Remote control and maintenance outsourcing networks and its applications in supply chain management

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Abstract

The paper analyzes the impact of e-business technologies on maintenance management and supply chain operations. The aim of this work is to investigate the network organization level of supply chains in case of remote maintenance application and to understand how maintenance policies are coupled with information technology (IT) solutions. To this purpose two literature reviews are presented: firstly, on the supply chain and network integration, and then on the evolution of maintenance using information technology. Following this, the paper present four specific industrial case-studies of eMRO network organisation. They have been chosen as reference models from a set of practical applications and pilot tests performed by the authors in different production sectors in the last 5 years. Technology complexity environments, maintenance outsourcing level, and supply chain integration context are discussed for each case-studies with particular regards to the profitable forms of collaboration provided by the introduction of IT and the Web. This analysis work toward the development of a framework useful to: (1) classify different e-maintenance systems and understand the relationships between the different members of the network, and (2) identify the variables which can influence the introduction and development of the systems.

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1. Introduction

Growing international competition, especially in e-business and supply chain operations, has increased the need for all engineers, managers, and e-business developers to ensure the level of quality, robustness, and efficiency of services by using communication technologies in the most cost effective way. Hence, interest in e-business technologies for supply chain operations has been growing in recent years.

Over the last two decades several business models and supply chain strategies have been developed by companies in various business and IT applications in the hope of responding effectively to customer demand, globalization trends in business, product growth, and acceleration of item obsolescence. The rapidity of both information technology (IT) development and the growth of information on the Internet have forced the pace of this trend, revolutionizing communication and information inside and outside industries. Internet-based services, e-procurement and e-fulfillment solutions, the co-ordination of material and production
flows, are important tools in managing the integration of commercial, manufacturing and logistic activities. The high rate of technological innovation and the need to concentrate available resources on their core skills are forcing many companies to outsource their less important activities as they are carried out more effectively and efficiently by external suppliers.

A new concept, known as integrated value system, is emerging where companies within a shared market segment collaborate on planning, implementing and managing the flow of goods, services, and information along the system so that the value perceived by the customers increases (Dobbs, 1998). The view which emerges from the literature is that improvement in service quality, the need for strategic flexibility, and the focus on core competencies are now becoming predominant concerns in sourcing decisions (Van Laarhoven et al., 1999). DiRomualdo and Gurbaxani (1998) argue that firms use outsourcing commonly based on the following three strategies: business improvement (cost reduction and enhancement of efficiency), business impact (improving contribution to companies’ performance within existing lines of business), and commercial exploitation (focus on leveraging technology-related assets). Examples of outsourcing such as design, manufacture, distribution, asset maintenance, information systems, and human resources can be found in Huber (1993), Campbell (1995), McIvor (2000), and Polo and Piattini (2002).

Today the greater complexity and number of sectors involved have transformed the supply chain into a supply network of interdependent partners, which can be reconfigured quickly to meet the specific customer needs or develop new opportunities in the new markets. The efficiency of the interconnectivity depends on the third-party service providers and the development of strategic partnership between the suppliers and customers in order to on the one hand, improve the service level and on the other hand, reduce costs and shorten the time to market.

In this increasingly competitive environment, many manufacturers heavily depend on the advanced manufacturing technologies and just-in-time philosophy in order to improve the product’s performance (Swanson, 1999; Pham, 2001). The need for a continuous flow forces industry to improve constantly in terms of product quality, operation efficiency, and production capacity optimization. To reach these goals, companies have been actively looking at various ways of outsourcing maintenance activities (Campbell, 1995). However, this process presents organizational, functional, knowledge, and technological criticalities.

Many companies have developed or are developing an e-maintenance system in order to provide a better service to customer’s needs such as: service supplier, service user, and maintenance activities. This paper discusses the impact on the maintenance management and supply chain operations by introducing the IT. The aim of this work is to investigate the network organization level of supply chains in case of remote maintenance application and to understand how maintenance policies are coupled with information technology solutions. To maintain competitiveness companies must reach efficiency in three different but linked directions (Fig. 1): remote maintenance, information technology and supply network integration. This research try to develop a framework useful to study the relationship and links between this three fundamental aspects, which constitute the competitive scenario of a modern industrial plant.

We validate our proposed approach by analysing four industrial case-studies of real-world applications in e-maintenance systems. In particular, the different members of an e-maintenance system, the variables influencing the introduction and development of the system, the effects of these parameters on the relationships between the different members, the supply service structure adopted by the actors of the e-maintenance system, and the different maintenance services offered, are also studied. This paper also discusses some management directions about the best application environments for the e-maintenance systems, the strategies, tactical and operational activities, the benefits and drawbacks of any configuration emerged from the classification of the variables affected.

The paper is organized as follows: Section 2 reviews the literature about the supply chain and network integration. Section 3 discusses the impact of IT on maintenance management. Section 4 studies four industrial e-maintenance applications and Section 5 discusses the results and findings of those case applications. Section 6 discusses the new system classification based on real experience and systems implementation, the
identification of benefits and criticalities, and important suggestions for plant managers. Lastly, Section 7 draws the conclusions.

2. Supply chain and network integration

The market demand variability and the global business environment have seen companies change from using internal optimization based on their own strategy to a more flexible structure linking their own internal processes to both external suppliers and customers in an integrated supply chain. Sharing the information between the parts and the co-ordination of the decisions to reach global system objectives can guarantee the effectiveness of system performance (Forrester, 1958; Clark and Scarf, 1960; Lee et al., 1997a,b). Such co-ordination can be used as effective performance measurement schemes and mechanisms, including price and non-price strategies such as transfer pricing arrangements between sites, performance metrics, and operational constraints (Sahin and Robinson, 2002). Frohlich and Westbrook (2001) analyze the relationship between the manufacturing supply chain integration strategy and operational performance using the International Manufacturing Strategy Survey (IMMS) data from 1998. They identify five types of supply chain strategy, defined by the direction and the degree of partner integration, showing that the greatest degree of supply chain integration is associated with higher level performance.

