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Enhancing On-Site Maintenance Execution with ICT – A Case Study

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Abstract: Information and communications technologies (ICT) can be used to improve the efficiency of field service processes. The role of ICT in assisting the planning process of preventive equipment maintenance has been abundantly discussed in the literature, but the actual on-site maintenance execution and the value of information have escaped the attention of most researchers. This gap in research has been pointed out by a few authors [4][25]. Due to the scarce literature on ICT support for maintenance operation execution, we pose the following research problem: How can maintenance execution be helped with better information? This problem is approached by examining how the unavailability of information does affect maintenance execution performance, and what the most often required pieces of information are.

This study includes a literature part and a case study. In the literature part, we first examine the maintenance environment where breakdown maintenance policy and field service are distinguished as the most challenging environments in terms of managing equipment down-time. After that, we examine equipment down-time and uses of ICT systems in accordance with a framework for the components of defect rectification time that is built upon a model according to Knotts [21]. In the case study, we examine the service company network of a Finnish capital goods manufacturer. We use interviews, survey of service companies, and data analyses to examine the case in accordance with the framework developed in the literature part.

The study revealed that about 40% of the failed service visits are caused by the unavailability of information. In addition, almost a third of the service visit's duration is used to inquire for equipment details and to diagnose the problem. We conclude that better information would increase the service call success ratio and would cut down the duration of the on-site service operations.

Keywords: SCM & E-logistics; Case study in E-business.

I. Introduction

The benefits of information and communications technologies (ICT) in maintenance services are widely recognized. As early as in 1988 Ives and Vitale claimed that ICT could be a significant factor in leveraging investments in maintenance and in directing a company's overall approach to the maintenance issue. More recently, Agnihothri et al. [4] among others have pointed out the usefulness of ICT in maintenance. In the literature of ICT facilitated maintenance, the focus seems to be on the sophisticated maintenance solutions, such as condition-based maintenance [18][34], problem diagnosing tools [18][28] and life-cycle information acquisition [25][30][31]. While the value of these sophisticated systems must not be understated, we find it surprising that the information needs in performing the actual service operations are scarcely addressed in the literature. Marsh and Finch [25] have pointed out the same issue by claiming that there still are problems in providing the basic product information for the service personnel. We argue that this is a notable deficiency since the on-site operations are the most critical element in providing effective field-service. Whether the service call is triggered by the decreased condition of the equipment, a maintenance schedule or an equipment breakdown, it always comes down to fixing the problem on-site. Moreover, the on-site operations are the most visible element of field-services for the customers.

Based on a survey of field-service companies in an industry of electrical investment goods, we present effects that information availability has on field-service execution in terms of service call accomplishment ratio and on-site time usage. Our research problem is how maintenance execution can be helped with better information. The paper is structured as follows. In the first part, we discuss relevant maintenance literature addressing maintenance policies, equipment down-time and information needs in maintenance operations. In the second section, we give the research design of this study. The third part presents the results of the study, followed by discussion and further research suggestions.

II. Literature Review

First, we give background and motivation for studying and developing maintenance operations. We do this by analyzing maintenance policies and presenting the restrictions in their

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applicability. In the second section we exhibit a framework for analyzing service operations in terms of process steps and the possibilities of influencing the steps with better information availability. In addition, reported ICT tools for maintenance operations are reviewed in light of the framework.

II. I Maintenance Environment

The primary objective of equipment maintenance is to preserve system functions in a cost-effective manner [34]. Under this general goal, different parties have their own objectives for maintenance and that is why maintenance performance should be measured from several viewpoints. Consequently, maintenance performance measures can be divided into three common categories [33]: equipment performance, cost performance, and process performance. From the equipment user's viewpoint, the most important goal of maintenance is to minimize the down-time of equipment. This is the equipment performance standpoint. For a manager of a maintenance organization, the interests are also in maintenance costs and efficient execution of the maintenance process. These represent cost performance and process performance standpoints. In this paper, the focus is on maintenance process performance since it delineates the maintenance execution performance. In addition, improving process performance typically enhances also cost performance and equipment performance and is therefore a very important measure for a field-service organization.

The objectives of maintenance can be pursued using different maintenance policies which all aim at reducing the equipment down-time. These policies can roughly be divided in corrective maintenance and preventive maintenance. In the former case, maintenance operations are carried out after an equipment failure has been identified, while in the latter group the goal of operations is to replace equipment or return it to good condition before failure occurs [15][34].

Preventive maintenance methods are further divided to scheduled maintenance methods and condition-based maintenance methods [36]. Scheduled maintenance is achieved when maintenance tasks are performed following a time or usage based schedule. Optimal schedules can be determined using quantitative decision models, but usually they are only drawn up on the supplier's recommendations on mean failure times [15][34].

Condition-based maintenance (CBM) is a more sophisticated type of preventive maintenance. The condition of the item is monitored continuously or intermittently to carry out preventive maintenance actions only when failure is judged to be imminent. Thus, replacing or servicing equipment prematurely can be avoided. Decision when the maintenance task is carried out is made based on the condition monitoring techniques, as vibration monitoring, process-parameter monitoring, thermography, and tribology [34].

However, despite that the preventive maintenance policies are designed to reduce the number of equipment breakdowns and reduce the uncertainty of down-time by planning in advance, equipment breakdowns cannot be totally eliminated.

First, there are trade-offs between the costs of scheduled maintenance or condition monitoring and the costs of a breakdown. The aim of maintenance policy selection is to find the most cost-effective strategy [24][34]. When striving for optimal maintenance costs, different parts of a production facility most likely require different maintenance policies [36], thus potentially leaving some equipment to be serviced only in cases of breakdown.

Second, breakdowns cannot wholly be eliminated with preventive maintenance measures. Scheduled maintenance is often based on either measured or supplier specified equipment mean-time-between-failures, but in reality the failures take place at random times, and therefore breakdowns will at times happen between scheduled maintenance actions [27]. Also, with condition-based maintenance it is to be noted that no inspection or monitoring can be 100% effective, as the condition needs to be identified correctly, and the symptoms of a failure are not always noticed [13]. Further, the opportunity window between the emergence of abnormalities and consequent failure may be too short for the symptoms to be recorded in an inspection or monitoring process [27].

Third, the implementation of sophisticated maintenance strategies can be difficult in companies with established maintenance traditions. A study of four manufacturing firms in the UK indicated that in practice many advanced maintenance philosophies are not adopted fully in organizations, as the service technicians may remain unfamiliar with the concepts. As a result, planned maintenance activities give way to short-term needs of keeping the plant running, which results in firefighting activities and breakdown maintenance [12]. Thus, corrective maintenance in the form of breakdown repairs is not always a deliberate choice, but rather results from ignorance towards maintenance planning [16].

