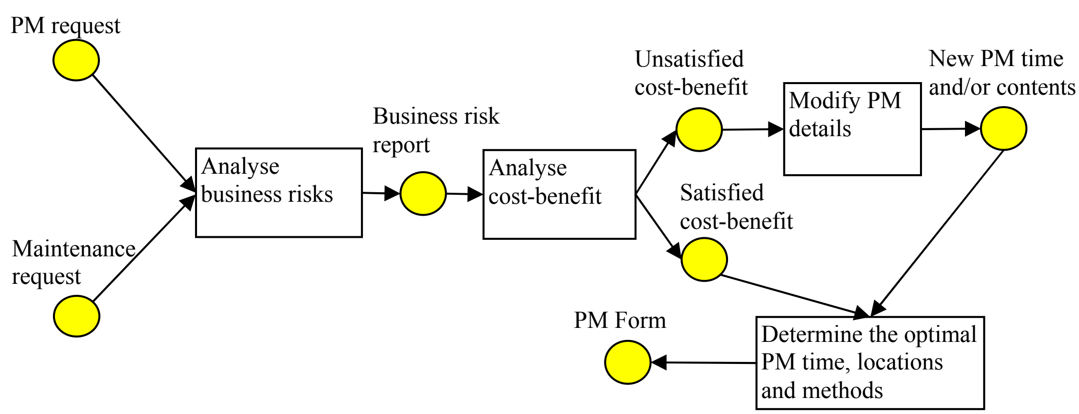

Figure 5 The improved PM confirmation sub-process model

The IEEE Power and Energy Society (2009) standard c57 104 indicates that many malfunctions such as arcing, partial discharge, low-energy sparking, severe overloading, pump motor failure, and overheating in an insulation system can often be detected by certain gases generated in oil-filled transformers. When these events occur, either singly or simultaneously, the insulating materials will decompose and form various combustible and non-combustible gases. Therefore, Dissolved Gas Analysis (DGA) is one of the most commonly used techniques to diagnose the health conditions of transformers under a CBM strategy. Once the condition monitoring parameters are determined, the manufacturer helps the customer decide the frequency and devices for monitoring each parameter based on its experience, international

