MASTER

Improvement of the Assembléon service system using e-maintenance technology

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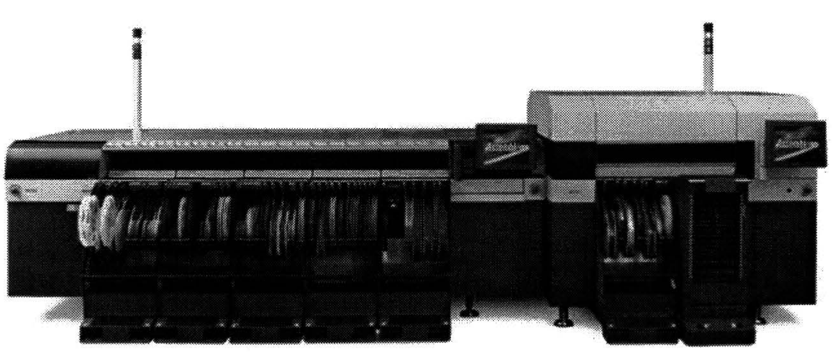
Master's thesis



CONFIDENTIAL

Improvement of the Assembléon service system using e-maintenance technology

Master's thesis

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Abstract

In this study the application of e-maintenance technology in the Assembléon industrial maintenance service system is explored. First, using a model-based approach, architecture descriptions of the system are developed. Then, a change management program is proposed to facilitate extension of the system. Finally, an open and flexible design for component-based implementation of e-maintenance technology in the service system is proposed, enabling the introduction of new service products, as well as improved delivery of the current service products.

Management summary

Assembléon is a global supplier of SMT placement solutions, enabling customers to generate a desired amount of output at the lowest possible cost. Assembléon's product consists of equipment and complementary after-sales services, which are delivered by the Assembléon service system. The service system is the scope of this research project.

Point of departure

Historically, services are not seen as part of Assembléon's product portfolio. However, as pick-and-place equipment technologies mature, Assembléon equipment is tending towards a commodity and services will become more important as a product differentiator and profit generator. At the same time, service sales are decreasing, mainly due to decreasing spare parts sales. Furthermore, Assembléon's service system is not optimized, leaving considerable room for improvement. It is expected that service profitability can be increased by increasing effectiveness and efficiency of delivery of the current services and by extension of the service product portfolio.

Assembléon has developed a basic system for remote operation and troubleshooting during alpha and beta testing of equipment at customer's sites. This system is based on e-maintenance technology. Assembléon expects that this technology can be used to improve efficiency and effectiveness of the service delivery process as well.

The subject of this research project is the improvement of the service system by application of e-maintenance technology. The following research questions have been defined:

(1) *What does the current Assembléon service system architecture look like, when it is mapped to generic service system architectural patterns synthesized from literature?*
(2) *What are the problem areas in the current Assembléon service system architecture?*
(3) *What changes to the current Assembléon service system are required to implement e-maintenance technology?*
(4) *What are the benefits and limitations of application of e-maintenance technology within the Assembléon service system, specifically in relation to the problem areas as identified in research question (2)?*
(5) *How can the service system changes as proposed in research question (3) be implemented?*

Based on the research questions, a research approach is synthesized from relevant publications. The foundation for the research approach is formed by the regulative cycle. This method provides a generic method for analysis and solution of problems, but is not detailed enough for IT projects. Therefore, it is combined with an IT-specific methodology. Combination of these two methodologies results in a framework for project management, which is completed with deliverables. This results in a component and model-based system development methodology.

Analysis

In the Assembléon service system, five types of information resources are distinguished; operational equipment data, CRM data, service activities data, technical documentation and logistics data. The current implementation of the five resources is specified in models depicting the functional components and technical deployment.

While the current service system architecture is described, problem areas that negatively affect the service system's performance are identified as well. A distinction is made between strategic, tactical and operational problems. Based on the problem analysis, several areas of improvement are discussed:

- Implementation of a change management program, including service system performance measurement and improvement project portfolio management.
- Extension of the service portfolio with customer production process improvement services.
- Improve efficiency and effectiveness of the service delivery process by improved use of service system business information resources

Derived from the identified areas of improvement, the following design objective is defined:

"Design a flexible e-maintenance extension for the current Assembléon service system, providing actors in the system with capabilities for optimized processing of operational equipment data, thus enabling more efficient and effective delivery of current service products, as well as the introduction of new service products. Furthermore, the current architecture must be adapted to facilitate a program for incremental implementation of the design."

Design

First, the requirements for the e-maintenance extension of the service system are specified. A distinction is made between functional and non-functional requirements. Furthermore, four levels of functional requirements are distinguished:

- Level-1 access to raw operational equipment data.
- Level-2 performance reporting functions.
- Level-3 equipment condition monitoring.
- Level-4 automatic action taking.

For different actors in the service system, functions are defined based on these levels. Also, a variety of non-functional requirements is defined. The most important are:

- Incremental implementation of e-maintenance levels.
- Use of mainstream and open standards.
- Scalability of the e-maintenance infrastructure.
- Interoperability with other business information resources.
- Design based on current hardware infrastructure.

Based on the requirements, a logical design is created. It consists of components on all four levels, which can be developed and implemented incrementally. Incremental implementation is supported by a strategic change management program. Five types of components are distinguished; data capturing, data transmission, data retrieving, data storage, data manipulation and data displaying. To meet the non-functional requirements, the components are based on the current component structure and are implemented as flexible and scalable services. Furthermore, the e-maintenance components are designed as part of a platform combining all business information resources.

In the technical design, the services are deployed on the equipment computers, the on-site production line servers that will be installed in the near future and the remote service center. Clients can access the services from within the Assembléon office network.

The design is validated against the identified problem areas, resulting in strategic, tactical and operational benefits. On the strategic level, change management enables structural improvement of the service system. On the tactical level, e-maintenance functions facilitate the introduction of new service products and enable a proactive service strategy. On the operational level, e-maintenance functions enable cheaper and faster delivery of service products, specifically, general technical support, break-fix services and software support.

The proposed solution does not solve all identified problems. On the strategic level, integration of the service system in the rest of the organization is not addressed in detail. Furthermore, the required change management program is not elaborated in detail. On the tactical level, no business models for new service products are explored. On the operational level, process changes are not addressed.

Finally, the extendibility of the proposed solution is validated by introducing a problem outside of the scope of the research project; life cycle management of spare parts. This problem can be solved in the change management program. Furthermore, a link with e-maintenance components is beneficial.

Implementation

A change management program is proposed to facilitate gradual implementation of the e-maintenance functions. It consists of the following elements:

- Maintenance of a repository of models that describe the architecture of the service system.
- Measurement of system interrelated strategic, tactical and operational performance indicators.
- Management of a portfolio of improvement projects and execution of these projects based on the regulative cycle.

Assembléon has to decide whether or not the development of the e-maintenance functions will be outsourced. When outsourced, a choice between readily available off-the-shelf solutions or build-to-order systems has to be made.

Development of the e-maintenance functions consists of augmentation of functional services to a basic service-oriented infrastructure. A technology has to be chosen as a foundation for the infrastructure, to allow extension with e-maintenance functions and interoperation with the other business information resources.

The application of e-maintenance technology is a long-term strategic project. Therefore, the ROI must be determined on the long term. Determining the short-term ROI may result in a negative ROI.

The implementation of e-maintenance technology has implications for the customer. Additional hardware and software is installed at the customer's site. Furthermore, access is granted to Assembléon to access critical customer data. Therefore, the customer must be convinced of the advantages of e-maintenance technology.

For Assembléon employees, the way of working will change. Involvement of the employees in requirements specification and providing training and technical support will increase acceptance and effective use of the new e-maintenance functions.

Conclusions

- In this report, a repository of models is presented that describes the current architecture of the service system.
- While analyzing the service system, a variety of problems that negatively influence the performance of the service system was identified.
- An e-maintenance solution is proposed that provides solutions to service system problems, thus improving the performance of the service system.
- The e-maintenance solution meets the functional and non-functional requirements.
- Implementation of a change management program is proposed, facilitating all service system improvement projects, including application of e-maintenance technology. Part of the change management program is the repository of architecture models.
- Implementation of e-maintenance functions in a change program is a long-term strategic project.

Recommendations

- Implementation of a strategic change management system as proposed.
- Adaptation of all processes in the Assembléon organization to deliver a balanced pick-and-place product, consisting of equipment and complementary services.
- On the tactical level, continue the program of development of e-maintenance functions. First, choose a technology as a foundation for the e-maintenance infrastructure.
- Furthermore, if required, adapt business models for new service products.
- Support the implementation of e-maintenance functions by elaborating the operational processes in which these functions are used, involving the users, providing training and technical support.
- Optimize the use of all business information resources in the new information system that will be implemented in the near future.

Preface

This report is the result of the research project I have conducted at Assembléon Netherlands B.V. It has two primary goals. First, the report forms the master's thesis to receive my Master's degree in Industrial Engineering and Management Science at the Eindhoven University of Technology. Second, it provides Assembléon with a framework of concepts which are useful for successful implementation of e-maintenance technology in the Assembléon service system.

First, I would like to thank the Assembléon TOAST partners, specifically Jan van Dalfsen and Hai Peeters, for providing the opportunity to conduct my research project within an actual service system. I also want to thank everyone at Assembléon, specifically Rini Stoffelen, for their helpfulness and willingness to provide me with the information I needed. Furthermore, I would like to thank Robbert van Leijsen for the time he invested to review and discuss my work.

I would like to thank Jan Goossenaerts and Gudrun Kiesmuller for their academic input and constructive commentary, which has been essential to developing a structured approach to creation, processing and presentation of the results.

Finally, I would like to thank my family and friends for their compassion and heartwarming support and my colleagues at Assembléon for their humor and pleasant company.

The graduation project has proven to be a true challenge and an extremely meaningful learning experience.

Maarten van Laarhoven

List of abbreviations

CCM	Cumulative Components Model
CRM	Cumulative Requirements Model, or Customer Relationship Management
ERP	Enterprise Resource Planning
ICT	Information and Communication Technology
IT	Information Technology
ISMI	International SEMATECH Manufacturing Initiative
OEM	Original Equipment Manufacturer
PCB	Printed Circuit Board
PDA	Personal Digital Assistant
PSM	Platform Specific Model
Philips EMT	Philips Electronic Manufacturing Technology
RMA	Returned Material Authorization
ROI	Return On Investment
SMT	Surface Mount Technology
TCOO	Total Cost Of Ownership
TU/e	Eindhoven University of Technology
VPN	Virtual Private Network
VARM	Value And Risk Model
WOM	Work system Operations Model

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Chapter 1 Introduction

This master's thesis is the final deliverable of the research project that has been conducted for the global customer support operations department at Assembléon Netherlands B.V. (Assembléon) The research project is part of a larger project called TOAST. In this introductory chapter, first the TOAST project will be introduced. Also, an overview of the structure of the report will be given.