Integration across the supply chain is achieved by integrating the physical flow from suppliers to customers and the information flow from customers to suppliers. The instruments used in integration include: sharing of planning and control activities (Bowersox and Daugherty, 1995), product postponement and mass customization (Lee, 1996; Lee and Tang, 1997; Garg and Tang, 1997), collaboration with third-party logistic partners (Bowersox et al., 2000; Wong et al., 2000), use of the electronic data interchange (EDI) (Sheombar, 1992; Narasimhan and Jayaram, 1998), and knowledge of inventory levels (Bourland et al., 1996; Gavirneni et al., 1999; Chen et al., 2000; Lee et al., 2000).

In moving toward a network organization, integration and collaboration are complex issues and time consuming tasks but they avoid the continuous emergency and reactive changes required in responding to the market pressure. As a structure network, organization often requires firms to downsize to their core activities and skills, de-layer management hierarchies, and outsource a wide range of activities (Raymond, 1992). The relationship between the actors moves towards a strategic alliance, characterized by the independence of the parties, the sharing of the benefits between the parties, and the ongoing participation in one or more key strategic areas (Yoshino and Rangan, 1995). In a network organization, the firms would prefer to use collective assets and capabilities located at different points along the supply chain rather than hold all the assets in-house for the production of a given product or service (Quinn and Paquette, 1990). While the various components of the network recognize their independence, they are willing to share the information, co-operate with each other, and customize their products and service while each also keep maintaining their position and all their functions in the network (Raymond, 1992). The relationship exists as long as both parties perceive that they are obtaining value, which should be the overall criteria for measuring the success of an alliance, along with the competitive technology, cost, quality, and cycle time (GEBN, 1995). These partnerships benefit from increased market share, inventory reductions, improved delivery service, improved quality, and shorter product development cycles (Corbett et al., 1999). In order to achieve maximum efficiency, these relations, however, require the plain consensus of the parties, clear sharing of the benefits, solicitation of a high-level sponsor inside the company, activity mapping, the use of analysis and redesign tools, and the setting of realistic expectations.

The co-ordination structure of a network organization, where some firms provide services to the other actors, clearly impacts on company performance (Anand and Mendelson, 1997). The fully distributed co-ordination structure, where all data are shared and the decisions are based on both local knowledge and all system data, is better than the decentralized system. This is because the branches in the latter make their own decision using their local knowledge and system data, and it is also better than the centralized system, where the center makes the decisions using all of the system data but none of the local knowledge.

Firms that produce machinery and offer maintenance as an additional service, or firms that make maintenance their core business need in depth knowledge of the network structure, the creation of co-operative relationships with the customers, and the knowledge of asset histories. Maintenance companies need this information to co-ordinate the planning of the maintenance interventions and the level of spare parts inventories. The biggest change that is occurring in maintenance is the introduction of the Internet because it has the potential to change the relationship between the equipment user and equipment supplier (Kennedy et al., 2002). Hence, the use of IT would allow a
greater frequency and the speed of communication, the creation of new business models, and cross-enterprise interoperability (Papazoglou et al., 2000).

3. The impact of information technology on maintenance

The recent rush to embrace computer integrated manufacturing (CIM) has increased productivity further but has also increased the cost in terms of the investment requirements. A failure in a CIM system can cause the downtimes of machines and production and it creates a huge loss of productivity and capital (Lee, 1995). Consciousness of the relevance of this problem has recently pervaded the market because of huge maintenance costs. Several studies have examined both the introduction of various concepts in maintenance (Ashayeri et al., 1999; Wang and Pham, 2003), and recent condition-based maintenance approaches (Li and Pham, 2005). Reliability engineering approaches such as total productive maintenance (TPM) and reliability centred maintenance (RCM) can be applied to improve the plant performance, system availability, systemability, and knowledge of personnel (Persona et al., 2002; Waeyenberg and Pintelon, 2002; Pham, 2005). In maintenance question, and particularly for the policies of intervention, the often implemented corrective philosophy is now flanked by preventive, predictive, and opportunistic strategies (Wang and Pham, 1997). Experience shows that the best policy is generally a mix of these systems (Vanneste and Van Wassenhove, 1995; Li and Pham, 2005). The determination of the correct level of each type of maintenance policy is a challenging problem and remains research questions. A leading solution is proactive maintenance: continuous monitoring of plant degradation, remote monitoring and diagnostic services, and consequent execution of targeted activities (Leger and Morel, 2001). Technological progress in sensors and in communications (the Internet for example) mean problems can be resolved that in the recent past prevented the diffusion of proactive solution (Laugier et al., 1996). In fact, plants can be difficult to control and evaluation of model parameters can be very difficult (Haange, 1995; Fragola, 1996).

In an industrial plant environment, new information technologies not only change the way people work and do business but also how they interact and make decisions. Advanced IT sets the stage for improved communication between plant workers and outside experts, and provides the vehicle for sharing information, knowledge, experience, and wisdom. The technological advances resulting in the highly collaborative design and manufacturing environment is based on multimedia type web-enabled engineering tools and a highly reliable communication system enabling distributed procedures in concurrent engineering design, remote operation of manufacturing processes, and operation of distributed production systems (Lee et al., 2001). Advanced communication supports the team approach to problem solving even though vast distances often separate members. Teams often make better decisions than the same people working independently.