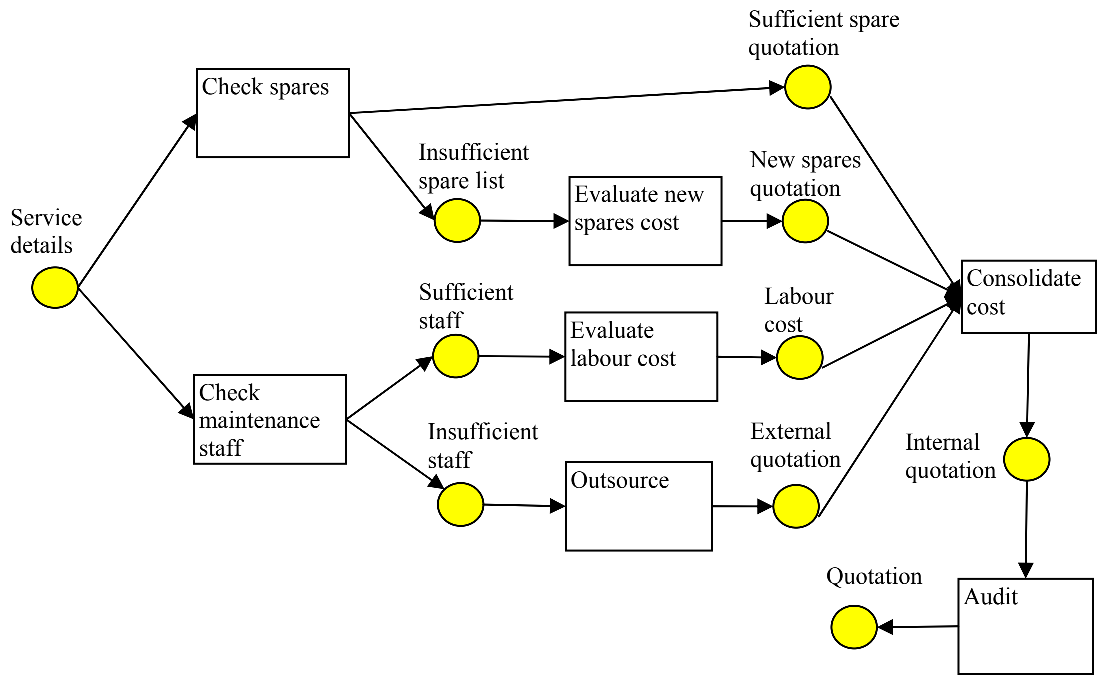

Figure 6 The improved cost estimation sub-process model

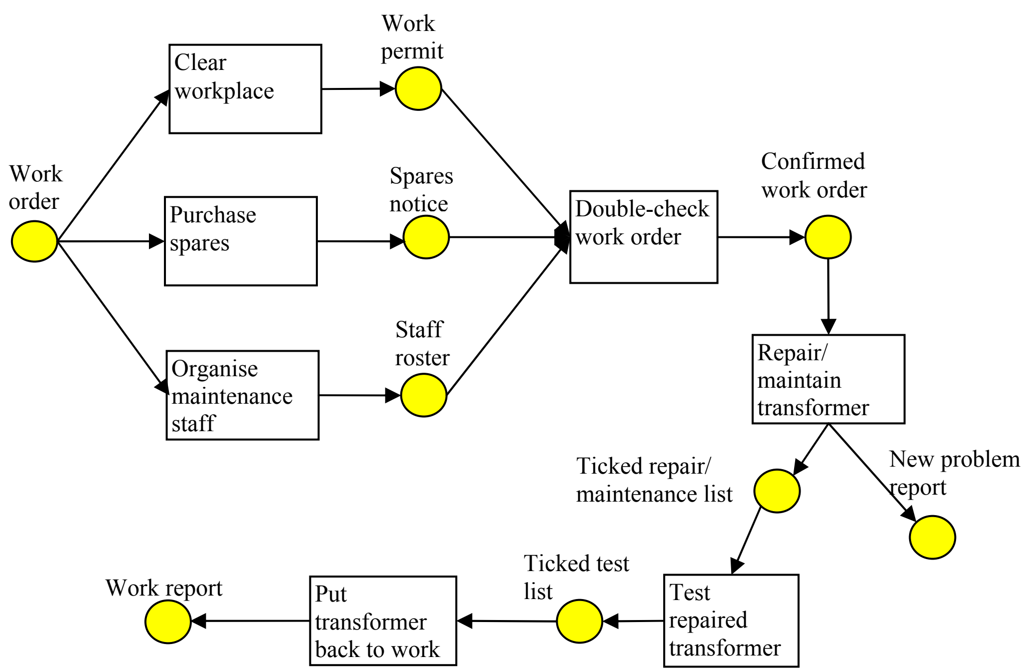

Figure 7 To-be maintenance service sub-process model

Table 5 Activity details for the to-be CM sub-process model

Activity	Description
Analyse failure modes, effects and criticality	Analyze the major failure modes and effects of the transformer based on manufacturer's experience and historical data and determine the criticality of transformer components and failure modes.
Determine condition monitoring (CM) parameters	The technical department tells customer which parameters such as vibration, temperature, dissolved gas in oil, require to be monitored.
Determine CM frequency	Determine the inspection and data acquisition frequency for each CM parameter.
Determine CM techniques	Determine the CM and inspection technology for each CM parameter.
Install CM devices	Install CM sensors to the transformer and the corresponding CM systems at the customer site.
Define thresholds	The technical department defines different thresholds (alert, alarm and shutdown) for each parameter, including a combined threshold for an overall transformer operating status.
Collect CM data	CM system measures the CM parameters and sends the measurements to the technical department electronically. The customer views the data when needed.
Analyse CM data	After receiving the CM data, the technical department analyses the data using signal processing and data mining technologies.
Analyse failure risks	The technical department assesses and predicts failure risks of transformer failure based on the analysis of historical and current CM data.

standards, and customer's business demands. Some international standards have been published for guiding transformer condition monitoring such as IEEE standard c57 104 (IEEE guide for the interpretation of gases generated in oil-immersed transformers) and ICE (2005) international standard 60567 (Oil-filled electrical equipment: Sampling of gases and of oil for analysis of free and dissolved gases). These standards should be followed in transformer CBM practice. To ensure the applications of the standards, they are saved in manufacturer's database as e-documents and a link to these documents is built in the improved process implementation system.