1.1 TOAST project

Traditional service delivery methods for complex electromechanical and software-intensive machines are becoming difficult and expensive for Original Equipment Manufacturers (OEMs), for their customers and for the end-users involved. New methods and tools, as part the equipment supplier's after sales service capabilities, are gaining importance due to the need to efficiently deploy services on a global scale, increasing complexity of machines and constant market pressure to reduce service costs per machine. Today, the Internet enables the introduction of e-maintenance as a tool to provide equipment supplier's experts with the ability to remotely link to factory's equipment. This allows for remote setup, control, configuration, diagnosis, repair and improvement of the equipment (Hung *et al.*, 2003).

To examine the possible benefits of application of e-maintenance technology, the TOAST project was initiated by the OEMs Assembléon and OCE, software developers SIOUX and Philips TASS and the Eindhoven University of Technology (TU/e) as a source for public knowledge. The main goals of the TOAST project are improved customer satisfaction and decreased service delivery costs due to the application of e-maintenance technology. Furthermore, the requirements for successful implementation of e-maintenance technology, including customer appreciation, are evaluated.

In the TOAST project, the objectives of the TU/e are to create models of the OEMs service processes and to present the models within an architectural framework and repository. This thesis focuses on mapping of the Assembléon service processes, as well as evaluating the benefits and limitations of application of e-maintenance technology in the Assembléon service processes.

1.2 Overview of the report

This section provides a general overview of how the report is organized.

In *Chapter 2* the point of departure of the research project is introduced. The results of both internal and external orientation are presented. Furthermore, the research project motivation is discussed and a problem definition is presented. Finally, based on the problem definition, a research approach is synthesized from literature.

In *Chapter 3* the current system is analyzed and mapped to reference patterns synthesized from literature, resulting in a set of models that describe the current system's architecture. Furthermore, resulting from the analysis of the current system, problems that reduced the current system's performance are discussed, as well as a vision for change to solve the identified problems and improve the system's performance. Finally, a specific focus is chosen for a redesign of the system.

In *Chapter 4* the changes required for improvement of the system's performance are discussed in terms of changes relative to the models that have been presented in Chapter 3. Furthermore, the proposed architectural changes are validated in terms of benefits and limitations in relation to the service system problems as identified in Chapter 3.

In *Chapter 5* several issues that have to be taken into account for implementation of the changes that have been proposed in Chapter 4 are discussed.

Finally, in *Chapter 6* conclusions that are drawn from the research project are presented. Furthermore, recommendations that have not been specifically addressed in the thesis are discussed briefly.

Chapter 2 Point of departure

Both an internal and external orientation have been carried out to establish a point of departure for the research project. As a result from the external orientation, first, a generic theory on life cycles of systems is presented. Also, relevant publications regarding service organizations and e-maintenance are discussed. Then, the results of the internal orientation are presented, explaining the motivation for Assembléon's involvement in the research project. Combining the results of the internal and external orientation, a problem definition and accompanying research questions are defined. Based on the problem definition and research questions, a research approach is synthesized from several system development methodologies. Furthermore, an overview of the deliverables as presented in this report is given.

2.1 Work systems life cycles

Business organizations can be seen as systems in which human participants and/or machines perform work using information, technology and other resources to produce products and/or services for internal or external customers. According to Alter (2003) this is the definition of a work system.

The life cycle of any work system can be divided into two stages, *system development* and *system operation and maintenance* (Figure 2.1) (Whitten *et al.* 2007). In the system development stage, the system is (re)developed and (re)built, while in the system operation and maintenance stage it is used and supported. Two key events mark the changes from one stage to the other. *Conversion* takes place when the system is ready for use after development and when the system becomes *obsolete* it is redeveloped.

To monitor performance of the system during the operation and maintenance life cycle, a continuous *monitoring and evaluation* focus is implemented. Monitoring and evaluation is goal based, meaning that system performance is constantly compared to predefined goals. If goals are not met, system performance is unsatisfactory and the obsolescence transition is triggered. The system then enters the life cycle stage of system development. New *opportunities*, changing *business drivers* or *directives* can cause goals to change. Opportunities occur when performance improvement is possible, for example because of new technology, without current performance being unsatisfactory. A changing directive is for example new legislation. When goals change, or it is expected that they are going to change, a performance alert is triggered, which in turn triggers system obsolescence. The obsolete system is then redeveloped.

Within the development stage two types of focus can be distinguished; *project portfolio management* and *project execution*. An obsolete system that enters the stage of redevelopment triggers project portfolio management. It is then decided whether the reaction to the problem, opportunity or directive will be in the form of a new project or an adaptation of an existing project. After this has been decided, the project is executed, using suitable methodologies.

The system as it is in use during the operations and maintenance stage is described by an accumulated architecture, resulting from preceding development projects. System development can then be seen as invoking changes to the accumulated system architecture. The changes are managed and executed in projects, as parts of the project portfolio. Once the changes have been implemented, the architecture is updated and can be used as a foundation for forthcoming projects.

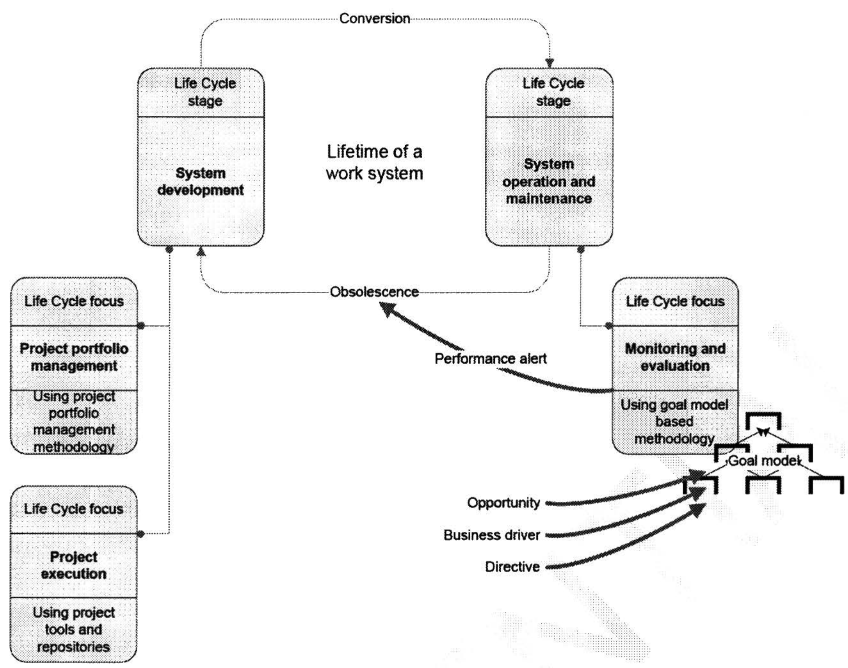

Figure 2.1 Life cycle of a work system

2.1.1 IT-reliance of work systems

Alter (2003) defines IT-reliant work systems as "work systems whose efficient and/or effective operation depends on the use of IT." Often, the appearance of new technologies on the market introduces new opportunities of work system performance improvement, triggering the life cycle stage of system development.

2.2 Service system knowledge

In this section, service systems are introduced as the work systems that produce service products. First, relevant publications regarding maintenance service systems in general are presented. Furthermore, several publications regarding e-maintenance technology are discussed; a generic definition for e-maintenance technology is established.

2.2.1 Maintenance service systems

A service system is a work system that creates value in the form of services. The service production process is a result of a concerted effort by various components of a service organization. Haksever *et al.* (2000) argue that for many services the process and the output of the system are closely related, thus the service delivery process is the service product itself.

Service products offered by manufacturing firms basically constitute maintenance and improvement of the manufactured goods. The objective of a service system in a manufacturing context is to maximize equipment availability in an operating condition, thus permitting the customer to produce a desired output quantity and quality, at the lowest possible cost (Pintelon *et al.*, 2002).

In this report, maintenance service systems are defined as work systems that are responsible for the strategic, tactical and operational development and delivery of a portfolio of service products that are aimed at maintaining and improving equipment.

A maintenance concept can be defined as the set of various maintenance interventions and the general structure in which these interventions are foreseen (Pintelon *et al.*, 2002); it is the method of delivery of a maintenance service product. Gits (1992) distinguishes three basic types:

- *Failure-based maintenance;* maintenance activities are initiated in the event of equipment failure.
- *Use-based maintenance;* maintenance activities are initiated on expiration of a specific period of equipment use.
- *Condition-based maintenance;* maintenance activities are initiated on attainment of a specific equipment condition.

2.2.2 E-maintenance technology

The TOAST project specifically focuses on the possibilities of e-maintenance technology within maintenance service systems. It is expected that application of e-maintenance technology will positively contribute to a service system's performance. Locy (2001) has found that for companies similar to Assembléon, the implementation of e-maintenance has indeed increased performance.

As no uniform definition exists for the term e-maintenance, in this report e-maintenance is defined as a solution for remote delivery of maintenance services. Based on Qiao *et al.* (2005) three basic components in are distinguished in an e-maintenance solution; the service provider, the service receiver and the internet-based communication media. Furthermore, based on Spiess (1998) an e-maintenance solution is defined by three criteria:

- *Geographical distance;* the service is delivered over a geographical distance that separates the service provider and service receiver.
- *Use of information technology;* internet-based information technology is used for delivery of the service.
- *Industrial service;* the service product is an industrial service (e.g. maintenance, or technical support).

The International Sematech Manufacturing Initiative has proposed a framework for application of e-maintenance technology in failure-based and condition-based maintenance (ISMI, 2005). Based on this framework, five levels of data processing automation are distinguished (see Appendix I):

- A *level-0* system is a system in which no e-maintenance technology is used, thus all data processing is done manually.
- In a *level-1* system, raw data is transported automatically, without any analysis being carried out.
- A *level-2* system also includes automated analysis of the transported data, but it does not draw conclusions.

- A *level-3* system also draws conclusions and may advice the user of actions to take. The essential difference between level-2 and level-3 is that a level-3 system compares the actual data with a predefined set of data.
- A *level-4* system is fully automated. It is able to analyze a given situation, develop a solution in case of a problem and take the required action to solve the problem without user involvement.

2.3 Company profile

In this section, Assembléon is briefly introduced as a company. The company and its organization structure are discussed.

2.3.1 Assembléon

Assembléon was founded as Philips Electronic Manufacturing Technology (Philips EMT) in 1984 as an internal supplier of pick-and-place machines for the Philips Consumer Electronics division. The company has grown since to become a global force in state-of-the-art hard- and software solutions in surface mounting technology.

In January 2001, Philips EMT changed its name to Assembléon and established legal entities in several countries throughout the world where the company was already operating as an independent unit of Philips. Currently, Assembléon is a 100% subsidiary of Royal Philips Electronics.

From the company mission, Assembléon is a global supplier of SMT placement solutions. Assembléon develops, manufactures, sells and services pick-and-place equipment for the global electronics industry. Current customers are manufacturing companies using Assembléon machines to place a variety of electronic components on Printed Circuit Boards (PCBs). PCBs are used in most modern electronic applications, e.g. telephones, computers and consumer and automotive electronics. Customers include some of the world's largest equipment manufacturers.

Assembléon's product portfolio includes pick-and-place equipment and complementary services for high volume continuous production, through to medium volume, high mix batch production of electronic assemblies.

2.3.2 Organization structure

Assembléon's organization is divided into an operational unit and a commercial unit. The operational unit is responsible for product development and production, purchasing, logistics and customer support. The commercial unit is responsible for market development, sales and account management.