Recent studies and applications of remote maintenance have been developed in high risk sectors including nuclear and chemical fields (Haange, 1995). Remote maintenance was then extended to “capital intensive” industrial sectors. General Electric was as a pioneer in proactive maintenance in large power plants (Rosi and Salemme, 2001; Rotival et al., 2001). The starting point must be the modern idea of a maintenance system: an integrated and organic structure used to analyze all the aspects relating to the technical management of plants, reliability analysis, spare parts allocation strategy, and the training and management of personnel (Ferrari et al., 2001). Remote control offers enormous possibilities in all these fields, benefiting plant managers, plant suppliers, and external companies offering global maintenance services.

Velocity and integration are the main advantages permitted by the Internet and remote control, which in practice leads to a significant reduction in total costs. Improved information technology systems mean productivity and equipment uptime can be maximized. Productivity improvements come from simplifying tasks and using a higher level of automation. Improvements in uptime can result from improvements in understanding the causes of system failure and the affects of unreliability. In an e-manufacturing environment, quality is no longer an option but is a prerequisite for companies to compete in the global marketplace. Smart companies will focus on service innovation and asset optimization for customer intimacy, not just customer satisfaction. In addition, the complexity of today’s products has greatly increased consumer attention on product life cycle cost (Lee et al., 2001). Other benefits also include an improved working environment, better communication, and increased worker effectiveness.

The Internet is an instrument through which value-adding services can be marketed to the customer in order to maintain future competitiveness, and the productivity and quality of these services are becoming a more and more central criteria in the decision making process for the customer (Westkämper and Osten-Sacken, 2000).
The Internet and remote signalling are a very powerful instrument for continuously monitoring both off-line and system online functions as well as having a great impact on the inspection and maintenance aspects. IT can reduce the cost of capturing, saving, and transmitting data to all members of the supply chain organization, making it easier to integrate strategies and performance in manufacturing and services (Frohlich and Westbrook, 2002).

In an IT production context, it is possible to develop a failure database quickly by capturing recorded data, even from multiple locations. A set of optimization algorithms and different approaches can be obtained from this information using the expert systems or neural network approaches (Sandtorv et al., 1996). Moreover, this centralized and continuously updated source of data guarantees maximum flexibility and practical diffusion of knowledge in real time.

Linking business objectives to information systems helps plants understand and improve equipment reliability. The link is not defined by how much data is collected and stored, but by how efficient and effective employees are at using the information to make decisions that affect reliability (Pham, 2003). This new vision makes each modification in the management system of maintenance data very quick and easy: firstly, it is based on the centralized master system, and only secondarily on remote and locally on slaves (Fragola, 1996).

Many companies have found that there is a barrier to accessing the collected data, and combining it with information gathered from other parts of the organization. This new approach offers relevant opportunities for integration between users and suppliers of plants. This innovative link allows rapid direct remote intervention, and can limit intermediate levels in the maintenance structure (maintenance engineer and local technicians) (Lee, 1998).

The heavy data exchange between customer and supplier often suffers delays but can be simplified by means of on-line counselling, remote training, remote management of spare parts, technical support, and purchase orders (Sihn and Graupner, 2003).

4. Industrial applications—case-studies

The critique in previous sections has underlined the importance of maintenance outsourcing as a strategic weapon for improving manufacturing productivity and customer satisfaction in a global scenario of higher speed plant technology. This trend is being imposed by the advent of the Internet and wireless communication technology that means outsourced activities can be managed more efficiently and effectively.

Several Italian companies have become service suppliers by developed e-maintenance systems, utilized by service users, and monitor maintenance activities and skills. In this section, four specific industrial case-studies are discussed and compared. They have been chosen as reference models from a significant set of practical applications and pilot tests performed by the authors in different production sectors in the last 5 years. All the other industrial cases performed by the authors can be easily brought back to one of these four guiding case-studies: (1) a plywood producer who has outsourced maintenance activities adopting remote control; (2) a remote maintenance company that offers remote control and maintenance services; (3) a machine tools producer that has created an Internet portal to offers new maintenance services and to integrate its spare parts suppliers; finally (4) an engineering company that has created a network organization to offer its customers a complete maintenance service.

4.1. Case 1: plywood producer

This is an application of remote maintenance to a “peeling line” for wood panel manufacturing. In particular, the company is the European leader for plywood panel production. The plant considered is located in northern Italy, while the supplier of wet wood is a large north European company. In 2001 the manufacturer accepted an offer from the supplier to adopt remote control and maintenance management of spare parts and continuous training of personnel via the Internet in order to improve the performance of the plant by utilizing the considerable resources of the supplier.

This plant works 16 h/day (on 2 shifts) and has production loss costs of about US$ 750 h⁻¹. Tele-control has requested the introduction of a management system for the installation of new sensors so that useful information signalled from them can be obtained. To achieve the remote check, the fundamental variables requiring control are angular velocities of shafts, temperatures, intensity of currents and vibrations both for machines and for working environment.

The company has achieved integration of the Computer Maintenance Management Systems (CMMS) and the Plant Asset Management Systems (PAMS) in order to optimize the maintenance plan. So the plant technicians are able to notice conditions that request maintenance interventions, to assist in fault diagnosis, and to suggest corrective measures. Moreover, it achieves condition reporting of asset performances by monitoring...
key performance indicators (KPI) and enables the visualization of the actual health-state of the plant. Thanks to the standard technology of the Internet, the system information can also be displayed in an outside environment, such as a remote site.