Two additional steps involving analysis and decision making in the to-be condition monitoring sub-process model are called define threshold and analyze failure risks. These two steps are used to ensure that transformer faults can be recognized at the earliest possible time so that appropriate preventive maintenance interventions can be carried out to minimize damage or avoid a failure. Defining thresholds is important because a condition parameter is useful for CBM decisions only after the thresholds have been determined. A threshold draws a line between two levels such as normal and abnormal. A parameter may have several thresholds and the health condition can be quantified using a multi-attribute scale

Table 6 The data objects for the to-be CM sub-process model

Object	Description
Condition based maintenance (CBM)	CBM policy includes budgets and targets. The information is shared by the customer and manufacturer online.
Failure modes, effects and criticality	An electronic form recording the failure modes, effects of the transformer, and the criticality of major failure modes and components. The information can be accessed online.
CM parameters	An electronic form listing all parameters that are required to monitor and assess. The information can be accessed online.
CM frequency	Scheduled frequency or times for monitoring each parameter. These data are recorded in the same electronic form as the CM parameters.
CM device list	Required devices and methods for monitoring each parameter. These data are recorded in the same electronic form as CM parameters.
Specifications	Specifications of the installed CM devices.
Thresholds	Predefined thresholds for each parameter. These data are recorded in the same electronic form as the CM parameters.
CM data	Measurements for each parameter.
Performance indicators	Information extracted from the CM data for monitoring the performance of the transformer over time.
Maintenance request	An electronic form from the technical department to request a preventive maintenance service based on transformer health conditions. The request is generated by the manufacturer's computer system and sent to the customer for confirmation.

measuring levels such as good, degraded, severely degraded, and failed. Thresholds are determined based on guidelines, manufacturer's experience, and historical data. Determination of thresholds often involves cost-benefit analysis and risk evaluation. For example, a transformer in normal operation will also generate gases. Some transformers even operate with substantial amount of combustible gases present during their whole life span (IEEE Power and Energy Society 2009). Therefore, gas quantities that indicate an event as abnormal can vary between transformers or customers. To determine the thresholds of generated gas quantities, the manufacture has to evaluate the serviceability conditions of a transformer in cooperation with the customer. If an event does not affect the serviceability, then the corresponding gas quantities are regarded as normal. During the failure risk analysis stage, the collected gas readings and predicted values are compared with the predefined thresholds. If they exceed normal levels, an abnormality is identified and a PM action is scheduled. In practice, the manufacturer will analyze multiple condition monitoring parameters simultaneously and use complementary analysis such as proportional covariate model (Sun, et al., 2006) and sensitivity analysis to increase the decision confidence.

4.2 Remarks on the To-be Models

Three commonly used maintenance strategies including breakdown repairs, TBPM, and CBM have been incorporated into the to-be processes and sub-processes. Several activities are conducted in parallel to increase process efficiency. Interactions between the manufacturer and customers are used to decide repair and maintenance details and to insure costs have been controlled. A number of web-based electronic forms replace paper based notes to increase communication efficiency. Two types of information exchanges are considered for the improved after-sales maintenance services: internally among different company departments and externally among the manufacturer, contractors and customers. The major improvements of the to-be model over the as-is model are highlighted in Table 7.

5. The Improved Model Implementation

The improved (to-be) processes are implemented using an Internet based after-sale service system. With this system, traditional paper documents are largely replaced by e-documents to minimize duplicated data entry and enhance the interactions among the manufacturer, customers, and contractors.

5.1 Internet Based Implementation System

The system follows the standard operating procedure depicted in Figure 8. When a user logs into the system, the appropriate data and views are provided depending on the user's account authority. Two kinds of service events

Table 7 The estimated service performance improvement evaluation

Items	As-is processes	To-be processes	Commnets
Maintenance stategies	Only consider breakdown repairs and TBPM.	Consider breakdown repairs, TBPM, and CBM.	Providing CBM services can significantly enhance the manufacturer's competitive power.
Condition Monitoring (CM) process	No.	Yes.	Monitor transformer performance and reduce unplanned failure risks.
Maintenance service process	All activities, especially customers' activities, have not been defined clearly.	Activities have been well defined and conducted in parallel.	New process increases respone speed and cost-effectiveness.
Repair and maintenance contents	Decided by the manufacturer only.	Decided by both the manufacturer and customers.	Customer's involvement helps to insure cost control and builds a positive attitude toward the services.
Documents and data transfer	Largely paper based.	Web-based electronic forms.	Significantly improve communication efficiency.
Cost estimation process	Avtivities in the procurement depatment and in the technical department are conducted in series.	Avtivities in the procurement department and in the technical department are conducted in parallel.	Parallel process increases response speed.