Assembléon operates in three different regions: Europe, the Americas and Asia. Global operations are run from the global headquarters. Basically, strategic and tactical product development is run from the global headquarters, whereas operational sales and support are run by the regions. The regions are financially accountable and although they each operate the same basic business functions, they may implement their processes differently.

2.4 Drivers for the Assembléon service system

From the company mission, Assembléon is a global supplier of SMT placement solutions. Thus, Assembléon provides customers with equipment and, if desired, complementary after-sales services. The product Assembléon offers consists of a 'goods' part, in the form of equipment and a 'service' part, in the form of after-sales services, delivered by its customer support department. Assembléon's customers purchase equipment to generate desired output at the lowest possible cost and after-sales service to support them in actually reaching the desired output at the lowest possible cost.

Assembléon operates in a highly competitive market, with around twenty suppliers offering products comparable to Assembléon's equipment. The main competitors are Fuji, Panasonic and Siemens. Due to its relatively small market share, Assembléon is very sensitive for tendencies in its market. In 2001, after Assembléon had changed its name from Philips EMT to Assembléon, the market collapsed. Sales went down and costs had to be cut by reducing the amount of personnel. As the market is currently growing again, Assembléon's needs to expand its organization again.

As the market is highly competitive, Assembléon is constantly striving to improve its profitability by creating a competitive advantage through product differentiation and low costs. As pick-and-place equipment itself is tending towards commodity status, product differentiation has to be increasingly based on quality of complementary after-sales services. High quality after-sales services generate new business, as well as repeat sales.

Assembléon is a company with a strong focus on equipment technology. From its roots as an equipment provider for Philips, the company's experience is in developing and building machinery. Historically, Assembléon has focused less on its after-sales service products and customer support operations were regarded as a cost center. In the current market, the company is looking for ways of extending its profitability. Customer support operations are no longer regarded as a cost center, but as a viable profit center with strategic value. Assembléon's focus is changing towards a balance between offering services and equipment. This paradigm shift in strategy is depicted in Figure 2.2.

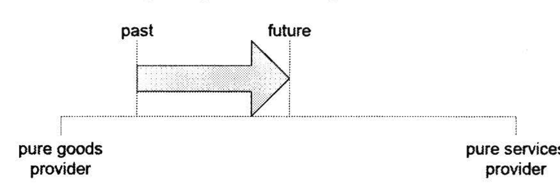

Figure 2.2 Strategic paradigm shift

As services were not regarded as the most important part of the Assembléon product portfolio, not all opportunities to implement new service delivery technologies have been taken, leaving considerable room for improvement in the service system. Furthermore, the current service product portfolio can be improved by extending it.

Currently, the market demands a short time to market for new equipment. Therefore, Assembléon puts equipment on the market in early stages of development. Specific customers agree to operate equipment at their sites that is still under development (during alpha and beta testing). Because having Assembléon development teams on-site is very costly, Assembléon has developed a basic system for remote assistance. This system enables developers to operate and troubleshoot equipment remotely. Therefore, Assembléon expects that this technology can be used to improve efficiency of the service delivery process.

2.5 Problem definition and research questions

Based on the results from the external and internal orientation, a problem definition is defined. The problem definition is stated as:

"As pick-and-place equipment technologies mature, Assembléon equipment is tending towards a commodity. Services are becoming more important as a product differentiator, but at the same time service sales are decreasing. Assembléon's service system is currently not optimized. E-maintenance technology is seen as a major opportunity to improve the service system. Assembléon wants to know the benefits and limitations of application of e-maintenance technology in the service system and how the service system must be adapted to obtain the benefits."

The problem definition leads to the following research questions:

(1) *What does the current Assembléon service system architecture look like, when it is mapped to generic service system architectural patterns synthesized from literature?*
(2) *What are the problem areas in the current Assembléon service system architecture?*
(3) *What changes to the current Assembléon service system are required to implement e-maintenance technology?*
(4) *What are the benefits and limitations of application of e-maintenance technology within the Assembléon service system, specifically in relation to the problem areas as identified in research question (2)?*
(5) *How can the service system changes as proposed in research question (3) be implemented?*

In order to structurally answer the research questions, a research approach is presented in the next section.

2.6 Redesign oriented approach

A suitable research approach is essential to systematically find answers to the research questions. In this section a research approach will be synthesized from various suitable methodologies. First a generic system development methodology and a methodology that is specifically suited for information systems redesign are presented, after which they will be integrated into a project specific research approach.

2.6.1 Regulative cycle

As the subject of this research project is the redesign of a system, the regulative cycle (Figure 2.3 (Van Strien, 1997)) is used as the foundation for the research approach. This cycle starts with a *set of problems* that prevent a system from performing optimally. From this set of problems one or more problems are *chosen* and *analyzed* for redesign. After root causes of problems have been identified, improvement scenarios are generated. One or more scenarios are chosen for *in-depth analysis and design*. After the design has been finalized, the solution is *implemented* and *evaluated*.

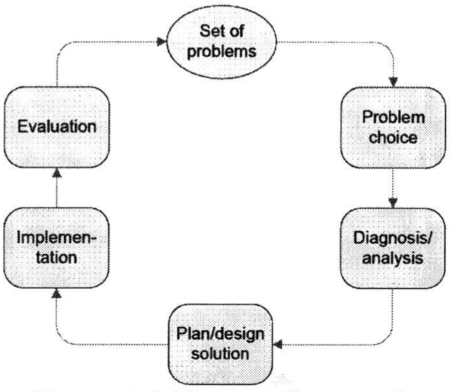

Figure 2.3 The regulative cycle

Based on the regulative cycle an initial research approach was created, which can be found in Appendix II.

2.6.2 IT-reliant work system development methodology

The regulative cycle does not provide sufficient detail to effectively support (re)development of IT-reliant work systems; specific development methodologies have been developed for such projects. Whitten *et al.* (2007) have developed a methodology for system development that is a combination of best practices from commercial methodologies. The methodology is called FAST and consists of eight phases (Appendix III).

Goossenaerts (2006a) has shown that the phases from the FAST methodology can be mapped to three levels: *direct decision*, *operations project* and *ICT project* (Figure 2.4). After the decision for (re)development of a work system has been made, the first phase is *scope definition*. In this phase the borders of the project and thus of the work system are defined. A first *decision* is then made, whether or not the performance improvement can be realized by a direct decision. If possible, the improvement is directly *implemented*. If not possible, feasibility of a performance improvement project is determined. If feasible an operations project is started. The problem or opportunity is then further *analyzed*, including its causes. Again, a *decision* is made whether or not the improvement can be realized by changes in business operations. If possible, the work system's operations are *redesigned*. If not possible, the feasibility and *requirements* of an ICT project is determined. A third *decision* is made, whether or not performance improvements are to be expected from an ICT project. If improvements are to be expected, the IT reliance of the work system is *designed* and *implemented*. Thus, for an ICT project the phases D1, D2, O2, O3, I3, I4, I5, I6, O4 and D3 are carried out.

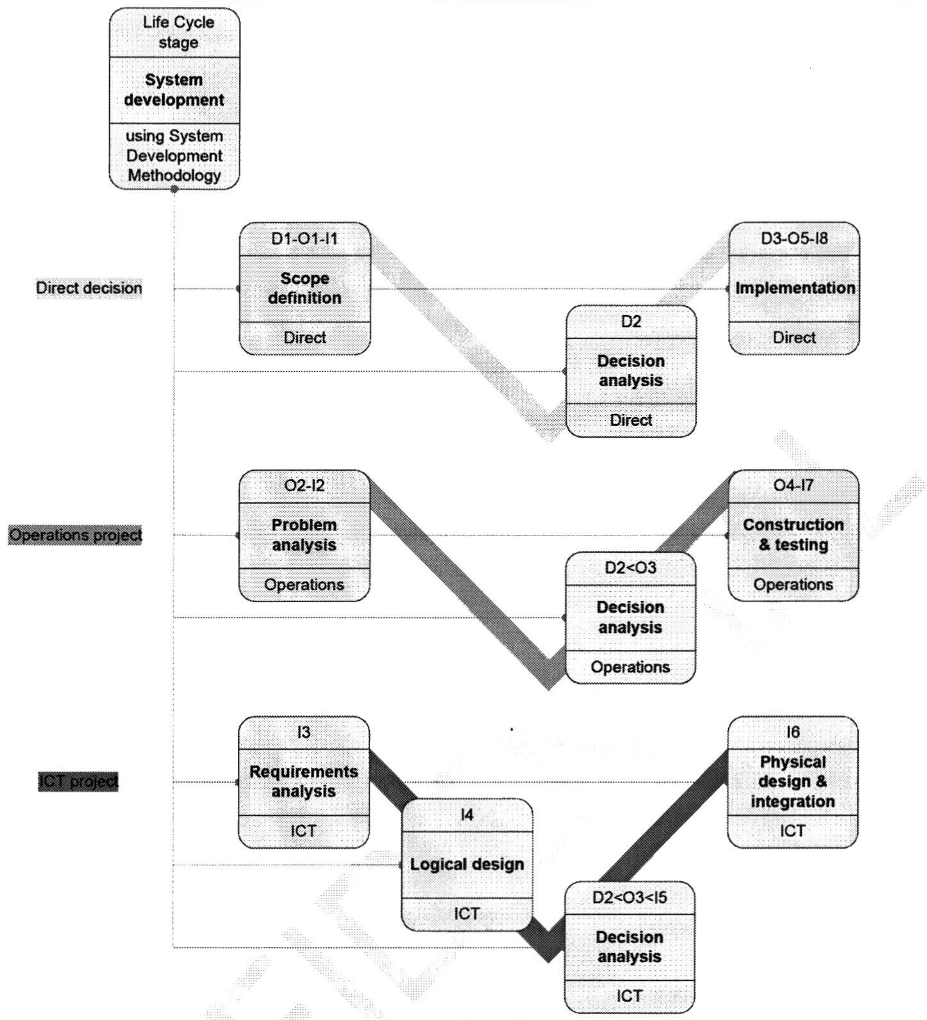

Figure 2.4 3-V system development model

2.6.3 System development methodology deliverables

The 3-V system development model provides a basic structure for system (re)development projects. Furthermore, the model provides sufficient detailing to support IT-reliant work system (re)development projects. However, the model does not contain clear project deliverables.

Berre *et al.* (2006) have developed a use-case driven, model-focused approach to system development, called COMET. Although less suitable for project management, the COMET approach provides a framework for a repository of models that can be used to depict a system's current or desired architecture.

In addition to the project levels in the 3-V model, Goossenaerts (2006b) distinguishes three scales of IT-reliant work systems; the society scale, enterprise (or organization) scale and person/equipment/tool scale. The original COMET model methodology focuses mainly on the enterprise scale. Goossenaerts argues that the COMET deliverables can be applied on each scale and has mapped the deliverables from the original COMET model to the society scale and person/equipment/tool scale, resulting in a the COMET+ set of deliverables (see Appendix IV).

Furthermore, Goossenaerts (2006b) argues that it is essential for effective work system life cycle management to strictly separate the work system repository on the one hand and project charters and deliverables on the other hand. The work system repository is maintained during a system's operation and maintenance life cycle stage and contains the consolidated or cumulative models resulting from all past changes in the work system. The project charter and deliverables are maintained during the system development stage and describe the changes (delta's; Δ's) to the repository. As multiple projects may exist at a single point in time, project portfolio management is essential.