As we presented, equipment breakdowns cannot be totally eliminated. What makes this notion important is that down-time is especially problematic for equipment that relies on corrective maintenance or otherwise breaks down. First, such equipment easily experiences a longer down-time than equipment with preventive maintenance, which is demonstrated in the following section. Second, the resulting unplanned down-time of equipment is far more costly than planned stoppages due to loss of committed production, decrease in quality, and inefficient use of facilities, equipment and personnel [7]. Examples of down-time costs per hour have been quoted as 1.000 EUR in the energy industry to 13.000 EUR in the chemical industry [24]. Due to these reasons, reducing down-time for equipment breakdowns is especially important.

Before examining the components of down-time in detail, we present the concepts of field-based and facility-based maintenance that also have an impact on the down-time components. In field-based maintenance i.e. field-service, it is the responsibility of the service provider to perform maintenance operations to the equipment located at a customer's site [4]. The opposite approach is facility-based service, where customers access the service facility [4]. In this study, we focus on one sub-category of field-service that is after-sales service support. Agnihothri et al. [4] point out that after-sales service support is the most problematic in terms of down-time. For companies engaged in after-sales service support, it is important that they manage both service response time, i.e. time it takes to access the service site, and on-site time, i.e. time it takes to carry out the on-site operations.

To summarize the main findings, it seems that in terms of maintenance policy, it is corrective maintenance that poses the greatest challenges for managing equipment down-time. In addition, the most challenging type of field-based maintenance, in terms of down-time, is after-sales service support. The case study presented in this paper comes from an environment where both of these challenges are realized, and therefore it provides a good research platform to study this phenomenon.

II. 2 Equipment Down-Time and Uses of ICT Systems

According to Knotts [21], the time it takes to rectify a defect consists of four main phases: identification that a problem exists, gaining access to the equipment, diagnosing the problem and locating the cause, and taking necessary corrective action. Knotts argues that there are differences in the predictability for the durations of the different steps of defect rectification time. He explains that time covering access, defect rectification, and test and close up can be forecasted based on either experience or predictive techniques using time standards. On the contrary, the problem identification and fault diagnosing times are difficult to predict. Knotts argues that the unpredictability arises from non-standardized procedures and lack of time prediction techniques covering fault diagnosis and isolation. His presentation of down-time is especially useful, when evaluating the impact of different ICT systems on the maintenance execution process.

The context where Knotts applied his framework was that of facility-based maintenance [21], where it is possible to warehouse scores of spare-parts as back-up and have a variety of tools and documentation available at the service facility. This is not possible in field-based service, which makes it necessary to prepare in advance for the operations [8]. Consequently, we add an additional step "preparation" and a possible return loop that results from failure to deal with the defect (Figure 1). The importance of this addition is highlighted by statements that the probably most typical problem in field-service is not having the correct spare-part available on site [26]. For comparative purposes between maintenance policies, we also distinguish between three different initial stages for the defect rectifying process (Figure 1). Next, the information needs and utilization of ICT in different phases of the maintenance process is examined through a review of reported ICT systems. In general, it seems that the ICT solutions in field-service have not been the focus research area of academics. Nevertheless there are reports of maintenance support systems used in various field-service organizations published mainly in non-academic trade journals. This literature review aims at enlightening the different kinds of maintenance support tools that are adopted in field-service, but it is not intended to be inclusive. Appendix 1 summarizes the example cases of ICT tools used in the field-service execution.

II. 3 Problem Identification

The uncertainty for the duration of the first phase, problem identification, relates to the need of timely and correct information that the equipment is performing at an unacceptable level. For equipment run under breakdown maintenance policy, the problems are identified after the failure has occurred and the down-time timer has started ticking. This does not hold true in preventive maintenance where the problem identification is carried out using non-intrusive techniques while the equipment is operational or during planned stoppages, thus the time required for identification does not result in additional and unexpected downtime for the equipment.

The most typical ICT tools in the failure reporting and confirmation phases are condition monitoring tools. These facilitate automatic identification of the occurring and upcoming problems and thus reduce the uncertainty related to the prediction of the duration of these phases. The earliest case-reports come from the 1980's and the reported utilization cases of condition monitoring and CBM have become more frequent since. Today, condition-based maintenance encompasses several techniques and it is used in various industries including automobile manufacturing [3], power industry [2][23], aircraft engine maintenance [22], and ship engine maintenance [19]. There is some variation in the terminology of the CBM systems, for example term *Built-in-test-equipment* (BITE) is commonly used in the aircraft industry [20], but the operating principles are the same.

II. 4 Preparation

The preparation step is critical for successful accomplishment of a service call, especially in field-based service. The objective of this phase is to ensure that the correct maintenance resources, the required documents and spare-parts, and the subject of maintenance operations i.e. the equipment will all be available during the service visit. Inadequate preparation may denote that the service technician is unable to rectify the defect, which leads to a failed service visit and a need for a follow-up visit, indicated as the return loop in Figure 1. In facility-based maintenance [4], the role of the preparation phase is less important, since the maintenance resources, documents, spare-parts, and subject of maintenance are all located in the service facility. If a service call cannot be accomplished in facility-based maintenance the servicing is postponed but there is no need for additional preparation and access gaining phases.