Operations on hardware entailed a cash flow about US$ 130,200 while the annual fee for the services from the supplier of remote counselling, training, and purchase of spare parts was still about US$ 9,300 year⁻¹.

The analysis of the new system’s work has been used based on the most relevant maintenance factors. In fact, by exploring this kind of maintenance application, the manufacturing company has achieved significant reductions in terms of downtimes, products defects, and spare part inventory costs. This resulted in payback of the investment within 3 years.

Finally, by adopting the management system based on remote maintenance, the manufacturing firm has significantly improved process activity and plant availability, and has even reduced the maintenance budget (Fig. 2).

4.2. Case 2: remote maintenance company

The second case presented in this section is an Italian company that offers remote maintenance for equipment installed by packaging machines producers. The opportunity to start a common service company is studied by producers who lack the resources to offer the service themselves. In fact, the investment is remunerative for a number of controlled machines greater than a “critical mass”.

The companies carried out a preliminary study of 41 potential clients in order to gain their acceptance and clinch pre-contacts. This study aimed at obtaining the participation of prospective customers, and some tests to evaluate benefits, criticalities, and profits in different operating conditions were completed. After this, the resources were designed on the basis of manufacturer experience and from previous marketing analysis. The services offered by the company are: installation and set-up of the system, tele-control of machines, suggestion of interventions, spare parts inventory management, remote training, and where requested, direct intervention (Fig. 3).

The collaborative service offered to potential clients was developed through the following sequential steps:

1. preliminary assessment by the managers of the organizations;
2. analysis of the conditions of use of the equipments and the current maintenance policies used;
3. analysis of the current information system and the available data;
4. analysis of the current maintenance function and the reorganization needs;
5. agree on the KPI to measure performance;

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<tr>
<td>Total hours available (hours/year)</td>
<td>5100</td>
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<tr>
<td>Production losses (hours)</td>
<td>293.3 (5.6%)</td>
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<tr>
<td>Production losses ($)</td>
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<tr>
<td>Corrective interventions by supplier (a)</td>
<td>16</td>
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<tr>
<td>Corrective interventions by supplier (b)</td>
<td>46,370</td>
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<tr>
<td>Corrective interventions by manufacturer (a)</td>
<td>24</td>
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<tr>
<td>Corrective interventions by manufacturer (b)</td>
<td>4,130</td>
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<tr>
<td>Preventive interventions by supplier (a)</td>
<td>3</td>
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<tr>
<td>Preventive interventions by supplier (b)</td>
<td>6,410</td>
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<tr>
<td>Preventive interventions by manufacturer (a)</td>
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<td>Preventive interventions by manufacturer (b)</td>
<td>1,950</td>
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<tr>
<td>Remote interventions by supplier (a)</td>
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<tr>
<td>Total spare parts costs ($)</td>
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<td>Production losses ($)</td>
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<td>Maintenance policies total costs</td>
<td>60,960</td>
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<tr>
<td>Spare parts total costs</td>
<td>35,010</td>
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Fig. 2. Peeling line process diagram of the plywood producer (case 1).
6. definition of indicators threshold value to evaluate the balance of bonus-malus.

The KPI was based on both the evaluation of sharing the benefits of the relationship and on the rapid identification of any deviation from the optimal performance. The definition of suitable KPI and identification of the ideal values are dependent on the specific operating environment of the company. The KPI adopted in the projects are maintenance and operational indicators such as plant availability, percentage of interventions completed as planned, mean time between failure (MTBF) of the parts, number of failures, mean time to repair (MTTR), cost of the annual interventions, and spare parts inventory accuracy. Other indicators are related to economics performance such as costs of quality service level requested or the performance improvement gained from the exploitation of external skilled personnel. The use of the CMMS system means the relationship between the outsourcing processes can be analyzed.

Good results have been obtained from initial applications, bringing about reduction of production losses and overall maintenance costs. The detailed feasibility study showed an initial investment of about US$ 480,000 and an annual cost of about US$ 655,000. Costs for clients are fixed at around US$ 23,000 for initial quote and an annual fee about US$ 27,000. The return on investments period for the service company, based on 41 clients, was only of first 2 years.

4.3. Case 3: machine tools producer

Remote maintenance represents one of the e-industrial services by which a machine tool producer can obtain product differentiation. The company is an important European leader located in the North East of Italy which has recently consolidated its presence in the strategic markets of the U.S.A. and China. The company has developed a project of relationship care in order to improve involvement and management of relationships with customers and suppliers. The purpose of the project is to enable clients to be as autonomous as possible in both ordinary and extraordinary maintenance of machines, and simultaneously to accelerate and to make spare parts delivery more efficient. In fact, the analysis of historical maintenance data shows that many assistance interventions made in the past could have been avoided by managing them through a more structured knowledge-based approach.

The company has created a platform that holds all maintenance data, with a client web interface. IT provides the opportunity to create an information network with low set-up costs and operating costs, providing suppliers with information about customer spare parts requests.
Before the introduction of the application, the after sales customer service took place through immediate telephone assistance without displaying the information to be feedback to the company in a structured way. Recently the progress achieved with technical machines, and the commercial growth of the company have forced the firm to strengthen customer care in a more structured and less expensive way.

The service Internet solution was largely implemented for the purpose of making a knowledge-base available to all customers so that direct assistance interventions would significantly decrease due to the causes of well-known failures being resolved through web-training. With regard to any self-made maintenance intervention, the portal enables customers to order spare parts and to consult any technical information about machines and similar previous interventions.