2.6.4 Approach composition, project deliverables and report structure

The methodologies presented so far in this section can be integrated into a research approach for (re)development of IT-reliant work systems, providing both a project management structure and clear deliverables. The proposed research approach is based on the regulative cycle, combined with the 3-V model approach and COMET+ deliverables. Table 2.1 represents the resulting research approach.

Table 2.1 Research approach and deliverables

Regulative cycle (adapted from Strien (1975)	3-V Model approach (based on Whitten *et al.* (2004))	Deliverables (based on COMET+) Architecture repository and architectural changes	Chapter	Section	Appendix
Problem choice	Scope definition	Value And Risk Model (VARM)		3.1	
		Research approach		2.6	II
Analysis (as-is)	Problem analysis	Work system Operations Model (WOM)		3.2	
		Actors model			VIII
		Process model		3.2.4	
		Business Information model			IX
		Cumulative Requirements Model (CRM)		3.3	
		Cumulative Component model (CCM)		3.4	
		Organization Component Structure			XII
		Platform Specific Model (PSM)		3.5	
		Deployment model			XIII
Diagnosis	Decision analysis	ΔValue And Risk Model (ΔVARM)		4.1	
	Logical Design	ΔWork system Operations Model (ΔWOM)		4.2	
Design (to-be)	Requirements analysis	ΔCumulative Requirements Model (ΔCRM)		4.3	
		ΔCumulative Component Model (ΔCCM)		4.4	
		ΔOrganization component structure		4.4.2	
	Technical design	ΔPlatform Specific Model (ΔPSM)		4.5	
		ΔDeployment model		4.5.2	
Implementation	Construction & testing	Implementation plan	5		
Evaluation	Installation & delivery	Validation		4.6	
		Conclusions and recommendations	6		

Chapter 3 Assembléon service system architecture (as-is situation)

In this chapter, the current Assembléon architecture is analyzed, based on the research approach that was synthesized in section 2.6. Where possible, the models are formatted according to the COMET methodology. For each of the different models, reference patterns are synthesized from relevant publications.

In this chapter, the following research questions are answered:

(1) *What does the current Assembléon service system architecture look like, when it is mapped to generic service system architectural patterns synthesized from literature?*

(2) *What are the problem areas in the current Assembléon service system architecture?*

3.1 Value And Risk Model (VARM)

The Value And Risk Model provides a description of the value the system provides to its customers. It defines the context and goals for the system.

Assembléon's mission states that the company provides its customers with value by supplying them with SMT placement solutions, including equipment and supporting services. From the customer perspective, Assembléon offers SMT placement solutions that enable them to generate pick-and-place functionality output at a given specification, against the lowest possible cost over the equipment's total lifetime. Output specification includes speed of placement, but also flexibility of applications that the equipment is able to handle. Costs that are evaluated are the total costs of ownership, including both equipment purchase costs and supporting services costs. A detailed description of the Assembléon value proposition for both equipment and services in relation to output and costs can be found in Appendix V.

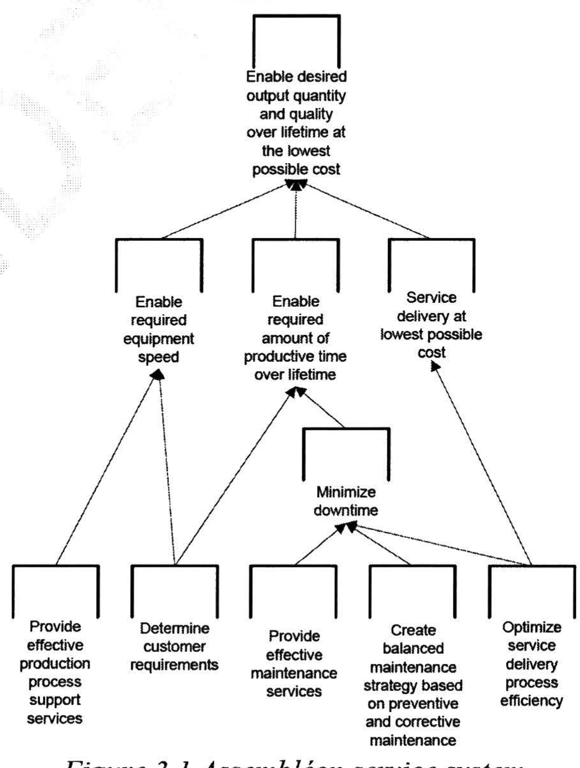

Figure 3.1 Assembléon service system goal model

Deduced from the company mission and in accordance with the definition of Pintelon *et al.* (1992), the service system mission is to permit customers to reach the desired output quantity and quality over the equipment productive lifetime, by ensuring maximum equipment availability at the lowest possible costs. This ultimate goal is represented on the top level in the goal model in Figure 3.1. Konopka (1995) proposes a model in which various equipment states are combined with various equipment processing speeds (see Appendix VI). Based on this model, the sub-goals are distinguished: a sufficient equipment speed to reach the desired output, a sufficient amount of productive time and efficient processes to minimize costs. A sufficient amount of productive time is provided by minimizing the amount of downtime. Sufficient equipment speed can be realized by offering the customer effective production process support, in the form of training and consulting services. Based on the classification of maintenance concepts proposed by Gits (1992), a maintenance strategy that is balanced between preventive and corrective maintenance can be developed, ensuring a minimum amount of downtime. Furthermore, assuming that costs and lead time of the processes are positively related, optimizing the efficiency of the service delivery processes leads to both cost price and downtime reductions. Finally, accurate determination of the customer requirements enables the service system management to manage the service delivery system accordingly.

3.2 Work system Operations Model (WOM)

In this section, different components of Assembléon's realization of the service system will be analyzed. To support the analysis, a service system operations model pattern was synthesized from literature (Appendix VII). The instantiation of the different subsystems in the pattern will be described and the concepts are mapped to COMET+ deliverables; the goal model (section 3.1), the Assembléon and customer actors models (Appendix VIII) and the resources in the business information model (Appendix IX).

3.2.1 Service system governance

The organization of a service system is rooted into the company's mission, vision and strategy. Assembléon's top-level management is responsible for development of the top-level mission and is therefore part of the service system, executing the service system governance function. In order to develop a competitive strategy and matching service system, it is essential that Assembléon's top-level management realizes the importance of services to the company.

Table 3.1 lists the service system governance goals, actors and resources.

Table 3.1 Service system governance actors and resources

Subsystem	Goal	Actor	Resources
Service system governance	• Enable desired output quantity and quality over equipment productive lifetime at the lowest possible cost	• Assembléon top-level management employee	• Company mission, vision and strategy • Service system mission and vision • Market Intelligence

3.2.2 Service marketing

As a result of the strategic paradigm shift towards services as a strategic line of business, Assembléon runs a service marketing unit. It is mainly responsible for developing the service portfolio, using the top-level strategy and market intelligence as inputs.

The traditional part of Assembléon's service portfolio consists of maintenance and technical support services that react to equipment related problems. These services are aimed at installing equipment and restoring performance to specification when a customer experiences degraded equipment performance. In addition, operator training and spare parts are provided at customer request.

To improve the product differentiation of services, the service marketing unit is currently developing new performance improvement services. Whereas traditional maintenance only restores equipment to its original performance capability, the new services provide added value in helping the customer maximizing output by optimizing the production process of which Assembléon equipment is part of.

Within Assembléon's current service portfolio five types of service products can be distinguished; logistics, training, performance improvement, installation and technical support. A table listing the service categories, the various service products within each category and their descriptions can be found in Appendix X.

Table 3.2 lists the service marketing goals, actors and resources.

Table 3.2 Service marketing actors and resources

Subsystem	Goal	Actors	Resources
Service marketing	• Determine customer requirements	• Assembléon service marketing employee • Assembléon key account management employee	• Equipment owner • Equipment owner requirements • Service portfolio

3.2.3 Service operations management

Assembléon's global customer support operations unit and regional operational management are responsible for development and execution of the operating strategy and delivery system. The service system operating strategy generically describes the way in which the service portfolio is delivered to the customer. Assembléon's operating strategy is mainly based on the failure-based maintenance concept. Although the concept is mainly reactive, a limited amount of preventive maintenance is carried out.

Although performance monitoring of the system is an important requirement for effective management and efficient processes, Assembléon has implemented only a limited measurement system, largely due to the limited focus on services and the limited performance measurement possibilities of the information system. Table 3.3 lists the service marketing goals, actors and resources.

Table 3.3 Service operations management actors and resources

Subsystem	Goals	Actors	Resources
Service operations management	• Optimize service delivery process efficiency • Create balanced maintenance strategy based on preventive and corrective maintenance	• Assembléon service operations management employee • Assembléon global customer support management employee • Assembléon technical support & call center manager • Assembléon training manager • Assembléon field service manager	• Service system mission and vision • Service portfolio • Operating strategy • Maintenance policy and maintenance concept • Service activity operational performance

3.2.4 Service delivery system

The service delivery system is the concrete realization of the operating strategy. Within it, two types of activities are distinguished; service activity administration and scheduling and service activity execution.

Service activity administration and scheduling

Currently, the service system interface with its customers consists of call center, through which all services can be ordered. Due to language and time zone differences, each of the three regions has its own call center and regional technical support and field service units are responsible for providing the interface in their region. The customer support coordinator is responsible for planning of on-site and remote service activities into the existing service activities schedule. Obviously, effective and efficient planning requires the availability of CRM data.

Apart from the planning of service activities, customers may order spare parts. Although spare parts ordering is a service activity, administration of this activity is handled by a separate actor, the Assembléon logistics administrator.

Service activity execution

The interface channels a customer service request to the appropriate unit. Training, technical support and maintenance requests are handled by the regional technical support and field service department, for language, time zone and travel distance reasons. Spare parts requests are channeled to the global logistics unit. This unit then ships spare parts orders to the customer. Table 3.4 lists the service delivery system goals, actors and resources for both types of activities.

Table 3.4 Service delivery system actors and resources

Subsystem	Goals	Actors	Resources
Service activity administration and scheduling	• Minimize downtime	• Assembléon customer support coordinator • Assembléon logistics administrator	• Maintenance policy and maintenance concept • Service activity schedule • CRM data
Service activity execution	• Provide effective production process support • Provide effective maintenance services	• Assembléon field service engineer • Assembléon technical support specialist • Assembléon development employee • Assembléon trainer • Assembléon process engineer • Assembléon logistics employee	• CRM data • Logistics data • Operational equipment data • Technical documentation • Service activities data

Service delivery process model

A process model for a single customer request in the service delivery system is depicted in Figure 3.2. Currently, first the customer request is analyzed and a suitable service activity is identified as a spare parts request, a technical support or maintenance request, or a training request. The request is administered and in case of technical support, first line support is provided. A spare parts order is immediately handled by the logistics department. If on-site support by a field service engineer or a trainer is required, a service activity is scheduled in the service activity schedule. In case of insufficient knowledge for on-site support, remote or on-site second line support is provided. If the problem still cannot be solved, third line support is provided by Assembléon equipment development.