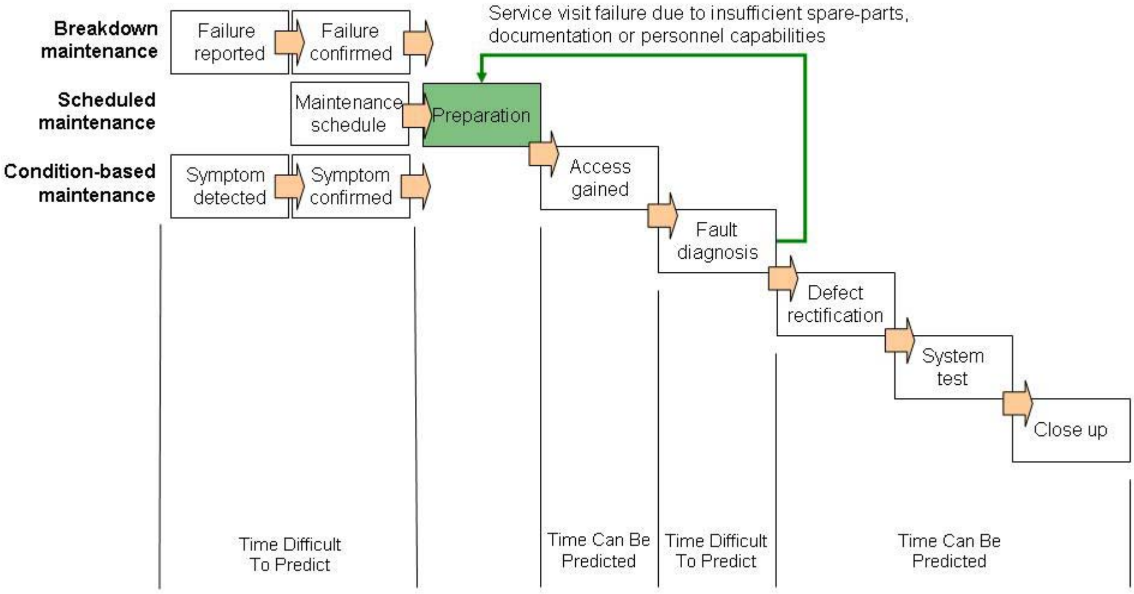

FIGURE 1COMPONENTS OF DEFECT RECTIFICATION TIME (APPLIED FROM KNOTTS, 1999)

The effectiveness of the preparation phase depends strongly on the advance information available on the identity of the equipment and the type of failure. Identifying the equipment based on e.g. its model or serial number allows the selection of the right kind of maintenance resources, spare-parts, and documentation for a service call. Advance information on the failure type may make this more efficient if the possible problem can be hypothesized.

The amount and quality of advance information varies among the maintenance policies. In breakdown maintenance the available information is most uncertain: the identity of the equipment and description of the failure rest on the expertise of the person reporting the failure. With scheduled maintenance, the service technician knows the identity of the equipment, but there is no information available on the equipment condition. However, in scheduled maintenance there typically are predefined periodic maintenance tasks that are to be carried out. For example, in case of elevator maintenance, the periodic maintenance tasks may include adjusting equipment, examining and repairing or replacing worn components, and lubricating parts and cleaning certain areas [9]. The periodic maintenance operations can be used to determine the necessary tools and the spare-parts most likely needed. In principle, the situation is best when using condition-based maintenance where the equipment identity and symptoms are known in advance and thus the failure type can be hypothesized.

Besides the condition-monitoring devices listed above, the ICT tools designed for the preparation phase assist in ensuring that the correct maintenance resources, the required documents and spare-parts, and the subject of maintenance operations will all be available during the service call. Xerox has been reported to use a system telling which spare-parts will the most likely be needed during the service visit [18], and thus reducing the number of return visits and increases field-service function’s efficiency. One example of preparation in facility-based maintenance is a system that determines spare-part needs for a damaged ship-engine, identifies the nearest repair facility, and guides the ship crew to prepare the engine for the repair [18]. Preparation can also be done for the follow-up service visit if such is needed. For example, Sears Roebuck & Co. is using a wireless support system to order a spare-part and schedule a second visit for the service technician to install the part [6]. This kind of system provides assistance when it is not possible to predict the spare-part needs before the service technician analyses the problem on-site.

II. 5 Gaining access

The next step in the defect rectification classification is gaining access to the equipment, which in field-based service is carried out so that the service technician moves to the equipment. In this phase, the service technician needs to know where, when and how the equipment should be accessed. In principle, the selected maintenance policy does not affect the access gaining phase. Instead, service response times are typically determined in maintenance contracts and service-level agreements (SLA) [35].

The ICT solutions available for the access gaining phase are related to routing the service resources. The most modest systems provide service technicians with information on available service calls [14]. In order to gain scale benefits, the systems can be used to route the field-service workforce more efficiently to complete more service calls a day. Several example cases can be found for using wireless field-service support systems for routing and service call management [6][9][32]. The factors considered in assigning routes can be geographic proximity, technician workload, necessary skills, and customer relations [9]. One significant benefit of these systems is that the service technicians can acquire new job orders online, without returning to the workshop, which increases service responsiveness and efficiency. Because a routing system can take into account the skills of the workforce, they may also assist in correct preparation.

II. 6 Diagnosis

The fault diagnosis phase aims to identify the problem and determine the required corrective actions. It is an information intensive phase, where maintenance technicians traditionally rely on technical publications for information covering fault diagnosis procedures, configuration details, and functionality descriptions [21].

There are some reports on ICT tools used in the fault diagnosing & isolation phase, which aim at aiding the service technicians to locate the problem quickly and properly. Automatic failure diagnosing tools take symptoms and some other parameters as input information, and based on a knowledge base, suggest what the probable failure reason is [18]. In addition, there are tools to provide the service technicians with information that might help in them decision making [25][37]. The pieces of information that seem to be valuable in the fault diagnosing & isolation phase are service history for the serviced equipment, service call reports for similar cases, and schematics [6][25][37].

II. 7 Failure loop

The fault diagnosis phase continues with defect rectification step. However, it might turn out that – for a reason or another – the service technician is unable to rectify the defect and has to return with the proper utensils to access the equipment again (indicated as the return loop in Figure 1). This increases the need for accurate information for service personnel to ensure they have all the necessary documentation, tools and parts with them for the first time. It is especially critical in breakdown maintenance, where the down-time continues if the first service visit fails. In addition, an unaccomplished service visit decreases customer satisfaction, and a follow-up visit to the facility decreases operational efficiency of the maintenance personnel. It comes as no surprise that reducing the requirement for repeat or follow-up service calls has been commented to be one of the largest cost-saving opportunities for companies engaged in field-service [10].

II. 8 Rectification and reporting

The final steps are defect rectification, system testing and close up. These steps include adjusting, repairing or replacing equipment and ensuring that the resulting configuration is operating as it should. Finally, the required documentation, e.g. service report and invoice, is produced. [21]

The supporting ICT tools include means for accessing technical documentation in electronic form and for generating service reports and invoices. The productivity improvements in defect rectification from having technical information available via a wireless computer compared to paper-based systems may be significant, since all the information can be accessible through one interface. In the case of SkyWest Airlines Inc. [29], this time saving was anticipated to be as much as 1,5 hours a day for one service technician. The role of accurate information in defect rectification is emphasized by the fact that there are reports on maintenance induced failures, where subsequent equipment failures have been pinned down to be caused by mistakes of service technicians due to lack of information on correct procedures and parts [13].

Finally, during the system testing and close up phases, the most important tasks for the service technician are to make sure the equipment is in order, and to invoice the customer. Automatic diagnosing systems and condition monitoring tools may help the service technician in the system testing phase, but there seems to be no case examples in that area. However, automatic test equipment have been reported to reduce test times by more than 60% in factory production environment [17], so evidence for increasing testing efficiency with ICT tools exists.