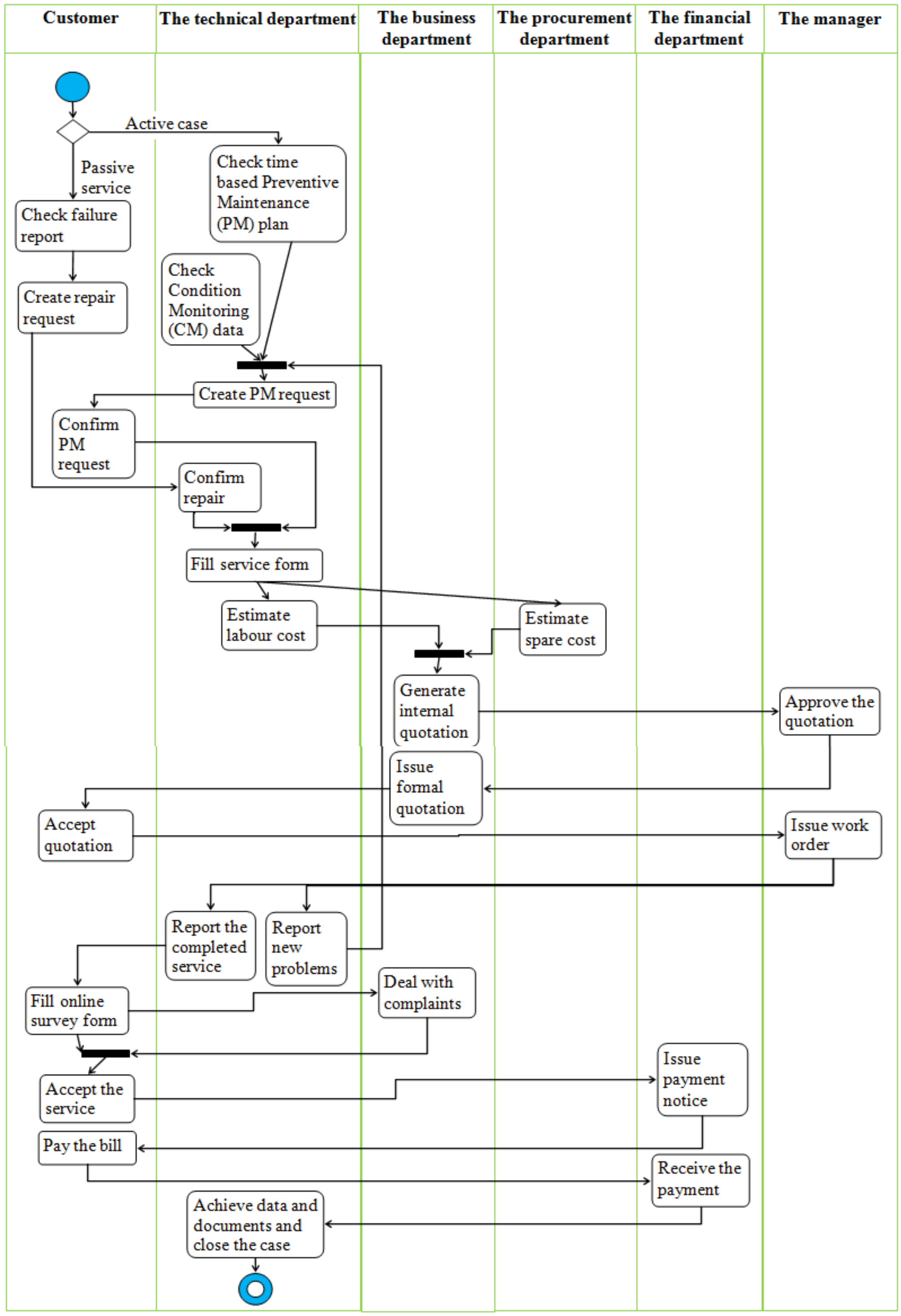

Figure 8 Simplified system standard operating procedures across roles

are managed by the system. The first covers repairs requested by customers (i.e., the active case) and the other case covers PM actions suggested by the manufacturer (i.e., the passive case). The first service event occurs when a customer's transformer malfunctions. The customer enters the problem details into the system which sends an online repair request to the technical department and the business department of the manufacturer. A designated engineer in the technical department reviews the problems, checks the history and specifications of the transformer, and calls the customer to confirm repair details. The second service event occurs when the predefined PM schedule or CM data of a transformer notifies the need for maintenance service. On this occasion, a designated engineer in the technical department creates a PM request (using an online form with data based information) and sends it by e-mail to the customer. The customer checks the company's internal business requirements to see if the PM date and duration are appropriate. If not, the customer may suggest modifications and discuss the issues with the technical department using the system. After the repair or PM details are confirmed, the engineer creates a quotation request using the system. Sometimes, repairs and PM requests are processed at the same time. In this case, the engineer consolidates the repairs and PM actions, and then creates a consolidated quotation request.

When using the online quotation system, the procurement department and the financial department are responsible to enter the required cost data. The manager of the company monitors the status of all ongoing cases and approves the quotations. The approved quotations are then sent to the customers by e-mail and are followed by a phone notification. For each accepted quote, a corresponding work order is issued online. All information is available to managers, salespeople, technical staff, financial officers, and the customer. After the work order is confirmed, the customer clears the maintenance working place, obtains