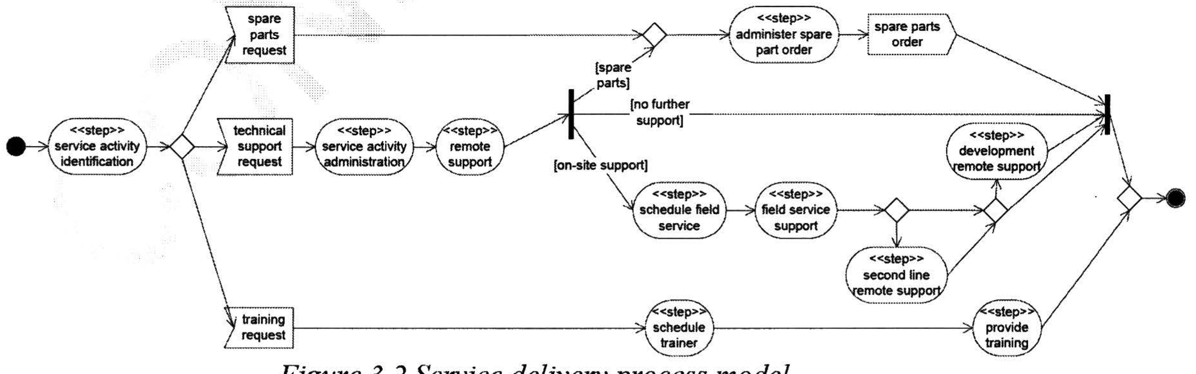

Figure 3.2 Service delivery process model

3.2.5 Logistics management

Assembléon logistics management is responsible for spare parts management, including procurement, inventory management and returns and warranty administration. Currently, Assembléon has outsourced parts warehousing and shipping to Exel. Due to the limited time available for the research project, the logistics process is not part of the scope. However, the interaction with the service system in the form of spare parts delivery is taken into account.

Table 3.5 lists the logistics management goals, actors and resources.

Table 3.5 Logistics management actors and resources

Subsystem	Goal	Actor	Resources
Logistics management	• Minimize downtime	• Assembléon logistics employee	• Logistics data

3.2.6 Equipment development

Technical information resources that are used in the Assembléon service delivery system are produced by Assembléon product development and the service activity history is analyzed for equipment improvement opportunities. Assembléon has implemented service delivery system feedback to equipment development in the form of field problem reports.

Table 3.6 lists the logistics management goals, actors and resources.

Table 3.6 Equipment development actors and resources

Subsystem	Goal	Actor	Resources
Equipment development	• Enable required equipment speed	• Assembléon development employee	• Technical documentation • Service activities data

3.2.7 Customer interaction with the service system

The service system provides value to Assembléon's customers, by converting customer assets into enhanced customer assets. To do so optimally, the service system interacts with the customer in various ways. First, service products are delivered to the customer via the service delivery system, which has been described in the section above. To measure customer satisfaction with the service product delivery, Assembléon conducts customer satisfaction surveys. The results of these surveys are used to improve the service portfolio and service delivery.

Various customer actors are involved in the interaction with Assembléon's service system. They are depicted in the actors model in Appendix VIII. Customer operations employees are responsible for configuring and running equipment and are therefore likely to be the first ones to notice equipment performance problems. Derived from ISMI (2005), four customer operations actors are distinguished; the process engineer, the equipment engineer, the equipment operator and the production manager. The process engineer is responsible for defining the complete process in which Assembléon's equipment fulfills a specific task, thus generating customer production process requirements. The equipment engineer tunes equipment to meet the process requirements and the equipment operator is responsible for managing equipment execution. Finally, the production manager is responsible for managing the complete operational process, measuring its performance and implementing improvements.

Larger customers often operate their own equipment maintenance department. Again, derived from ISMI (2005), two actors are distinguished within the customer maintenance department; the maintenance technician and the maintenance manager. The maintenance technician is responsible for performing periodic maintenance and troubleshooting equipment problems. The maintenance manager is responsible for developing an optimized maintenance strategy.

In case of equipment problems, customer operations personnel is likely to be the first to notice and contact either the customer's own maintenance department or Assembléon's service delivery system.

3.2.8 Service system information resources

Business information is a very important resource in the service system. It is required for effective and efficient delivery of service products. The various types of business information that are used in Assembléon's service delivery process and the relations between the types are represented in the business information model that can be found in Appendix IX. Five types of information resources are distinguished and will be explained below; *operational equipment data, CRM data, service activities data, technical documentation* and *logistics data.*

Operational equipment data
Equipment is run based on *recipes*. Recipes are application specific instructions on how the equipment must carry out its pick-and-place tasks. Furthermore, equipment can be configured with a variety of parameters. As some equipment hardware modules are optional, equipment hardware may differ from customer to customer. The complete combination of software and hardware parameter settings is called the *baseline configuration*. While equipment is running, *events data logs* are created. They include all exception events (e.g. errors and warnings) and non-exception events (e.g. equipment state changes and start and completion of tasks). For Assembléon equipment, event logs are created that are based on the CAMX syntax (IPC, 2006). Analysis of operational equipment data results in *equipment usage data* and *equipment performance data.* Certain *performance requirements* may be defined that must be met to reach the desired output quality and quantity.

CRM data
Subject of the service delivery system is *equipment,* owned by the *equipment owner*. Equipment consists of *modules* and modules consist of *parts*. The equipment owner has a service relationship with Assembléon (the *equipment supplier*) and certain *service requirements*. Three types of relationships between Assembléon and its customers are distinguished; service contract, warranty and per-hour rate. A *service contract* is a formal definition of the service products that will be delivered to the customer at a fixed price over a certain period. If the customer chooses not to establish a service contract relationship, the customer still can order services, but these will be billed at a per-hour rate for manpower and a list price for spare parts. Warranty can be seen as a special type of service contract, as it includes a variety of services that will be delivered at no extra cost (obviously, the costs are included in the equipment price) over the period of one year after purchase of equipment.

Service activities data resources
Service activities are service products that are delivered by Assembléon support personnel to equipment. More specifically, subjects of the service activity are specific modules or parts of equipment. As noted in section 3.2.2, different types of service products are distinguished that together form the service portfolio. Thus, a service activity is always of a certain type.

Service activities are triggered by a customer *request*. In case of a problem, the *root cause* is identified, as well as a *solution*. Operational implementation of service activities management includes maintaining a *service activity schedule*. The actual service activity is then executed resulting in a specific *service activity operational performance*.

Furthermore, if an employee identifies a root cause and a solution that calls for structural equipment improvements, the employee can create a *field problem report*. This report functions as a request for change for product development.

Technical documentation resources
Part of Assembléon's development process is the documentation of equipment and parts. Not limited to designs and specifications, technical documentation also includes service product delivery process definitions.

Logistics data
For spare parts logistics management, including inventory management, *spare parts* information and *spare parts events* must be administered. Furthermore, for each part, a supplier is defined, which in case of in-house production may be Assembléon itself. Finally, as some parts are readily available for purchase as a *service part* by a customer, a list price is maintained.

3.3 Cumulative Requirements Model (CRM)

The Cumulative Requirements Model defines the accumulated requirements for the current IT-reliant part of the service system; generally, functional and non-functional requirements are distinguished. Functional requirements determine what functionality a system should provide, whereas non-functional requirements determine the qualities of the system other than the functions it should provide.

Currently, Assembléon has implemented a service system information system providing the functions as described in Table 3.7 for each of the information resources.

Table 3.7 Current service system information system functional requirements

Information resource type	Service system information system function
CRM data	• Equipment owner records creation and maintenance (customer relationship management) • Financial CRM (service contracts, invoices and accounts payable)
Service activities data	• Work order creation, scheduling and execution for both preventive and corrective maintenance • Partly equipment work order history
Operational equipment data	• Limited equipment configuration creation and maintenance • Transport of raw data
Technical documentation	• Management of equipment technical documentation
Logistics data	• Logistic management of spare parts (e.g. inventory control, purchasing)

3.4 Cumulative Component Model (CCM)

In this section, the Cumulative Component Model is presented, describing the current components that have been implemented to meet the cumulative requirements of the system. First, a general overview of the service system information system components is given. Then, specific e-maintenance components are described.

3.4.1 Service system information management components

Figure 3.3 depicts the current architecture and components for management of the resources in the business information model (Appendix IX).

In accordance with the cumulative functional requirements, components have been implemented to manage *CRM data, service activities data* and *technical documentation* and *logistics data*. Currently, the components are accessible separately and combined use of the resources is hard.

Operational equipment data is currently available on equipment itself. For the Assembléon service system, it is accessible only on a limited basis, as only a small amount of customer's equipment have been outfitted with a component for remote access of baseline configuration data, recipes and events. The current component does not contain logic and is also implemented separate from the other resources' components.

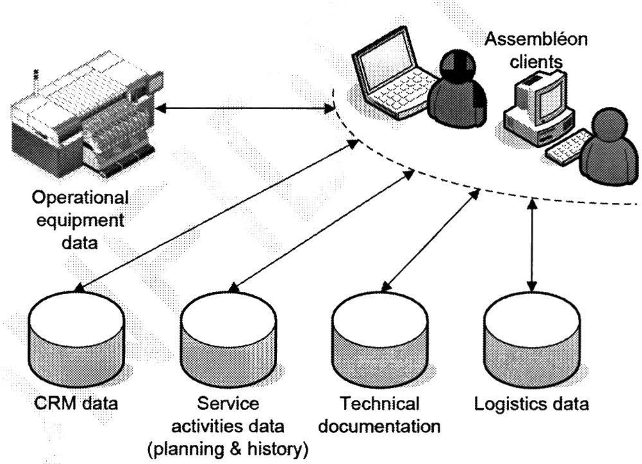

Figure 3.3 Service system information architecture

3.4.2 E-maintenance components

As can be seen in the component model in Figure 3.3, Assembléon has already implemented a basic system for transporting raw operational equipment data from equipment to Assembléon users. It only provides level-1 transportation of raw equipment data.

The current system consists of equipment data capturing, data transmission, data storage, data retrieving and data presentation components (see Appendix XI for types of data processing components). Data capturing is realized by equipment sensors that directly store data in the data storage component. The data storage component contains equipment event logs, equipment recipe data and equipment baseline configuration data. The data is retrieved and presented on user request by the retrieving and presentation components. Currently, a real-time data streaming interface is in place, but it is not yet used. A component model of the current situation can be found in Appendix XII.

Currently, the underlying infrastructure enables the current components to interoperate and consists of a basic directory service, security service and system management service. The directory service provides clients with information on where to find what service and how to interoperate with that service. The security service provides user authentication services to prevent unauthorized use of the Assembléon e-maintenance interface. System management services are used to manage the system infrastructure, for example to update the service directory, or to add or delete users.

3.5 Platform Specific Model (PSM)

The Platform Specific Model describes the deployment of the components in the current architecture. In this section, deployment of the general service system information system components and the specific e-maintenance components are discussed.

3.5.1 Service system information management components deployment

Currently, the information system used to manage CRM data resources, service activities and logistics data is MFG/Pro. It is used to manage basic customer information, such as name and equipment owned, as well basic financial data. Furthermore, customer requests are registered, as well as basic information on root causes and solutions. Finally, spare parts orders administration and inventory management is done through this system.