In field-service context, there exist reports on ICT tools for creating and managing service reports and invoices. Brown [10] and Albright [5] stress that by using wireless computers to create the service reports on-site it is possible to reduce the amount of paperwork and improve data accuracy. In addition, one significant benefit of making the invoice on the site is that the payment cycle starts immediately.

As a conclusion from the down-time examination, the down-time of equipment is likely to be the longest with breakdown maintenance, and the information for identification and rectification the scarcest. While condition-based maintenance is designed to inherently provide the best information to carry out maintenance operations effectively and efficiently, there is no reason why information availability should not be secured for less sophisticated maintenance approaches, especially as shown, it is not possible to completely avoid breakdowns.

Summarizing the ICT review, there clearly seems to be indications that ICT can provide great assistance to the different phases of field-service execution. The exemplary ICT use cases are summarized in Appendix 1. Unfortunately, it seems that the support that ICT might give to the effectiveness of field-service operations has been scarcely studied [4]. Especially the magnitudes of the impact or the types of information making the impact have not been evaluated. Understanding the potential implications and sources of impact is especially important in the evaluation of the feasibility of different ICT systems, and therefore we address this as a notable gap in the literature.

III. Research design

Despite the reported ICT solutions, the implications of information availability in maintenance have not been addressed in such a level that it would be possible to assess the benefits of implementing ICT solutions. Therefore we pose the following research problem: How can maintenance execution be helped with better information? To approach this problem, we seek for answers for the following research questions:

How does the unavailability of information in field-service affect maintenance execution performance?

What are the most critical pieces of information required in different process phases?

The purpose of the first research question is to determine how big performance efficiency losses the unavailability or incorrectness of information may incur. The efficiency losses will be quantified in terms of service call accomplishment ratio and service visit time usage. With service call accomplishment ratio we mean the share of service calls that are accomplished during the first service visits. The second research question seeks to define the unavailability of which particular pieces of information is causing the problems. That way it is possible to give recommendations on how the information availability could be improved.

As was discussed before, breakdown maintenances and field-based maintenance service form a challenging environment where the requirements for information to manage and reduce down-time are high. On the other hand, such an environment provides a good research platform to study how maintenance execution can be helped with better information, and thus our study was conducted with a manufacturer whose service company network is operating in such a challenging environment.

The focal case company of the study is a capital goods manufacturer. Its customer base includes hundreds of companies of various sizes who utilize the case company's products in their own operations. In practice, the equipment manufactured by the case company are located in customer sites scattered to various locations.

IV. Research Methods

The study included interviews, a survey, and database analyses. The case setting was first studied in detail with initial interviews including 14 interviewees at the focal company, 3 interviews with service companies, and 2 interviews with customers of the focal company. Most of the interviews were performed with two researchers to guard for interviewer bias by allowing comparisons of interview notes and perceptions. After agreeing on all interview items, the interview memorandums were stored in a case study database for easy later access.

To answer the research questions, we performed an industry-wide survey of maintenance companies. The initial interviews with representatives from the manufacturer, maintenance companies, and customer organizations were used as input while designing the survey questionnaire. The survey was targeted to the service company network of the focal capital goods manufacturer including 56 service companies with a geographical coverage of the entire Finland.

The questionnaire used in the survey consisted of open-ended questions and multiple choice questions which were used to collect both qualitative and quantitative data. The questionnaire had two main parts. The first part concentrated on the service operations and the implications of poor availability of information. The second part aimed to solve what information would be needed for better operations. Before launching the survey, the questionnaire was tested with three service companies whose feedback was used to reform the questionnaire. Each company was contacted by phone beforehand and the questionnaire was delivered by mail, e-mail, or fax, based on each the respondent's preference. All non-respondents were contacted again after the initial deadline for returning the questionnaire. The response rate turned up to be 55% with 31 responses, and the respondents were mainly service managers and company owners.

The respondent companies diverge, to some extent, in terms of their scope of servicing activities and the company specialization. The respondents are mostly small companies with only a few service technicians; 75% of them have from one to three service technicians, while the largest respondent has from 50 to 80 service technicians. Respectively, the number of service calls the companies are managing per week is quite modest: 64% of the companies have ten or less service calls per week and the median number of service calls is eight. 14% of the respondents have over twenty service calls per week. In addition to the differences in the scope of the servicing activities, some of the respondents seemed to be focusing on other lines of businesses than field-service of the focal type of capital goods. Based on the survey, servicing is an important of very important line of business only for 71% of the respondents. Some of the remaining 29% respondents informed that they were mainly involved with the installation works of the capital goods.

After the survey was carried out, the results were validated in discussions with experts from the manufacturing company, and compared with warranty invoicing data from the equipment manufacturer where applicable. All the service invoices and reports from a five-month period in 2004 were analyzed, including 83 invoices from 23 service companies.

V. Results

V. 1 Introduction to the Case Company

The equipment manufactured by the case company can be divided into two categories which in this study are called small-scale and large-scale products. The large-scale products are fixed equipment which are fitted to a particular site and have a large capacity. On the contrary, the small-scale products have a smaller capacity but they are not fixed and thus can be transferred to another site if required. In addition, the large-scale products can be equipped with electronic controller systems that enable remote diagnostics and condition-based maintenance functionalities.

Based on the initial interviews, it was identified that the most used maintenance method in the examined line of business is breakdown maintenance, i.e. the customer site personnel order a service after the equipment is not working properly. Therefore, the context of this case setting enabled us to examine the effects of the unavailability of information in an environment where the maintenance execution is highly time-critical. In some individual situations, there is a maintenance agreement between the customer and a service company, where condition-based maintenance or scheduled maintenance is practiced, but this is more uncommon.

Next, the typical maintenance process in context of the case is examined following the components of defect rectification time.

V. 2 Problem Identification Phase

According to the interviews, the defect reporting and confirmation phase is carried out following one of the three possibilities in Figure 1. The most common means is breakdown maintenance, where plant personnel observes that the equipment is not working properly. After that, a service is ordered either by contacting the equipment manufacturer or by contacting a service company. In some cases, a customer plant and a service company have signed a service contract which obliges the service company to regularly, e.g. once a year, service the plant equipment. This is scheduled maintenace, but it is rather rare in the examined industry. The third possibility is condition-based maintenance, where automatic condition monitoring devices set off an alarm that notifies the plant personnel of improper operation. In addition, the service companies have the prospect to take a remote connection to the plant's condition monitoring system in order to gain run-time information of the equipment in the plant. This is, of cource, possible only if both the plant equipment are connected to the remote monitoring system and the service company has the required terminal equipment.