The company portal is structured in six dedicated sections:

- knowledge-base, contains the documentations of last 3 years interventions;
- technical assistance, for the customer requests for interventions and monitoring progress;
- preventive maintenance, contains maintenance procedures and status of inspections;
- training, includes documentation of information about how to use machines correctly;
- spare parts, where customers can order spare-parts directly;
- supplier, either to make the order directly, or in order for the progress of orders from suppliers to be checked.

The classification of each intervention is based on the following framework: problem category, symptoms, causes, solution, and safety conditions and requirements. Moreover, it is integrated with photos, demonstration videos and attachments.

The portal provides e-maintenance services through the implementation of a remote control system: in particular, it offers machine state control, remote failure intervention, remote support to customer technicians, and pre-assistance analysis. The remote control system is implemented using the followings applications and devices: teleservice, web-cam, black-box saving data, and telemetry devices. Teleservice allows numeric control and PLC of various machines to be consulted via the web, and offers remote modification and update of software when functional degradation occurs. Web-cam, in addition to checking the status and functionality of machines, permitting intervention by supporting customer service counselling technicians. Black-box records any machine operation so that root causes analysis can be used to establish the causes of failures and where the responsibility lies (machine defects or wrong use by the customer) or to use the data to resolve warranty questions.

The benefits that the company has enjoyed through using the web-assistance service are optimization of the customers’ technical interventions, reduction in response time, decrease in the spare parts inventory level, reduction of intervention costs, collection of useful information about the machine utilization and customer behaviour. However, the company has had problems with the new technical application and customers’ approach. In order to cross these obstacles, the company has also provided the customers with a user handbook to support initial training in managing the new web-based assistance relationship.

The benefits noticed by the customers are the reduction of downtime costs, better production quality, lower maintenance costs, higher plant availability, use of best practices, access to important techniques, and access to training information.

Lastly, the portal enables an e-procurement service involving the suppliers, allowing access to real time information regarding orders, supply plans, quality of their supplies, and history of orders. The web-based architecture speeds up the supply process, increases machine reliability, maintenance data of the machines installed can be accessed, without any additional cost for any specific software applications installed or for personnel training.

4.4. Case 4: engineering company

The last case-study describes the application of IT by an engineering company. The engineering company is located in North East Italy and has over 40 years experience in the construction of petrol-chemical plants. It has also developed experience in providing after-sales services such as technical support, training simulator development, and turn around support.

The chemical plant systems, which are becoming more complex due to the enhanced functionality offered, technical progress, and environmental considerations, require skilled personnel who need high level analytical skills and ability to make judgements. The plant owners are trying to rationalise their plant operations by outsourcing the maintenance services in order to focus on their core skills and to keep the number of in-house service personnel down to a minimum level. Remote maintenance in this context offers efficiency, safety, and reliability for the plants,
and is an increasingly challenging business opportunity for the engineering company.

As ever increasing global competition forces the company to turn away from the traditional engineering, procurement and construction (EPC) business sector to a market of complete solutions for customers, the engineering company has had to extend its services to cover the entire life cycle of plants. However, since plants are distributed throughout the world, it is cost effective for the company to extend support services by itself. Therefore, it has decided to rely upon local partners for equipment procurement and maintenance services.

The equipment suppliers have recognized the importance of maintenance services for their products and the creation of a maintenance network system by using local manpower or remote support. When plant complexity is high, maintenance services offered by the plant supplier are limited, hence co-operation with an engineering company has become necessary.

In order to expand its services and offer a complete solution, the engineering firm has decided to develop a business model for after-sales services jointly with two other actors, that is, the equipment suppliers and the maintenance firms, generating a virtual enterprises network. This organization arises out of the business opportunity for all the parts involved. In fact, the engineering firm is offering a global solution for its customers including the equipments project, maintenance services, and personnel training. The plant supplier benefits from the network because it has access to important maintenance data for equipment development and improvement, reducing spare parts inventory level. The maintenance firm can collaborate with the supplier and the engineering firm so that spare parts delivery is more efficient and rapid, failure diagnosis faster, better choice of the maintenance policies mix results, and consequently maintenance costs are lowered.

The network is a temporary business entity established to provide after-sales services to the customers. It represents a global network of logistical services where each partner is an independent entity that provides its core skills and abilities, assuming the responsibility of performing its own tasks. Nevertheless, thanks to an IT infrastructure that allows data sharing and the holding of knowledge in common, the network is able to provide a complete service that cannot be provided by a single actor.

The engineering firm has implemented an Internet portal so that the different partners can be integrated, which all the networked companies can access, and is used for plant monitoring, preventive maintenance, equipment and system performance evaluations, training and knowledge management. The benefits for all the partners derived by the use of the portal are the low cost of implementation and set-up, flexibility, and ease of use. The case-studies have emphasized how new IT facilitates integration and collaboration between firms. The Internet allows the firms to connect much more easily while reducing the costs of exchanging information and increasing the quality of services and quantity of the data exchanged. IT provides the opportunity for growth with the services and offering complete solutions to the customers.

Lastly, this framework enables collaborative manufacturing management, obtains the best performance from the overall system by checking activities and managing key production processes in the network of companies.

5. Analysis and results of case-studies

The four case-studies illustrated above were chosen, as representative guideline, for their different features and numbers of companies involved. Table 1 summarizes the general aspects and results emerging from the analysis of the four case-studies presented in Section 4. The paper work toward the development of a conceptual framework (based on practice and real cases) useful to permit:

1. an easy classification of the eMRO organisation network where you operate and a fast comprehension of the relationships between the different members of the network,
2. a fast identification of the variables which can influence the introduction and development of a particular eMRO organisation network.