required permits, and monitors the maintenance progress online. The procurement department procures and supplies the required materials. The technical department implements the repair and maintenance service and monitors the working costs. During the course of the repair and maintenance, the technical department records service details into the system and keeps the customer, the company manager, and the related departments informed at each stage of the repair process. If new problems are found, a new maintenance service request is issued. After the service tasks are completed, the customer completes an online survey to document service satisfaction and future needs. Once the service is accepted and paid for, all data and documents are archived in the database.

5.2 Data Model

Currently, when service data are needed, paper based documents are physically transferred between departments within the transformer manufacturing company. In order to structure a means to communicate data across the Internet, a data object model is designed. Eight tables are defined to facilitate the exchange of data across the company and between the manufacturer and customers. These tables include Repair Content, TR_Profile, Repair Demand, Maintenance, Quotation, Material, Company and Contact. The attributes of each table and the relationships of the tables are presented in Figure 9.

The transformer manufacturer executes repair and PM requests. When a request is received, data from the Repair or Maintenance table are retrieved. These tables have attributes linking to the TR_Profile table. The details of the repair requests are recorded in the Repair Content table. Transformer defects and repair solutions are in turn related to the quotation in the Quotation table. The TR_Profile table contains specifications to help staff process the transformer repair and maintenance requests. The table also links to the Company table to provide additional details and communications.

6. Model Comparison

In order to verify process improvements, a set of key performance indicators (KPI) are used to quantify comparisons between the as-is and to-be models. KPIs are quantitative measures