In the interviews, the service technicians commented that by using the remote condition monitoring system, the upcoming problems may be recognized before the breakdown occurs. Therefore, in the examined case, it seems that information on the condition of the equipment i.e. pressure and temperature readings provides great assistance to the problem identification phase. The survey was used to determine how often this information is available. Based on the answers, 41% of the service companies have access to remote monitoring information. For two companies, this information is available for over 70% of the equipment serviced, and for the rest of the companies gaining this information, it is available from 4% to 25% of the equipment serviced. As a result, despite the value of remote monitoring information, it seems to be available not too often. In addition, for the equipment not under condition monitoring, the unavailability of information on the failure leads to longer downtimes by increasing the problem identification time. Nevertheless, the defect identification time is not included in scope of the study, as data on the duration of this phase should be interrogated from site owners that could not be included in the study.

V. 3 Preparation Phase

The second step in the defect rectification process is preparation. According to the interviewees, this means that the service technicians load the necessary spare-parts and documents to the service vehicle when leaving from the workshop. As was discussed before, this is a highly information critical phase where gaining advance information on the identity of the equipment and the type of failure are important for effective and efficient preparation. However, based on the survey, there seems to be inadequate data available in this phase. By using the survey, we determined what advance information the service technicians currently have for preparation.

In addition to remote monitoring information, one information source is the customer who orders the service. In the survey, we enquired how often different pieces of information are gained from this source. We found out that information on the type of the product, i.e. whether it is a small-scale or a large-scale product, is acquired the most often, in 66% of the service orders. Description of the failure is gained in 51%, and equipment's manufacturer in 44% of the service orders. Other information pieces are gained much less frequently. Information on the equipment's service history, previously installed spare-parts, and model are gained in about every fifth service order, and equipment's serial number is gained less than in every tenth service order.

The third information source in the preparation phase is the service companies' own records. In the survey, 71% of the companies responded to hold paper records and 11% responded to hold electronic records on equipment locations. Especially the companies that have installed 40% or more of the equipment serviced were all holding records on equipment locations. In principle, these records could be used to identify the piece of equipment to be serviced and thus help in effective preparation, but the research material gave no indication of this. The companies holding records on item locations were not showing better performance than the companies not holding records.

As a result, identification of the equipment to be serviced can take place based on remote monitoring information, customer information, or companies' own records. However, it seems that not one of these means can provide comprehensive information in all situations, or even used together, identity of the product serviced remains a mystery in the preparation phase. In addition, only remote monitoring can provide the technicians with accurate advance information on the condition of the equipment, but this information is gained quite seldom. The implications of inproper preparation can be detected in the later steps of the maintenance process.

V. 4 Access Gaining Phase

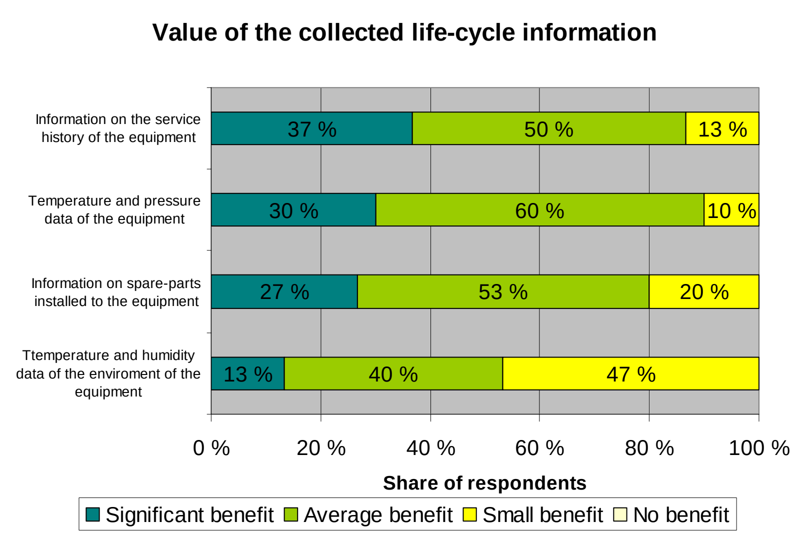

FIGURE 2 THE VALUE OF INFORMATION IN SERVICING OPERATIONS

The third component of the defect rectification process is gaining access to the equipment. In practice, this means that when the maintenance resources are available, a service technician drives to the customer site with his service vehicle and locates the equipment to be serviced. In the examined field-service organizations, this time depends on the service level that the companies are offering and it is agreed upon in the service contract. The response time is regulated also by the service pricing so that the service visits that are carried out during nights and weekends are more expensive than the ones during the office hours. Since the duration of gaining access is controlled by contractual issues, it is not relevant to examine in this context the effects of unavailability of information to the performance of gaining access to the equipment.

V. 5 Diagnosing Phase

After arriving at the customer plant, the service technician seeks to isolate and diagnose the fault. This is an information intensive phase and in addition to doing the diagnosing activities, the service technicians need also to acquire information to support the problem diagnosing. The duration of this phase was determined in the survey by inquiring the average on-site duration of a service visit and the share of on-site time used to problem diagnosing activities, problem fixing activities and inquiring for information. Based on the answers, the average duration of the diagnosing phase is 45 minutes, corresponding to 36% of the average total service visit duration. On average 14 minutes (11% of the total service visit duration) of this time is used for acquiring additional information. The standard deviation for the duration of the diagnosing phase is 27 minutes.

In practice, there are several sources from where to look for information. First of all, there are three possible information sources on-site. Some pieces of product information can be found from the product itself e.g. information on the type of lubricant is attached to every new product manufactured. In addition, some documents such as electric diagrams are delivered with the product to the site of usage. The problem with these documents is, as the service technicians pointed out in the interviews, that they are seldom found from the plant when needed. The third source of on-site information is the paper documents stored in the service vehicle. However, due to the large number of different products serviced, it is not possible to carry all the required documentation in paper format. Due to these issues, service technicians need to inquire for information from outside the service site. Based on the survey, we determined that the service technicians most typically contact their own office, if information is missing. Most often used medium for transferring information is telephone, but also fax and e-mail are used for transferring technical drawings. However, the service technicians contact the focal manufacturing company on average 0.7 times a month to inquire for information. In total, this encumbers the case company's technical support staff with hundreds of technical inquiries a month that are due to the poor availability of information.