Service activities planning is done manually on paper and by using the calendar function in Lotus Notes.

Technical documentation is currently managed in Lotus Notes and UGS Teamcenter Engineering.

3.5.2 E-maintenance components deployment

Assembléon has deployed a global *Assembléon data center*, which enables remote access to *customer's equipment computers* via an internet-based network connection. As the current system only provides access to raw equipment data resources, deployment of the components is limited to equipment and the data center.

On the equipment computer, data is captured from the operational process by the *data capturing* service. The captured data is stored in *event logs* residing on the equipment computer. The captured data is also streamed by a *real-time data streaming service*, but this output is not yet used. A *level-1 raw data access service* component is deployed on the equipment computer to provide access to the equipment operational resources, being the *event logs, recipes and the baseline configuration*. Furthermore, a local *user interface* is provided as well.

At Assembléon's data center a *level-1 data presentation service* component is deployed, which provides access to operational equipment data via the level-1 raw data access service. The data center services are able to interact with the equipment services via an *internet-based VPN*. Services are able to discover each other on the network via the *directory service component.* Furthermore, a *security service* component is responsible for authenticating users for use of specific services' functionality. Finally, a *system management service* runs on the data center server to provide administration functions, such as adding users and services.

User access to the data center service components is provided globally via a *remote desktop application*, which extends the data center functionality to remote desktops via a second VPN (the Philips Global Network).

Currently, Assembléon's other service system data resources, such as *CRM data, service activities* and *technical documentation* reside in separate systems, without a link to the e-maintenance system. Thus, combination of the data resources is not possible.

For the near future, implementation of an *on-site data server* is planned. This server is to collect data for tracking and tracing functionality. It is currently not used in the e-maintenance system, but will be taken into account as a possible processing node in the proposed design and is therefore depicted in the current situation.

A deployment diagram of the current system is depicted in Appendix XIII.

3.6 Project portfolio

In this section, the current service system life cycle situation will be discussed, as well as problem areas in the system. Furthermore, areas of improvement will be described.

3.6.1 System life cycle applied to Assembléon

Applying the system life cycle concepts to Assembléon's current service system, it is presumably rendered obsolete by the opportunity of e-maintenance technology and the inefficiency of the system. As Assembléon's overall financial performance has been unsatisfactory, a performance alert is triggered. Assembléon's customer support global operations unit expects considerable improvements to the current service system can be gained by implementing e-maintenance technology. Thus, obsolescence of the customer support work system is triggered by a supposed new opportunity and a business problem (Figure 3.4). In reaction to the obsolescence of the customer support work system, project portfolio management is triggered and a system redevelopment project is started. The TOAST initiative is part of this redevelopment project.

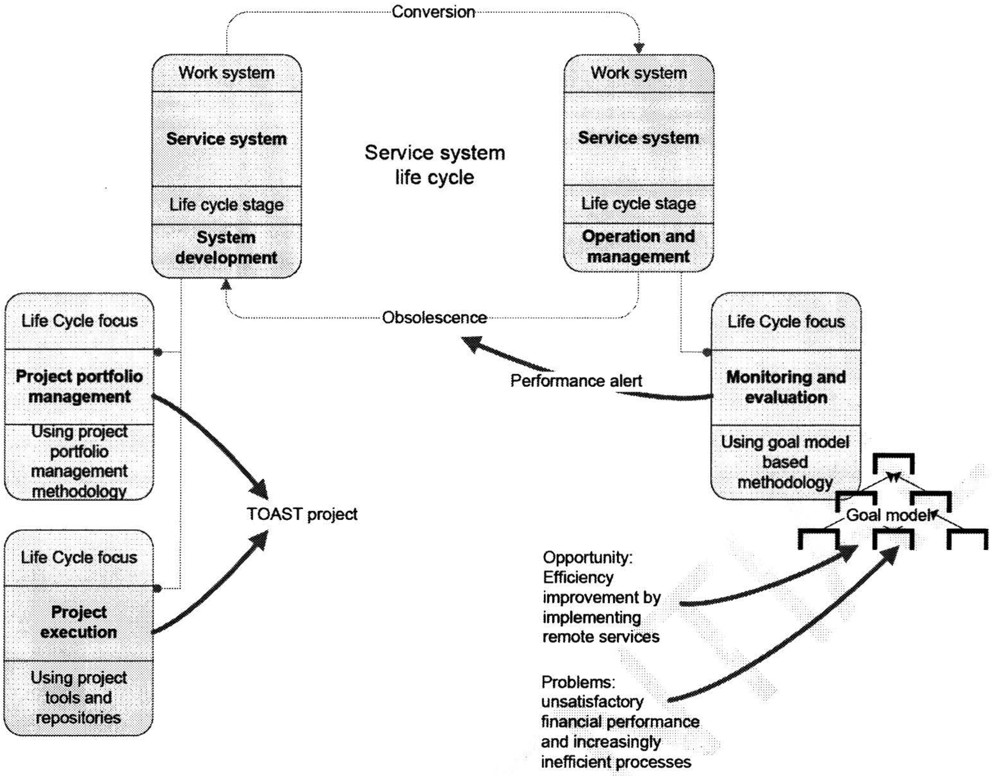

Figure 3.4 System life cycle concepts applied to Assembléon

3.6.2 Service system problem areas

To determine areas of improvement of the current service system, semi-structured interviews (see Appendix XIV) with stakeholders throughout the service system have been conducted. This has resulted in a set of problems that have a negative effect on the service system performance. To provide a clear overview, three problem levels are distinguished; strategic, tactical and operational. Furthermore, a distinction is made between core symptoms, main causes and sub causes. A well known technique to visualize this distinction is the cause-and-effect diagram (Van Aken *et al.*, 2003). The core symptom is placed at the far right of the diagram. Main causes are categories of sub causes and are displayed at the ends of the large arrows. Sub causes are then placed under each main cause, next to smaller arrows. In the following sections, the problems on the strategic, tactical and operational level will be discussed and for each of the levels a cause-and-effect diagram will be presented.

Strategic level

On the strategic level, Assembléon's service system performance is to be improved. As spare parts sales and margins decrease, profitability decreases as well.

First, Assembléon manages the life cycle of its service system only on a basic level. No complete architectural repository exists and performance measurement is done only on a limited basis. Specifically, the relations between operational and tactical processes and the strategic goals are not clearly defined. Insufficient life cycle management is a problem throughout the whole system; it results in tactical and operational problems.

First, service sales are decreasing, thus reducing service system profits. Traditionally, the services business model was geared towards generating profits from spare parts services. However, as equipment is tending towards a commodity, equipment quality is not a differentiator but a requirement just to compete. This results in more reliable equipment and reduced sales of spare parts. Furthermore, operational service delivery costs are relatively high, decreasing product margins.

Historically, Assembléon's mission was to provide customers with equipment and Assembléon's strategic focus was aimed at providing differentiating equipment value. Services were being offered, but were seen as a necessary evil and were managed as a cost center. Currently, this approach is not viable anymore. In the current market, offering a differentiated product is essential, but competing just on equipment differentiation becomes increasingly harder, whereas services still show potential. Over the years, many maintenance innovations have been developed in the market, but Assembléon has not implemented all of them. Thus, rooted into the tactical level, the current service portfolio can be improved. Rooted into the operational level, the efficiency of the service delivery process can be improved as well.

Inefficient service delivery also results in high service delivery costs and a high service delivery lead time and thus in reduced profit margins.

As the paradigm shift towards Assembléon as a service provider is only a recent development, it has not been fully integrated into the organization yet. Although the value of services may be recognized more now, Assembléon's culture still holds a relatively strong technical focus.

Finally, the service system and equipment development and production systems are not fully integrated. For example, equipment marketing and services marketing are separated. As the strategy shifts towards a more balanced approach, all processes will be better integrated and synchronized, resulting in synergetic cooperation between all subsystems.

The strategic level problems are depicted in Figure 3.5.

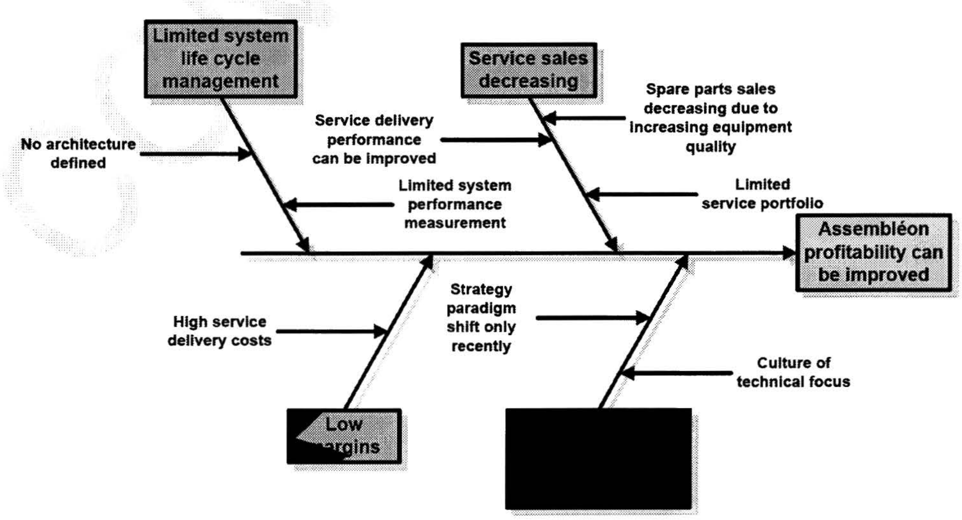

Figure 3.5 Strategic level problems

Tactical level
The service portfolio and service concept can be regarded as the tactical level in the service system. The undesired effect that is perceived is that the competitiveness of the current service portfolio can be improved. Four main causes have been identified.

First, the focus of the current service portfolio is limited. It mainly focuses on equipment itself. As equipment performance depends on its environment as well, it can be improved by environmental factors such as the production process that the equipment is part of. The current service portfolio does contain a 'production audit' service, but this has been introduced only recently and is offered only on a limited basis.

Second, performance measurement of the service concept is limited, mainly due to limited insight in customer requirements and customer satisfaction. Clearly defined customer requirements are important for effective and efficient delivery of service products. Also, feedback of current customers is an extremely valuable factor in optimizing the service concept. It is currently only measured on a limited basis and customer satisfaction measurement can thus be improved.

Third, the current service concept has its limitations. Operational costs are high (resulting in a high total cost of ownership for the customer and a lower profit margin for Assembléon) and service quality is not fundamentally different. Rooted in the operational level, the service delivery process is not designed to deliver performance improvement products. The service concept is based on a reactive strategy, whereas a mix of reactive and proactive concepts would usually result in lower costs, lead-time and customer satisfaction. Customers that experience problems would ideally want the service provider to have acted before the customer even noticed a problem, to limit unscheduled downtime and lost production (Tsang, 1995).

The tactical level problems are depicted in Figure 3.6.