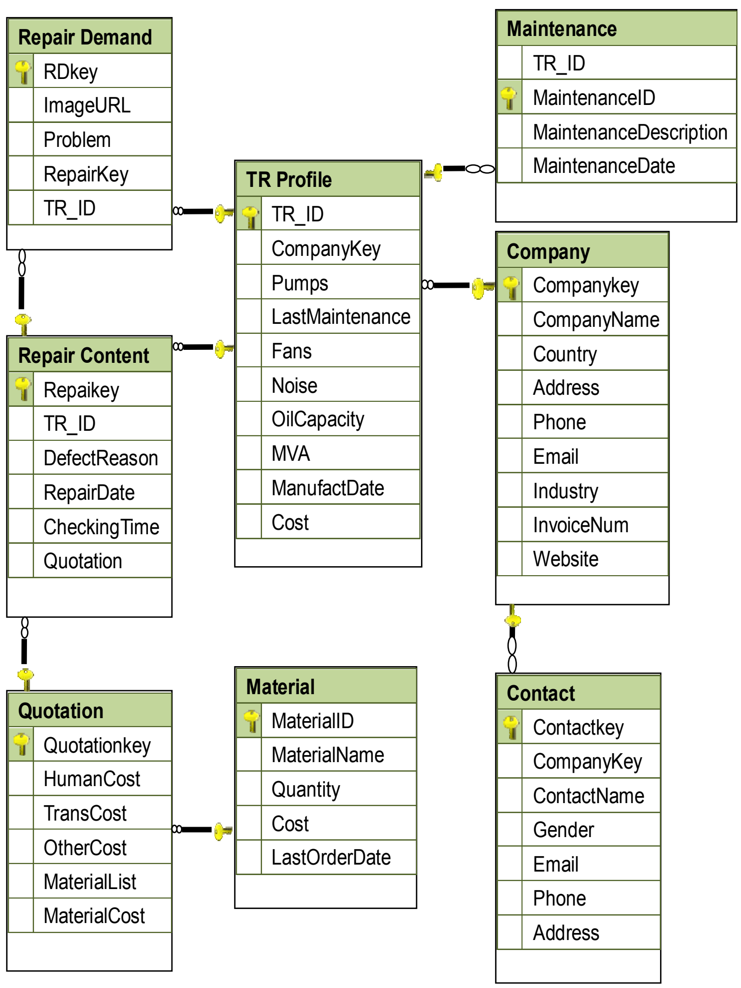

Figure 9 The entity relationship model for the improved after-sales service processes

that demonstrate progress towards goals and identify areas of improvement (Chan & Chan 2004). In this case study, service time, error rate, response time, data maintenance, and data security are used for comparisons in accordance with management's objectives.

These four KPIs measure the performance of information system and two scenarios model the performance of the system. The comparison determines the feasibility of constructing an e-business system. E-business systems produce accounting forms automatically and are designed to reduce manual data entry. The service processes are integrated into the collaborative platform, simplifying form confirmation and filing. The goal is to decrease the delay time for form transfer and to reduce human data entry error. For example, the technicians originally received a paper based customer repair order from the business department. The computerized process sends the repair request directly and instantly via the e-business system. Using the e-business system, all historical data are automatically archived in the database, greatly simplifying the former process. Staff can also access these data for different purposes and thereby save time and resources. These scenarios are depicted in Table 8, and the KPI's for the INCOME4 simulation run are shown in Table 9.

There is an estimated 50% improvement in average service time and error rate. Response time is reduced from three days to one day when the to-be e-business processes are used. The most significant improvement occurs with data processing. The new business model requires 27 fewer hours per month for data maintenance and security, a 90 percent improvement. All improvements are attributed to the e-business system which enhances service, data processing, and data integrity. In conclusion, the evaluation results show an overall improvement in service and the system should be prototyped and further tested to increase final implementation process efficiencies.

7. Conclusion

Transformers play a critical role in power industry and must be well maintained over the whole life cycle from purchase to disposal. Poor maintenance results in frequent breakdowns, longer power outages, and negative social and economic impact on the end users of electrical power. This paper studies the improvement of

Table 8 Scenario comparisons for as-is and to-be models

Input Categories	As-is	To-be
Number of people maintaining the database	4	1
Number of archiving processes	4	Automatic
Average Data Access Time	0.5 hours	Instant
Number of Form Types	7	N/A
Number of Paper-Based Work Processes	9	1
Number of Confirmation Points	5	1
Average Delay Time for Form Transfer	4.5 hours	15 minutes

Table 9 The estimated service performance improvement evaluation

KPI	As-is	To-be
Service Time	10 to 15 days	5 to 7 days
Error Rate	18%	9%
Response Time	3 days	Within one day
Data Maintenance and Security	35 labor hour/month	8 labor hour/month

transformer after-sale services using an e-integration case study approach applied to an electrical transformer manufacturer. The approach involves process reengineering and application of electronic documentation and Internet technology.

After analyzing the current after-sale service processes for the transformer manufacturing company, a number of weak points in the current practice were identified. The weaknesses resulted from a lack of cooperation and communication within the company, as well as between the company, its customers, and contractors. To increase the efficiency and effectiveness of services, improved service processes were developed. An Internet based integrated service platform accessible by all participating parties was implemented. Through the e-integration, the transformer manufacturer now provides better management of repair and maintenance activities, and a faster response to customers' demands. The computer based visualization of processes and activities helps customers understand how and when services are conducted, and thus builds a positive attitude toward the services. Although the study describes a case specific to a transformer manufacturer, the proposed e-integration approach and the findings are useful for dealing with similar problems in any engineering asset maintenance field where services play a crucial role in maintaining brand position and competitive advantage.

Acknowledgments

We are grateful to the research supports granted by Taiwan's National Science Council and the Australian Government's Cooperative Research Centers Program. We also thank the reviewers for their constructive comments.