In addition to having technical documents available in problem diagnosing, the literature review revealed that service technicians may benefit from collected life-cycle information. Therefore, the value this information was examined in the survey with a multiple choice question. The service companies were to estimate how beneficial the given pieces of information are. This question included all the pieces of lifecycle information on the devices and their value was estimated in a scale of significant benefit, average benefit, small benefit, and no benefit. The results of this question are presented in Figure 2.The most valuable piece of life-cycle information seems to be the equipment service history. It was responded to bring significant benefit by 37% and average benefit by 50% of the service companies. About as valuable piece of information seems to be equipment's temperature and pressure data, which was responded to bring significant benefit by 30% and average benefit by 60% of the companies. It was evaluated as a small benefit only by 10% of the respondents. Information on spareparts installed to the equipment was estimated to bring significant benefit by 27% of the respondents. Temperature and humidity data of the environment of the equipment was the least valuable of the given information pieces, almost half of the companies responded that it brings only small benefit to servicing operations. In general, the collected lifecycle information seems to be at least somewhat valuable to all the service companies, as no one answered that some piece of information would not be beneficial at all.

In the survey, the means to improve the fault diagnosing were inquired with an open-ended question. Subjects of improvement for failure diagnosing included information, technology, and training related issues. Information related development needs were dominant and comprised of better availability of existing documentation and needs for currently non-existing documents as trouble shooting diagrams and typical failure documents. Technology related improvement suggestions were automated failure diagnostics tools and remote monitoring devices, which already are in use to some extend. In addition, training held by experienced service technicians was mentioned as a way to improve fault diagnosing. Based on these answers, it seems that better availability of information would indeed improve the fault diagnosing phase. Currently, the service technicians have to work with incomplete information on the serviced equipment, which reduces their efficiency to locate quickly and reliably the problem at hand.

V. 6 Return loop

If the defect cannot be rectified during the service visit, the process returns back to the preparation step which is indicated as the return loop in Figure 1. The problems related to a failed return visit were discussed before, and next we dig deeper into the reasons behind the failing service visits in this case in order to be able to quantify the problems caused by poor availability of information.

An overview of the average situation for a service company in a month is given in Figure 3. Based on the survey answers, the average service call accomplishment ratio for the service companies is 79% (Figure 3: Accomplishment ratio). That means, on average 21% of the service visits go to the return loop. Only for 17% of the respondents the accomplishment ratio was 70% or less, so based on this measure, the maintenance performance of the service companies is somewhat uniform To assess the reliability of this result, the service call accomplishment ratio was determined based on the warranty service invoice data as well. The survey result received modest support, as the average accomplishment ratio for the services made under warranty was 75%.

From customer perspective, the down-time continues in breakdown maintenance until the service technician returns for a follow-up service visit to rectify the defect. The time customers have to wait for the follow-up service visit was determined based on the warranty service invoice data. On average, it takes three days for a follow-up visit but the spread is quite large. For 19% of the cases it takes longer that a week and 19% of the follow-up visits can be accomplished during the same day. Therefore, for a customer a failed service visits means several days more of unplanned downtime that cannot be from affecting the customer's perception on the reliability of the manufacturer's products.

To find out why some service visits fail, the failure reasons and their significances (Figure 3: Failure reason) were inquired in the survey. The respondents had to estimate weights for the given failure reasons: lack of spare-parts, lack of documents or information, and lack of tools. In addition, the respondents could fill in other failure reasons and their weights as well. It turned out that the main failure reason is the lack of spare-parts, which causes two thirds of failed service visits. Lack of information or documents is the reason behind 14% of the failed service visits while the lack of tools is the reason in only 3% of the cases. The last 16% is caused by other reasons, which were mainly customer-related and service process-related reasons, such as the customer's contact person being unavailable at the time of visit.

There are several reasons why the service technicians may be lacking of the needed spare-parts while on-site (Figure 3: Spare-part problem reasons). Therefore, the survey was used to determine what the relevant reasons in this particular case are. As a result, the two main reasons for missing spare-parts are that it is not known which parts should be taken with when leaving for service site, and that the spare-part is not stored and it must be ordered. These both account for 35% of the cases when a spare-part is missing. The next significant reasons are that the spare-part is temporary lacking from the service vehicle, and that the spare-part is out of stock. Other reasons account for the remaining 2%.

The service technicians have a need for a great deal of information when carrying out the on-site operations. In the examined case, the information is not always available due to the characteristics typical of most field-service organizations: paper-based documentation is poorly portable, and the amount of documentation is very large [25]. Based on the survey answers, the lack of information is the reason behind 14% of the failed service visits. In order to better understand this failure reason, the respondents were asked to specify the missing of which particular document or piece of information typically prevents from completing a service call. The answers to this open-ended question and their frequencies are presented in Table 1.

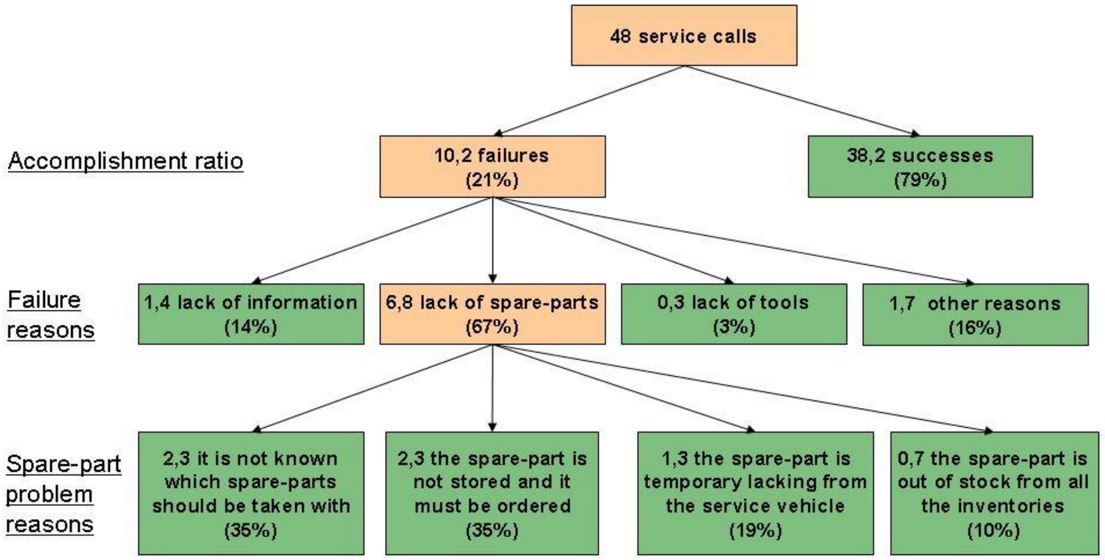

FIGURE 3SERVICE COMPANIES' AVERAGE SITUATION IN ONE MONTH PERIOD

Table 1Typically missing documents or information

Document or piece of information	**Mentioned in the survey**
Electric diagram	11
Electronic controller’s instructions or settings	4
Adjuster’s instructions or settings	3
Control settings or parameters	1
Instructions	2
Equipment’s special parts	1
Type of lubricant	1
Electrotechnical information	1
Equipment’s power	1
Inadequate failure description by the customer	1
Information on is it allowed to maintain the equipment and who will pay for it	1
Inadequate equipment’s operating report	1
False information from the customer	1
Total	**29**

The most typically missing document is electric diagram which was mentioned by 11 of the total 24 respondents to this question. Although this document is delivered to the plant with the equipment, the electricians often lose it during the installation works and therefore it is missing when needed. Other typically missing documents are instructions or settings for the electronic controllers and adjusters. Information on equipment’s special parts, type of lubricant, electrotechnical attributes, and equipment’s power were all mentioned once as typically missing pieces of technical information. Inadequate failure description by the customer, equipment’s operating report, false information from the customer, and missing of information on typical failures were mentioned as other causes for failed service visits.