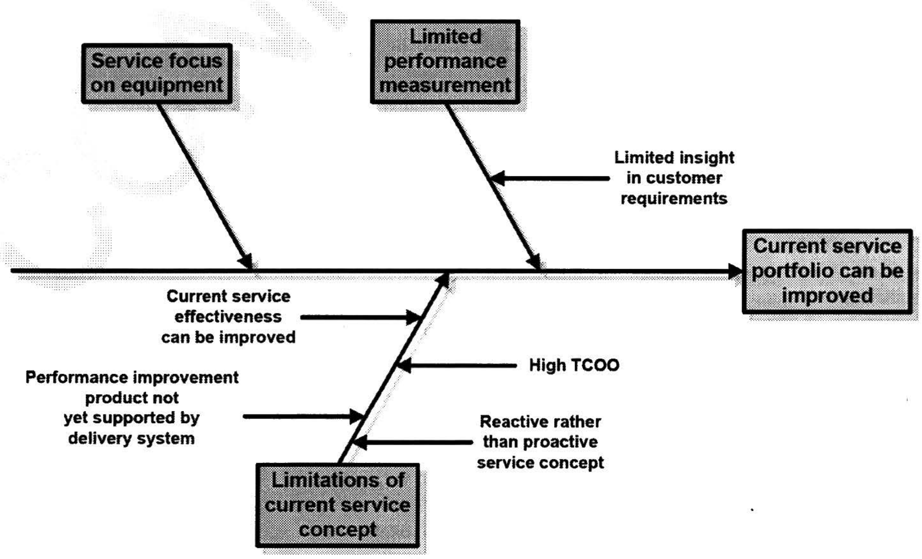

Figure 3.6 Tactical level problems

Operational level
On the operational level of the service system, several problem areas have been identified in interviews with stakeholders in the service system. The identified effects include:

- The *mean time to solution* is high, generating high labor costs. Increasing the efficiency of the service delivery system will result in lower operational costs. Currently, the mean time to solution is not measured, mainly because the information system that is used for call logging currently has no function to do so.
- The *first contact* (via phone) *solution rate* is low, generating high travel costs and waiting time because field service engineers have to travel to the customer's site. In the American region, the first contact solution rate is currently 80% for machine down problems (thus not including general technical support). Machine down calls make up 4% of total calls (see Appendix XV for calculation)
- *Wrong spare parts sent* as a result of wrong phone diagnosis, generating waiting time for the repair engineer and extra shipping costs to send the wrong parts back and the right parts to the site. Customers may also return spare parts under warranty (RMA) that are not broken. This generates extra warranty costs for shipping and replacing non-faulty parts. Equipment quality problems have aggravated this problem.

These identified effects are summarized as 'high service delivery costs and lead time'. Causes for these effects are to be found in the operating strategy and the delivery system.

Within the delivery system, maintenance information management is an issue. The information resources are hardly integrated, therefore excluding synergic use of the resources. Furthermore, several information resources are not managed effectively, partly due to the inadequate information system (MFG/Pro).

First, service records for each machine have limited detail. Assembléon personnel are not able to see what activities have been carried out on specific equipment. This makes problem identification harder. The current service information system is not suitable for an extensive service history. Relating to the business information model, a history of service activities cannot be looked up easily.

Second, operational equipment data is not used optimally. Currently, the only way of transferring this data from equipment to customer support personnel is via phone or via the level-1 data transport system that is installed at a limited amount of customers. This method does not allow the information to be stored and analyzed easily. Also, the level-1 system has limited functionality and the organization is not designed to use this information resource. The level-1 system has been implemented only recently and users have not been trained to use such tools efficiently and effectively.

Third, Assembléon's administration of the installed base has limited detail. When a customer calls with a problem, Assembléon support personnel are not able to directly see the complete equipment configuration, therefore having to ask the customer for detailed specifications. Again relating to the business information model, equipment baseline configuration cannot be looked up easily.

Already introduced with the strategic level problems, the limited life cycle management of the service system prevents management from optimizing the system's efficiency and optimization of the operating strategy, which is not optimally suited to deliver quality services at low costs in the current market.

First, the operations strategy is aimed at minimizing customer downtime. This is not a strategy that ensures maximum profit in case of customers that are charged per-hour. The per-hour rate includes a profit margin, thus as more hours are sold, more profit is generated. However, as the strategy is aimed at minimizing the amount of hours, profit is minimized as well. Of course, the more hours it takes to solve the problem, the lower customer satisfaction will be.

Second, part of to the limited management of the system's life cycle, its performance is not structurally measured. No formal targets have been set for process performance on an operational level. Employees that work without targets will work less efficiently. Furthermore, it will result in a limited insight in process performance and costs, limiting the ability to manage on costs. Relating to the business information model, service delivery performance is not measured and therefore cannot be used for effective service delivery management. This problem is partly rooted in the limited functionality of the current implementation of the information system MFG/Pro.

Third, the service delivery model for these services can be improved. It relies heavily on phone diagnosis and field service. As not all problems can be solved by phone, this delivery model generates high labor, travel and parts shipping costs. Increasing equipment complexity and geographic coverage of Assembléon customers amplify the need for updating the technical support and maintenance operations model.

The operational level problems are depicted in Figure 3.7.

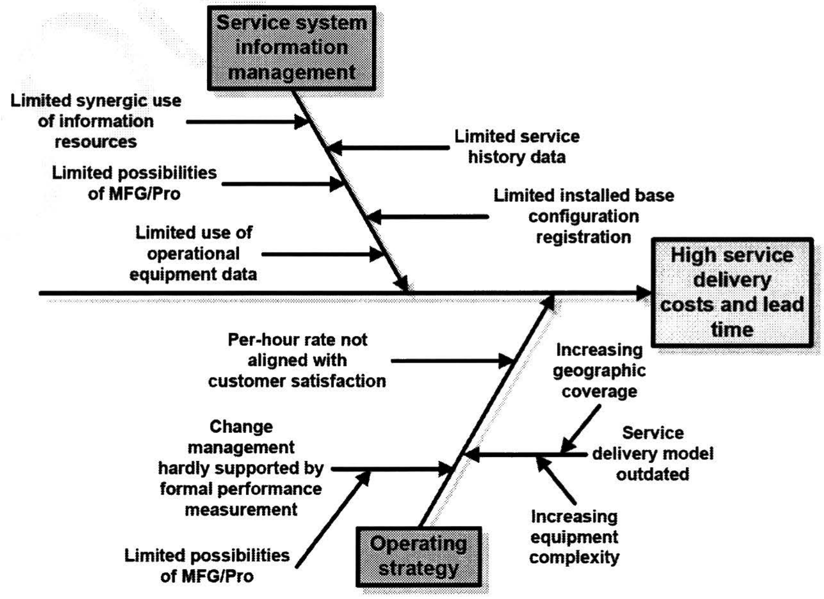

Figure 3.7 Operational level problems

3.6.3 Areas of improvement

From a service perspective, strategic, tactical and operational improvements must be carried out in order to improve profitability of the organization. For effective strategic management of the service system, life cycle management is essential. A change management program, including maintenance of an architectural repository, as well as continuous monitoring of the system's performance relative to predefined goals, is required.

Furthermore, the focus is shifting towards services. Services are now seen as a strategic line of business. This paradigm shift calls for a tight integration of the service system into the rest of Assembléon's organization and processes. Also, adaptation of Assembléon's business model might be required. As the importance of services has been established only recently and strategic changes take a considerable amount of time to implement, the transformation of the organization is not yet complete.

On the tactical level, extension of the service portfolio is already being developed. Results should include a balanced portfolio with both performance restoring services (technical support, maintenance and spare parts) and performance improvement services (production process consulting). By introducing new performance improvement service products, Assembléon hopes to compensate for the decreasing sales of spare parts and increase overall service profitability.

To optimize the service portfolio, customer requirements must be measured and integrated into the service concept. If customer demands are explicitly known, targets for each part of the service concept can be determined. The operation strategy and service delivery system can then be managed to meet these targets.

Operational changes are currently being developed as well, to meet changing strategic and tactical requirements. The need for efficient delivery of new and current service calls for a redesign of the operating strategy and service delivery system. As shown in Figure 3.7, the use of information resources in the service delivery process can be improved. Some information resources are not used at all and the resources that are used are not used optimally. Furthermore, methods of transfer of resources are also can also be optimized, as operational equipment data is currently transferred by phone and the level-1 system provides only limited functionality. As to eliminate these inefficiencies, improvement initiatives have been developed.

Among other initiatives, the MFG/Pro system will be replaced by a new ERP implementation in the future, optimizing management of local information resources. While this system will increase efficiency and effectiveness of management of local data resources such as CRM data, service activities and possibly technical documentation, it is unable to utilize remote data resources, such as operational equipment data. As e-maintenance technology offers possibilities for processing of remote operational equipment data, changes to the service system architecture should include e-maintenance technology. Furthermore, a proactive service delivery strategy should be considered. Not only does it decrease the equipment downtime at the customer's site, planned activities also tend to be cheaper and can be executed faster, thus increasing the service delivery efficiency.

Finally, improved system life cycle management also yields operational results. Operations performance measurement enables effective management and increased efficiency of the service delivery system.

3.6.4 Project charter and design objective

In accordance with the goals from the TOAST project, extension of the service system with e-maintenance technology is chosen from the areas of improvement as the design objective. Before such an extension can be implemented, the architecture must be adapted to structurally accommodate improvement projects by implementing an open and responsive change management program. As a starting point for discussion of the required architectural changes, the design objective is defined:

"Design a flexible e-maintenance extension for the current Assembléon service system, providing actors in the system with capabilities for optimized processing of operational equipment data, thus enabling more efficient and effective delivery of current service products, as well as the introduction of new service products. Furthermore, the current architecture must be adapted to facilitate a program for incremental implementation of the design."

Chapter 4 Proposed service system changes (to-be situation)

In this chapter, extension of the current service system with e-maintenance technology will be proposed. First, the current architecture is adapted to accommodate changes and extensions in general. Then, as the focus of the e-maintenance extension is on IT reliance, the changes will be proposed relative to the current architecture's requirements (Cumulative Requirements Model), components (Cumulative Components Model) and deployment (Platform Specific Model), as presented in Chapter 3. Furthermore, the implications of the changes in IT reliance for the organization will be briefly examined in terms of changes relative to the Work system Operations Model. Finally, the proposed changes are validated with the Assembléon stakeholders against the requirements.

In this chapter, the following research questions are answered:

(3) *What changes to the current Assembléon service system are required to implement e-maintenance technology?*

(4) *What are the benefits of application of e-maintenance technology within the Assembléon service system, specifically in relation to the problem areas as identified in research question (2)?*

4.1 Δ Value And Risk Model (ΔVARM)

Currently, the goals in the service system goal model (Figure 3.1) are not structurally enforced. Thus, to be able to effectively reach the goals through strategic management of the service system, implementation of a change management program for life cycle management of the service system (Figure 2.1) based on the goal model is proposed. It consists of maintenance of the current architecture repository and continuous monitoring of the system's performance relative to a predefined set of performance targets, based on the goal model.

The following elements in the service system change management system are proposed:

- *Maintenance of repository;* a repository of models of the service system architecture is maintained. This repository is the formal definition of the service system. In this report, a basic repository is developed with the COMET+ models as deliverables. The models in the repository serve as a starting point for performance measurement and improvement projects.