Several different companies can be involved along the supply chain in the relationships. The number of partners and the degree of co-operations and integration between the actors can create different structural collaborations ranging from a relationship between suppliers and customers to more complex network organization. The companies involved in this innovative application of IT to remote maintenance process include:

- Customer firm.
- Plant supplier.
- Service maintenance provider.
- Engineering company.
- Spare parts supplier.

The number of partners involved is a function of the production environment complexity, the technology
clock speed, the know-how of the production process, the competitive position of the customer, and the core-business of the customer firm.

The management of the customer firm sees the outsourcing of the maintenance as an opportunity to focus its scarce resources on those activities that are truly core to the business because maintenance is usually not a core business area. However, maintenance organizations have intelligent, hard-working, dedicated people who could implement best practices, but they often spend a lot of time reacting to breakdowns, fixing machines that have gone down, and searching out a part that is needed on a down machine. By outsourcing the maintenance function to the right service provider the plant gains rapid access to all the maintenance best practices. The opportunity for change is almost immediate and integrated with information systems for remote problem solving.

Outsourcing is not the right answer for every maintenance situation. In fact, in the context of low tech equipment and automation, specific equipment developed or engineered in-house, an internal maintenance process is a better solution. The most important consideration when outsourcing maintenance is to focus on change and improvement. An effective outsourcing service provider must be able to establish the culture, attitude, and discipline in the maintenance team that exists in other departments in the organization.

In some cases telemaintenance is a strategic weapon used to improve customer plant performance and
strengthen production management strategies. In fact, the evolution of the industrial market, global competition, reduction of the delivery lead time, price pressure, and the increasing costs of manpower are pushing management to take the strategic decision to delocalize plants. In this situation the remote maintenance service can be an owner resource, totally managed by the enterprise, used in maintenance scheduling, resource allocation, and production management.

On the other hand, remote strategies are very significant instrument for companies that use external services for the service maintenance providers. The maintenance service can become the core business of some companies that offer technological and advanced service for one or more plant suppliers or an independent global service.

The plant supplier is the first actor to offer the maintenance outsourcing service and usually concerns the machines they themselves have supplied. Plant supplier can take advantages of remote maintenance supplying skills and competences to a customer in a rapid and economic way, but can also have strategic data for the design of new equipments and for optimization of spare parts levels.

A great many service maintenance providers have particular skills in different sectors, offering a set of services for similar plants owned by different companies around the world. They offer specialized personnel, specific tools, and best practices to reduce the maintenance costs for the customer firms, which shift the internal maintenance activities towards performance and reliability control. Nevertheless, success comes only when a strong partnership exists between the maintenance service provider and the customer firm.

The generic engineering company can extend its services world-wide to cover the entire life cycle of plants which it project manages. Maintenance of plant floor assets is a critical component of the services offered. However, since plants are often distributed throughout the world, the use of the Internet, web-enabled and wireless communication technology is required so that the equipment can be monitored, analyzed, compared, reconfigured, and sustained by remote. But even though the e-maintenance system can fill the geographical gap between the partners, it would not always be cost effective for the company to extend the support services by itself. Therefore, it could decide to rely on local partners by outsourcing the supply of maintenance services to them.

The parts supplier is involved in the innovative application of IT to maintenance process and manages the spare parts supply via the web by implementing an e-procurement system. This actor assures the speedy supply of the required spare parts for maintenance interventions to the service maintenance supplier or to the plants supplier. In particular, it concerns the procurement of components to be used for company operations, maintenance, and repair (MRO).

Table 1 shows clearly that the results are similar in different industrial contexts and are independent from the number of actors involved. The most important cost reduction is related to plant idle costs. During a feasibility study it could be a problem, because usual this costs is not quantified with the necessary precision. Very important appears the reduction of the order delivery cycle of spare parts and the reduction of the number of corrective interventions. For all the case-studies discussed in this section, the payback period in less than 3 years.

6. The new classification: outsourcing and integration

The case-study analysis have emphasized several variables through which a generic e-maintenance environment can be classified. As discussed in Section 5, these four cases apply IT to the maintenance outsourcing activities in different ways, creating different relationships between the partners and various levels of integration. The case of the plywood producer represents the application of remote control by a plant supplier as a new service for the customer firm, implying a “customer-facing” integration. On the other hand, the remote maintenance company (case 2) shows the application of IT in creating a customer integration, but it entails the establishment of a maintenance outsourcing network through which several supplier companies enjoy a third part collaboration in providing maintenance services for several customers. The third case, the machine tool producer, applies the Internet so that a set of services to customers and suppliers is offered through a web portal leading to complete supply chain integration. Finally, the engineering company case represents the most complex scenario in the e-maintenance environment as it requires the establishment of both a maintenance outsourcing network and complete customer and supplier integration, which are achieved by using the Internet portal.

The real-world case-studies underline two variables from which the application of IT to the maintenance process can be framed: maintenance outsourcing, obtained through plant supplier maintenance outsourcing or maintenance outsourcing network, and supply chain integration, can be classified as customer
integration or complete integration. Fig. 4 shows by the use of a cross matrix the classification of the real cases based on the variables introduced.

To help the comprehension of the potential use of the framework represented by the cross matrix proposed in Fig. 4, two different real examples are proposed:

1. An North-Italian service company leader in the filed of remote maintenance of fuel tanks in petrol stations is connected by a strong partnership with an engineering company (which is specialized in the reclamation procedure design and planning) and with a fuel tanks supplier to provide an efficient global service maintenance to all the Italian petrol stations of the client. This three-partners network organization is actually improved by the use of a web-portal that allows data sharing and the holding of knowledge in common. This case-study can be easily framed by a theoretical approach to the case no. 4 of the matrix proposed in Fig. 4.