One important factor that causes the unavailability of information seems to be the observation that the current availability of documents and information is inadequate for the service companies. Service companies’ preferences for the locations where different pieces of information should be available were inquired in the survey. When these results are compared to the current availability of documents, some rather large discrepancies in information’s current availability and the wanted availability can be recognized. For the most typically missing document, electric diagram, 80% of the respondents wanted it to be physically attached to the equipment. For the settings and service instructions for electronic adjusters, the second typically missing document, 63% of the respondents wanted it to be available in the service instructions located at the customer plant. In addition, almost half of the respondents wished that at least one of the document types would be available in the Internet. The manufacturer is currently not satisfying these needs and therefore the service companies are facing problems in the information availability.

The observations from the return loop indicate that several of the current failure reasons are related to the unavailability of information. In fact, the study revealed that about 40% of the failed service visits are either directly or indirectly caused by the unavailability of information. Missing documentor piece of information is the reason behind 14% of the failed service visits. With better availability of information on the service site, these failures could be eliminated. The single most important reason for a service call failure is insufficient advance information on the spare-parts that will be needed during the service visit. This means the service technicians do not know which spare-parts should be taken to the service site, and it is the reason behind 24% of the failed service visits. If the service technicians would have advance information on the model of the equipment and possibly on the failure type, they could be better prepared with the proper spare-parts when arriving for the service site for the first time. Having all the possible spare-parts in the service vehicle is not achievable due to the large variety of spares and due to the large size the most often missing component. Therefore, the solution would be advance information that would allow more accurate preparation for the service calls. That way, the service technicians would also be able to prepare themselves with the required tools, the lack of which is currently the reason behind 3% of the failed service visits. These improvements in information availability would ultimately allow the service companies to accomplish 40% of the currently failing service calls, and thus increase the accomplishment ratio from the current 79% to around 87%.

V. 7 Defect Rectification

After a successful failure analysis, the service technician can rectify the defect. According to the service technicians, this can involve cleaning, adjusting, repairing, or component changing activities. According to the survey, this phase takes on average 1 hour 19 minutes corresponding to 64% of the service visit duration. The service technicians commented that the duration of this phase varies a lot, and consequently the results showed rather big variance with a range of 27 minutes to 240 minutes and a standard deviation of 42 minutes.

The defect rectification step can be argued to be the most important phase of the whole defect rectification process. The information needs during the rectification consist of product documentation on product structure, such as diagrams, and settings. The availability of these documents and consequences of non-availability have been included in the above sections addressing diagnosis and the reasons for failed service calls, while the defect rectification phase was measured to identify the share of time used to the corrective work with the equipment.

V. 8 Testing and close-up

The final phase in the defect rectification process is testing and close-up. In the interviews, the service technicians commented that testing is carried out only briefly. In most of the cases this is sufficient, but sometimes the failure recurs quickly because the actual defect was not rectified. Close-up of a service call means creation of a service report and an invoice. There is no standard format for a service report, and typically a service report means information on the invoice items of a service call: number of billed hours, traveling expenses, and cost of spare-parts. However, customers can require more detailed reporting. The manufacturer requires more information for identifying the service product and description of the type of failure in order to pay the warranty service invoice. However, as Christer and Whitelaw [11] argue, there would be more valuable information available that is not currently reported. The service technician could report his professional view on the cause of fault, consequences of fault, and means of prevention [11]. This information could be used in prevention of the future breakdowns.

The time it takes to create a service report and an invoice is rather short. However, the time it takes to handle the paperwork is longer. In order to study the duration of the reporting phase, we examined how long it takes for the service companies to invoice their customers. In the survey, we inquired the average duration for invoicing the customer after a service visit. The average result for the respondents is 7 days with a range from 1 to 20 days. This result is compared with the invoicing data. From the warranty service invoices, we could determine how many days it has taken from completion of the service call to the creation of the invoice. According to this data, the average duration for invoicing has been much longer – 17 days – and for 12% of the invoices the duration is 30 days or more. Therefore, it seems that the survey results do not reliably represent the actual operations of the service companies in terms of reporting duration. In addition, this indicates that there are inefficiencies in the close-up reporting process that can affect the value of data gathered.

V. 9 Discussion of the results

To provide answer for the first research question, we examined the maintenance execution process of the case in the light of the framework for defect rectification process (Figure 1). Based on our findings, there are several ways how the unavailability of information in field-service affects maintenance execution performance. In terms of maintenance efficiency, the most significant implication is that due to the unavailability of information in the preparation phase, the current service call accomplishment ratio is below 80%. We argue that with better information in the preparation and fault diagnosing phases, the service companies could accomplish up to 40% of the currently failing service calls, and thus increase the accomplishment ratio to around 87%. We emphasize that this improvement can be attained just with better preparation and better availability of information – without affecting the service companies' current spare-part ordering and inventory holding practices.

The second important implication of the unavailability of information is that valuable onsite time has to be spent to acquire information from several sources. Currently 36% of onsite time is spent with problem diagnosing and searching for information. We conclude that the information unavailability in this case was caused by nonconformity of means requested and provided. Better data could help to reduce the problem diagnosing time, and better availability of information could help to reduce the information acquiring time. Therefore, proper tools to access or other arrangements to make relevant information available could cut down the duration of the on-site service operations.

The objective of the second research question was to find out what are the most critical pieces of information required in the different process phases. We argue that the biggest benefits could come from increasing the effectiveness of the preparation phase. That could be done with information on the identity or type of the equipment to be serviced. If the service technicians knew which equipment they will service, they could prepare better in terms of spare-parts, documents and tools. That would improve effectiveness of preparation. In addition, advance information on the type of the failure would make the preparation more efficient. To improve the on-site operations, product documentation should be better available. In this case, especially electric diagrams and settings for adjusters and controllers are typically missing documents. Based on the results, the problem diagnosing activities could be made more efficient with life-cycle information such as service history and temperature and pressure data for the equipment.