References

[1] Bitner, M.J. (1997). Services marketing: perspectives on service excellence. Journal of Retailing, 73 (1): 3-6

[2] Chan, A.P.C. & Chan, A.P.L. (2004). Key performance indicators for measuring construction success. Benchmarking, 11: 203-221

[3] CIEAM (CRC for Integrated Engineering Asset Management). Available via DIALOG. http://www.cieam.com/. Cited February 16, 2010

[4] Frolov, V., Ma, L., Sun, Y. & Bandara, W. (2010). Identifying core function of asset management. In: Amadi-Echendu, J. (eds.), Engineering asset management review, Vol. 1. Springer-Verlag, London

[5] Frolov, V., Megel, D., Bandara, W., Sun, Y. & Ma, L. (2009). Building an ontology

and process architecture for engineering asset management. In: the 4th World Congress on Engineering Asset Management, 86-87, Athens, Greece, September, 28-30, 2009, Springer-Verlag, London Ltd.

[6] Gaiardelli, P., Saccani, N. & Songini, L. (2007). Performance measurement of the after-sales service network: evidence from the automotive industry. Computers in Industry, 58 (7): 698-708

[7] Gursel, I., Sariyildiz, S., Akin, Ö. & Stouffs, R. (2009). Modeling and visualization of lifecycle building performance assessment. Advanced Engineering Informatics, 23: 396-417

[8] Hammer, M. (1990). Re-engineering work: don't automate, obliterate. Harvard Business Review, 68: 104-112

[9] Hung, M.H., Chen, K.Y., Ho, R.W. & Cheng, F.T. (2003). Development of an e-diagnostics/maintenance framework for semiconductor factories with security considerations. Advanced Engineering Informatics, 17: 165-178

[10] ICE. (2005). Oil-filled electrical equipment - Sampling of gases and of oil for analysis of free and dissolved gases - Guidance. ICE International Standards 60567

[11] IEEE Power and Energy Society. (2009). IEEE guide for the interpretation of gases generated in oil-immersed transformers. IEEE STD c57 104

[12] INCOME. (2000). INCOME PROCESS DESIGNER User Manual. Karlsbad, Germany

[13] Jain, H. & Reddy, B. (2004). Layered architecture for assembling business applications from distributed components. Journal of System Science and Systems Engineering, 13 (1): 60-77

[14] Lapworth, J. & McGrail, T. (1998). Transformer failure modes and planned replacement. IEE Digest, 510: 9-15

[15] Ma, L., Sun, Y. & Mathew, J. (2007). Asset management process and its representation. In: the 2nd World Congress on Engineering Asset Management, 1354-1363, Harrogate, United Kingdom, June 11-14, 2007, Coxmoor Publishing Company

[16] Sun, Y., Ma, L. & Mathew, J. (2007). Asset management processes: modeling, evaluation and integration. In: the 2nd World Congress on Engineering Asset Management: 1847-1856, Harrogate, United Kingdom, June 11-14, 2007, Coxmoor Publishing Company

[17] Sun, Y., Ma, L., Mathew, J., Wang, W.Y. & Zhang, S. (2006), Mechanical systems hazard estimation using condition monitoring, Mechanical Systems and Signal Processing, 20(5): 1189-1201

[18] Tien, J. (2008). On integration and adaptation in complex service systems. Journal of Systems Science and Systems Engineering. 17 (4): 385-415

[19] Trappey, A.J.C. & Ni, W.C. (2009). A negotiation strategy of collaborative maintenance chain and its multi-agent system design and development. In: the Proceedings of the International Conference on Concurrent Engineering

[20] Zhang, Q.Y. & Cao, M. (2002). Business process reengineering for flexibility and innovation in manufacturing. Industrial Management and Data Systems, 102: 146-152

Amy J.C. Trappey is the Distinguished University Professor of Industrial Engineering and Engineering Management at the National Tsing Hua University in Taiwan. Dr. Trappey is an ASME and ISEAM Fellow.

Yong Sun is a senior research fellow at the School of Engineering Systems, Queensland University of Technology, Australia.

Charles Trappey is a full professor of marketing in the Department of Management Science at the National Chiao Tung University in Taiwan.

Lin Ma is a full professor at the School of Engineering Systems, Queensland University of Technology. She leads a research program in Cooperative Research Centre for Integrated Engineering Asset Management (CIEAM) in Australia.