2. An European company, leader in the production of elevators and freight elevators provides to its clients maintenance services and offers a full package price comprised of elevator installation and elevator ordinary and stra-ordinary maintenance. This company is connected with a number of different kind of costumers delocalized in all the continent. The use of strong partnerships and co-makerships with spare-parts suppliers and maintenance specialized teams (localized near costumers) improves the whole network efficiency. This company is working toward the implementations of IT solutions in order to reduce maintenance response time and total maintenance annual costs, thus it is moving to reach the reference model of case no. 3 in the matrix of Fig. 4.

6.1. Maintenance outsourcing

The application of IT to maintenance activities facilitates the outsourcing process and makes it possible to offer different levels of service. The maintenance outsourcing shown in Fig. 4 can involve a different number of partners and a variety of IT applications. While plant supplier maintenance outsourcing represents the process by which a set of machines or a whole plant can be remote controlled. Maintenance outsourcing network is a virtual enterprise composed of several members linked together through relationships based on remote maintenance processes.

The differences (emerging from case-studies analysis) between plant supplier maintenance outsourcing and maintenance outsourcing network seems to lie in specific factors in the maintenance environment itself, such as the number of subjects involved in the maintenance outsourcing process, the variety of the services offered, and the technology clock-speed of plants.

Plant supplier maintenance outsourcing is applied in cases involving a small number of actors, where the variety of the services offered is limited, and the equipment is located near the plant supplier. In contrast,
a network develops where there are a large number of subjects involved in the process, highly complex equipment and technology, a fast technology clock-speed, a significant number of different machinery suppliers, and widely distributed plant locations. However, in both cases the choice of a customer firm to implement a remote maintenance system is guided by several business needs, such as a reduction in on-site maintenance requirements, postponement of unnecessary preventive maintenance interventions, increased plant availability, reduction in repair costs, fewer product defects, lower spare parts inventory costs, and access to better skills in real time so that the best maintenance practices can be applied. The advantages for a plants supplier firm are the opportunity to develop new services with enhanced diagnostic capabilities, prolong after sales service to the customer, obtain important data aiding product development, reduce response time, and optimize customer technical interventions.

However, it is clear that the decision to remote control outsourcing is a very significant event that should be evaluated with great care and attention by customers. In fact, the process includes the evaluation of the type of services, format of the relationship, the internal corporate goal, and the control indicators (Haange, 1995; Lee, 1995, 1998; Campbell, 1995; Laugier et al., 1996; Pintelon et al., 1999; Lee et al., 2001). The fundamental question for technical criticalities is the definition of the parameters to be measured, sent, and controlled. This choice usually involves temperatures, velocities, vibrations, levels of torque, as well as electrical intensities, and requires models that link the states of plant to these parameters. However, if the number of sensors increases in order to record information, the same trend can also be expected for the problems related to managing it. Remote transmission systems, the Internet, and LANs involve protocol standardisation, data security, and pre-compression techniques in order to make data transmission less onerous (Lee et al., 2001; Payaro, 2004).

Advanced IT sets the stage for improved communication between plant workers, outside technicians, and provides the instrument for sharing information, knowledge, and experience. Advanced communication supports the team approach to problem solving in enterprises and organizations located far apart. The electronic and information technology must support suitable methods and instruments. A human contribution is still desirable in the subsequent interpretative phase. New technology systems need to enable workers to become more efficient by streamlining current business practices, so there is no improvement if the new technology system does not accomplish this goal. Moreover, an integrated CMMS should be able to provide web-based operator training, proactive maintenance programs, and co-ordination with the other partners such as equipment producers or parts suppliers. Metrics improving the measurement of an outsourced maintenance program might be based on maintenance cost per unit of production.

To summarize, the Internet and other communication technologies can facilitate:

- Remote monitoring, and consequently the analysis of plant degradation.
- Fault notification.
- Remote maintenance intervention.
- Real time on line help and remote counselling.
- Management of spare parts.
- Education of personnel and continuous training.

A common mistake made by the firms analyzed when considering whether or not to outsource maintenance is to focus solely on reducing cost of maintenance. However, the effective maintenance contributes to reduce the overall production costs. Remote maintenance helps maintenance managers to gather information in terms of improving maintenance processes and the availability of production equipment, no longer merely based on the labour cost. Moreover, maintenance should never be outsourced to any service provider who cannot demonstrate a history of collecting maintenance data and reporting performance metrics for the purpose of continuous improvement.

Efficient system performance and the service custom-ization can be obtained by implementing relationship and co-ordination mechanisms between the parties leading to the exchange of high value information, as for example, demand forecasting, production planning, production volumes, and downtime costs. The definition of the road map for the maintenance relationship created, the definition of efficient criteria for measuring the progress of the alliance, the level of data shared, and responsibility for the decisions, are critical aspects in developing the relationship.

There are also some psychological criticalities. Firstly, plant users are still suspicious of maintenance systems that decrease field presence and are based on remote suggestions. Secondly, the same plant suppliers are still reluctant to install sensor on machines. The applications of advanced communication systems promote changes and improve the way workers solve problems and conduct business. From this perspective
the latest positive results in industry will surely be a great influence.

Finally, in all cases responsibility for personnel and safety is one aspect that cannot be outsourced. In fact, while it is possible to outsource the responsibility of asset management and maintenance, there is no way to transfer the responsibility for ensuring assets work safely. Thus, the primary responsibility of managing and attenuating physical asset risks lies with the customer firm. For this reason the owner must keep control of management functions, asset management strategies, maintenance interventions scheduling, and definition of intervention methodology by respecting all safety proceedings and measures. Furthermore, in fields connected with remote asset maintenance, the contractor must apply strict controls, guidance, and evaluate the provider’s activities and performances.