The examined ICT-solutions in the literature part give indication on the means how information could be made better available. For the preparation phase, a system that takes product type and symptoms of the failure as input and propose the likely needed spare-parts would provide considerable assistance, corresponding to case Xerox [18]. To improve the availability of information in the on-site phases, it seems that portable computers could be the solution to ensure the availability of comprehensive product documentation. In addition, there is evidence that portable computers can help also in the reporting phase, where the service companies are currently facing long lead times in invoicing.

Our findings concerning the predictability of duration for the different phases of the defect rectification framework are somewhat contradictory to Knotts's statements. Knotts argues that the duration of problem diagnosing phase is difficult to predict, but the duration of defect rectification phase can be predicted [21]. However, our research material showed the opposite since the standard deviation for the duration of the diagnosing phase is 27 minutes but for the defect rectification phase it is 42 minutes. Greater deviation makes it harder to predict the duration of the defect rectification phase. We contend that the main reason for this poor predictability is the variance in rectification times for different failure types. For example, some service technicians commented that replacement of certain components is exceptionally time-consuming since it requires breaking down the whole equipment.

On the validity of the findings, the set-up of the study with service companies separate from the manufacturer is one factor that reduces the quality of information available to the service providers. Nevertheless, our discussions with representatives from investment goods manufacturers with own service organizations indicate that the results are not far from their experiences. The use of several sets of research material enables assessment of the reliability of the results. For the service call accomplishment ratio and invoicing lead time, the survey results gave a better image of the service companies' performance than the warranty invoicing data did. This indicates that the service companies may have answered overly optimistically, and it means that the potential of improvement may be even higher than the results point out.

.VI Conclusions

When selecting ICT tools for maintenance operations, it is important to understand which phases in the service process currently lack information and what the potential impact of better information could be. We have 1) demonstrated the magnitude of impact on process performance that unavailable information may have in the context of one case and 2) developed the framework presented by Knotts [21] further to enable analyzing the information needs in and impacts on distinct process phases. Based on our findings, the single most important means to improve the defect rectification process performance can be to provide better information for the preparation phase, which can yield considerable benefits in terms of improved service call accomplishment ratio.

The total improvement potential of better information is considerable especially from the customer viewpoint, as it would be possible to significantly reduce the equipment downtime that the customers are experiencing. Especially, making sure the equipment can be put into condition during the first service visit has a huge effect on the service level experienced by a customer, since she does not have to wait for the second service visit.

The realization of the improvement potential by means of ICT is in the interest of the manufacturer as well, since it ensures more reliable customer service that can increase both customer satisfaction and the company's brand image. From the service company viewpoint, better information would increase operational efficiency of the defect rectification process, which can turn into more business.

Our study proved that the lack of very basic information, here electric diagrams, may be a major reason for service delays, not necessarily the lack of sophisticated tools. Therefore, when selecting ICT tools for maintenance operations, it is important to understand the service technicians' real information needs and fulfill them.

Component of defect rectification framework (Applied from Knotts, 1999)	Example case	System description	Author
Symptom/failure/defect reported and confirmed	Palomar Technology International Inc.	Condition-based maintenance system. The maintenance engineer enters temperature and pressure readings from gauges associated with the equipment and vibration information gathered with a magnetic probe. Data is compared with historical data stored in the computer and the system identifies required repairs.	Ives and Vitale, 1988
	Light aircarft manufacturer	A condition-based maintenance system used to monitor the condition of the aircraft engine	Ives and Vitale, 1988
	Otis Elevator Inc.	A self diagnostics control systems that inform the company when maintenance is required.	Ives and Vitale, 1988
Preparation	Xerox	The customer support service system tells the maintenance personnel which spare parts will most likely be needed.	Ives and Vitale, 1988
	A ship engine manufacturer	Diagnostics tool to determine product service and spare-part needs after the failure has occurred. Data about the damaged engine and ship location are transmitted to the manufacturer抯 headquarters, where the nearest repair facility is identified, and replacement engine or spare-parts are dispatched. The system also guides the ship抯crew to prepare the engine for subsequent repair.	Ives and Vitale, 1988
	Sears Roebuck & Co.	The field service personnel can check spare-part availability and place orders using wireless computers. The back-end system schedules a second visit for the service technician to install the part. Previously the technicians had to call the headquarters for availability information and to order the spare-parts. The system has yielded 70% decrease in the back-office support.	Albright, 2000
	An electronic products manufacturer	A centralized diagnosis support system that is used by the call center employees. It advices customers to make small repairs themselves and dispatches a service technician for complex cases.	Pintelon et al., 1999
Access gained	Maytag Corp.	A mobile computer system provides repair workers with updates on the available service calls. The service vehicles can be tracked via the GPS. Since the rollout, the average number of service calls completed by the service persons has increased.	Hamblen, 2005
	Schindler Elevator Corp.	A routing system to assign routes for field service workforce that carries out periodic maintenance operations, breakdown maintenance operations and emergency services. Optimal routes are found by minimizing operational costs while taking into account geographic proximity, technician workload, necessary skills and customer relations.	Blakeley et al., 2003
	Sears Roebuck & Co.	Wireless computers are used to route the field-service personnel. The back-end system forecasts the proper number of technicians needed to serve each day's route and matches each technician's skill set with the jobs on the route.	Albright, 2000
	Southern Co.	Field service personnel get work orders and mapping information to their laptop computers using a wireless connection. Back-end systems take care of routing by taking into account the available workforce, materials and equipment. Imbedded GPS tracks the location of the service call and the crew, which is captured and mapped.	Townsend, 2004
Fault diagnosed & isolated	Honeywell Inc.	Portable diagnostic tool to help the service technicians locate the problem	Ives and Vitale, 1988
	Worthy Down Centre	Provide product information and maintenance history by means of 2D bar-coding. Benefits: faster data entry, improved decision making when carrying out the servicing activities, and reliable identification of serviced equipment.	March and Finch, 1998
	Sears Roebuck & Co.	The company's field service technicians are using wireless computers with the following applications: diagnostic tools, schematics and training materials.	Albright, 2000
	A capital goods company	The company is collecting service call reports to a centralized database. This database serves as a resource for unusual, or first-time, repairs	Zackariasson and Wilson, 2004
Defect rectified	SourceOne Healthcare Technologies	A wireless field service support system to provide to technicians with equipment and site history, parts and customer information, automatic time sheets, e-mail messaging, and inventory management functions.	Anonymous, Wireless News 2004

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