6.2. Supply chain integration

New developments in IT are facilitating connection of members in a supply chain. The advantages of the Internet such as global interconnectivity, ease of use, low set-up costs, result in different organizations being able to integrate with each other.

Nowadays the main difficulties in integrating the customer firm and the plant supplier or the maintenance company are not found in technical aspects but in co-ordination, definition of useful performance measures, defining correct indicator values, and monitoring of plant performance. The key performance indicators are usually specific maintenance indicators (for example, plant availability, accuracy of the planned budget compared to actual performance, percent of corrective preventive interventions), and variables relating to warehouse management and system safety.

Integration means the customer companies can use high-level expertise developed by outsourcers in different plants, thereby optimizing performance and costs. Service maintenance providers obtain concentration and scale economy by offering their service 24/7, useful to customers in terms of knowledge and costs. In other words, in global service conditions customers buy a completely integrated and customized maintenance service at a fixed level of availability and productivity of plants (Campbell, 1995).

The supply chain integration variable, shown in Fig. 1, measures the physical and information integration with the customers in an e-maintenance environment, creating customer integration and also integration with the suppliers, leading to complete integration. The customer integration configuration only represents a way of exploiting the Internet and IT potential in the maintenance outsourcing approach beyond the supply chain. In fact, this kind of integration provides the customers with an e-maintenance common platform, a user interface for data sharing, continuous training of personnel via Internet, remote control, and equipment maintenance.

The plant suppliers or the service maintenance provider introduce new services into opportunity market spaces that strengthens the relationships with customers through complete integration, and provide better plant performance for the customer firms.

The benefits for the customer firm derived from integration with the plant supplier or the service maintenance provider are better product quality, higher production throughput, reduction of overall costs, lower stock of inventory, better predictive ability of equipment, less unscheduled downtime, and improved overall availability. The benefits for the customer firm from integrating into a network system are fewer breakdowns, improved reliability due to better quality maintenance and service equipment, creation of new services, reduction of the response time, gathering of useful information about machines and customer behaviour, and fewer customer complaints. The advanced communication technologies allow team members, who are often separated by distance or time and frequently working in scattered locations or on different shifts, to work together thereby enhancing personnel skills through increased use of technology.

In the case of complete integration with customers and suppliers, it is useful to implement an Internet portal so that new e-maintenance services can be carried out. The portal represents a service platform that holds all maintenance data and makes sharing data available to all the partners involved in the network. In fact, in the real time maintenance environment, the reliability, the punctuality and the relevance of shared information are critical elements that affect the development of the maintenance processes. However, experts need to be on site to add valuable input to problem resolution, which allows teams of experts to work together to find the best solutions to problems. Today, many companies are trying to establish a team environment for more effective information sharing and problem solving.

The relationships between the partners in the cases analysed are defined in a contract, divided into an administrative part and a technical one. The first document formally defines the conditions and rules that govern the relationship, while the second defines the maintenance statements and the levels of performance, even describing any provisions for terminating the
contract at a later date. In this context the relationship has to be based on a service-level agreement (SLA) that represents a mutually agreed view of the service specifications, the day-by-day activities, and the development of the relationship. In fact, in the maintenance outsourcing relationship the desire to dump the maintenance problems on the outsourcing provider is a guaranteed formula for failure. A true partnership relationship between the plant and the service provider based on mutual trust must be well understood. In addition, it is important for the service provider, and for all their personnel, to be viewed as part of the plant team.

Even if this kind of contract calls for the spending of considerable amounts of time and the making of great efforts, the connected risks to the parties are reduced and trust in the relationship is created. The service provider should take part in plant social activities, be included in plant communications, and also participate in safety and other training programs.

7. Conclusions

Reviews in the literature show the importance of maintenance outsourcing as a strategic weapon to improve manufacturing productivity and customer satisfaction in a global scenario of faster plant technology. This trend is being reinforced by the advent of the Internet and wireless communication technology that mean the outsourced activities are managed in a more efficient and effective way. This research try to study the relationship and links between this three fundamental aspects, which seems to constitute the new competitive scenario of a modern industrial plant: remote maintenance, information technology and supply network integration.

The paper work toward the development of a framework of the main e-maintenance network systems as a function of maintenance outsourcing and the degree of supply chain integration. The research and findings presented in this paper are based on a significant set of real industrial cases performed by the authors in the last 5 years and summarized in the paper with four case-study, chosen as reference models. The case-studies differ in terms of production and market sector, number and typology of the members involved in the system, complexity of the technological environments, typology of Information Technology adopted, level of maintenance outsourcing, degree of integration with customer firms and plant suppliers.

The research emphasized how new IT facilitates integration and collaboration between the firms involved in the e-maintenance system: the customer firms, the plants suppliers, the service maintenance providers, the engineering companies, and the parts suppliers. IT provides the opportunity to offer the customers new services and complete solutions. The number of partners, the outsourced solutions, and the degree of co-operation and integration between the actors create different structures of collaboration, ranging from a supplier–customer relationship to a more complex network organization. The network develops where many subjects are involved in the process, there is a high degree of equipment and technological complexity, a fast technology clock-speed, a significant number of different equipment suppliers, and widely distributed plant locations.

Finally, the study emphasizes the new business opportunity provided by e-maintenance systems as well as the benefits and criticalities resulting from their introduction and development. The positive industrial results and findings presented in this paper may give plant managers important ideas and theoretical guide lines.

References