- *Measurement of system performance indicators;* based on the system models in the repository a performance measurement system is implemented. Basically, actual performance of the system processes as defined in the Work system Operations Model should be compared to predefined values for performance indicators derived from the goals in the goal model. Strategic, tactical and operational goals should be addressed. Assembléon measures its overall strategic goals in the balanced scorecard, thus the strategic service system goals are derived from the balanced scorecard goals. From the strategic goals, tactical and operational performance indicators are derived. Komonen (2002) provides a hierarchy of maintenance performance indicators which can serve as a framework for actual development of a measurement system (see Appendix XVIII). In the model of Komonen, strategic, tactical and operational performance indicators are linked to each other.

- *Portfolio management;* portfolio management is the activity of managing system improvement projects. As can be seen in Figure 2.1, improvement projects result from directives, performance alerts or opportunities. Performance alerts result from actual values that exceed predefined values in the measurement system. For each of the improvement projects in the portfolio, the regulative cycle is executed, possibly extended with one or more specific methodologies. In the regulative cycle, the problem choice is facilitated by continuous measurement of performance indicators, as it simplifies the quantitative estimation of expected service system performance improvement, which in turn provides data for the determination of the ROI for each project. Furthermore, the diagnosis and analysis phase is supported by the properly maintained system architecture repository, as no architectural analysis is required each time the regulative cycle is executed.

The project as described in this thesis comprises one regulative cycle and provides initial models for the architecture repository.

4.2 Δ Work system Operations Model

In sections 4.4 and 4.5 changes to the information system architecture are presented within the current architecture. The information system changes lead to the development and availability of a set of tools that support the actors in the service system. The impact of the information system extension will differ from actor to actor. In general, changes of the Work system Operations Model will be to include the information system e-maintenance extension in the set of tools for service system management and service product delivery.

4.3 Δ Cumulative Requirements Model (ΔCRM)

In this section, requirements for the system changes are determined. A distinction is made between functional and non-functional requirements.

4.3.1 Functional requirements

Various actors in the service system may require different system functions. Furthermore, different system functions may require different levels of automation. In interviews with stakeholders in Assembléon's service system, functional requirements have been determined from the identified service system problems. The proposed extension of the system's functions is visually represented in the use cases model in Appendix XVII. The use cases are only presented as a guideline, as the requirements are only defined on a high level. In each case, more specific definition is required for actual development.

It should be noted that e-maintenance technology can provide benefits to other stakeholders as well, such as Assembléon's customers or other Assembléon stakeholders, but as the scope of this research is limited to Assembléon's service system, these benefits will not be described as functional requirements.

The proposed functionality is only a starting point and more beneficial functions may be added in the future. Therefore, extendibility will be introduced as an important non-functional requirement in the next section.

Level-1 access to raw operational equipment data is provided. Raw operational data consists of the event, recipe and baseline configuration classes in the business information model. As only specialized technical personnel is able to analyze and interpret raw data, this function is provided only to Assembléon maintenance operations personnel, including field service engineers, technical support specialists and development employees, as well as specialized customer maintenance engineers.

Level-2 performance reporting functions are provided at three aggregation levels; equipment, production line and the complete installed base. In the business information model, two classes can be found that represent analyzed data: equipment usage data, which is aggregated event, recipe and baseline configuration data and equipment performance data, which is equipment usage data manipulated to represent equipment performance. Maintenance operations personnel can use equipment performance reports to troubleshoot equipment. Process engineers can use production line performance reports to optimize production operations. Furthermore, they can use equipment performance reports to optimize specific machines. Assembléon development can use installed base performance reports to analyze performance trends in the complete installed base that may indicate structural problems or equipment improvement opportunities. Assembléon maintenance management can use production line performance reports for optimizing maintenance activities. Finally, Assembléon key account management can use production line reports to monitor line performance in relation to promises that may have been documented in service level agreements.

On top of automated performance reporting, level-3 condition monitoring is implemented. Maintenance operations may be notified of equipment performance exceeding specific predefined values that indicate equipment failure in the near future. The predefined values can be found as the performance boundary conditions class in the business information model. Maintenance management can be notified of equipment exceeding conditions to schedule maintenance activities. Furthermore, process engineers may be notified of performance deviations that may result from suboptimal process parameters. Finally, Assembléon key account managers may be notified automatically in case of service level agreement violations.

Level-4 functions do not require the involvement of human actors; actions are automatically taken by the system, either manipulating the equipment itself, or the other service system resources. As stated before, a clear definition of an activity is required for automation of an activity carried out by humans. Several actions can be defined, including, but not limited to, automatic scheduling of engineers, ordering of spare parts or equipment configuration manipulation.

The functional requirements are summarized in Table 4.1 and linked to the actors model in Appendix VIII.

Table 4.1 Functional requirements

Functional requirement	System level	Actors
Enable real-time access to raw operational equipment data, going back a relatively small amount of time	Level-1	Assembléon maintenance operations
Enable viewing of equipment performance reports, going back a considerable amount of time	Level-2	Assembléon maintenance operations Assembléon process engineering
Enable viewing of production line performance reports, going back a considerable amount of time	Level-2	Assembléon maintenance management Assembléon process engineering Assembléon key account management
Enable viewing of installed base performance reports, going back a considerable amount of time	Level-2	Assembléon development
Enable real-time equipment performance notifications	Level-3	Assembléon maintenance operations
Enable real-time line performance notifications	Level-3	Assembléon maintenance management Assembléon process engineering Assembléon key account management
Enable automatic actions	Level-4	Automatic actions do not require an actor

4.3.2 Non-functional requirements

Non-functional requirements describe preconditions that the system architecture must meet in order to be able to effectively fulfill the functional requirements. Based on the model of non-functional requirements as proposed by Bowen *et al.* (1985), the ISMI (2005) guidelines and interviews with Assembléon stakeholders, non-functional requirements for the proposed system are determined (Table 4.2).

Table 4.2 Non-functional requirements

Non-functional requirement	Description
Incremental implementation of functions	The field of e-maintenance is relatively young. Experience in the industry is limited and mostly proprietary. There is a limited amount of publicly available research, but it often describes only level-0, level-1 and parts of level-2 in detail. Developing a level-2, level-3 and level-4 system is a complex process and implementing a proactive operating strategy requires a significant effort (Bangemann *et al.*, 2006). Experience with implementation of lower levels will help when implementing the higher levels. Therefore, the architecture must be designed so that different levels can be implemented incrementally, starting with the lower level functions.
Use of mainstream and open communication standards	Protocols used in the system architecture should be based on open standards. Hoe (2005) identified the following benefits, as opposed to proprietary standards: • less chance of being locked in by a specific technology and/or vendor • easier for systems from different parties or using different technologies to interoperate and communicate with one another; improved data interchange and exchange • better protection of the data files created by an application against obsolescence of the application Operational equipment data is not only valuable to Assembléon, but to its customers as well. To be able to maximize the value of the data for customers, the data must be easily exchangeable with the customer's systems. Open standards ensure this is possible.

Scalability	The solution must be easily scalable to accommodate for expansion of: • the installed base; the system must be able to cope with a growing amount of sites with equipment with e-maintenance capabilities in the field. • the amount, type and location of users; new applications of e-maintenance technology may involve the introduction of new users. For example, the introduction of equipment performance monitoring for customers may introduce a considerable amount of new users. Furthermore, these users may be dispersed globally and might require larger amounts of data and information.
Interoperability	Industrial enterprises represent a collection of activities. In the past, these activities were studied with the objective of optimization and increasing profits. But, having optimized different activities individually, it appeared that for global optimization, activities had to be integrated into a single platform. (Bangemann et al., 2006). By implementing an e-maintenance system, the operational equipment resource is made available, optimizing processes such as technical support and performance improvement. However, to fully optimize these processes, integration of all required resources is needed. Synergy is created by integrating CRM, service activity, technical documentation and operational equipment data resources and tools. In conclusion, an e-maintenance system must be designed so that it can be integrated with other resources into a larger system.
Interface customization	A large variety of potential system users are identified. To fulfill all users' requirements, the system's user interface must be easily adaptable for different views.
Reliability	The e-maintenance system must be reliable (high uptime) and must not go down with equipment. Furthermore, if the e-maintenance system breaks down, it must be clear that it is not equipment that is causing problems.
Use of current infrastructure / Porting to new infrastructure	In order to minimize investments, the solution must make use of the current infrastructure. Furthermore, the design must anticipate future infrastructure changes. Migration to a different infrastructure should not render the system useless.
On-site safety	Remote operation may cause unexpected results for on-site equipment personnel, equipment and facilities. Therefore, the solution must take safety into account.
Security	Exposing equipment data to an (outside) network involves a major security risk. As equipment is used in critical processes and uses critical data such as production recipes, security measures must be very strict to protect data. Hung et al. (2005) propose that data security is the most important issue for an e-diagnostics system.
System may not negatively affect equipment performance	Applications running on the equipment itself may not affect performance of the equipment itself.
Network performance	As relatively large amounts of data must be transported, network performance must be sufficient to accommodate for transferring the data. Furthermore, network performance must be able to accommodate for the expected growth of the system, by being scalable.
Data redundancy	Redundant data causes excessive data storage and the risk of inconsistent data.

4.4 Δ Cumulative Component Model (Δ CCM)

In this section a logical design will be presented. This design depicts the components that are required to fulfill the functional requirements. First, the generic service system information management components are described. Then, specific e-maintenance components are discussed.

4.4.1 Δ Service system information management components

From the functional and non-functional requirements, an e-maintenance solution must be designed as part of an integrated, extendable system, taking into account the value of all service system information resources. The proposed solution can be seen as an integrated architecture for management of service system information resources information.

The architecture provides a variety of users in the service system with software components for access to and manipulation of operational equipment data, CRM data, service activity data, technical documentation and logistics data. The variety of users is based on location, device and business role, as various business roles (see the use cases diagram in Appendix XVII) need to access the system globally via various types of devices (such as laptops, desktops and PDAs).

Not only does the proposed architecture connect clients with all business information resources; for operational equipment data, it also connects Assembléon equipment with the service system, so that operational equipment data becomes available for storage, analysis and reporting.

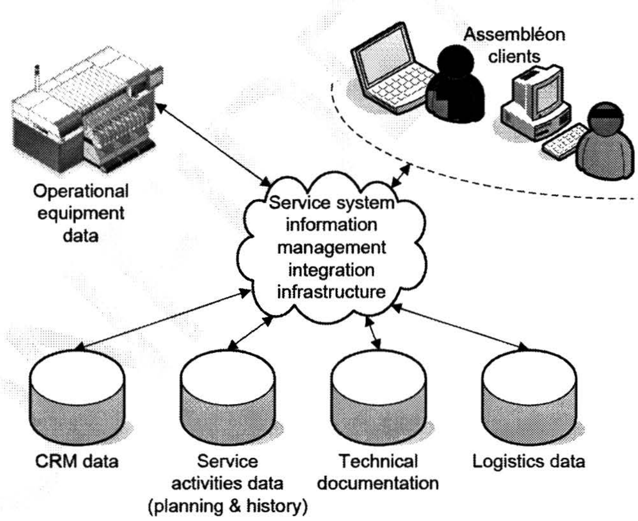

Figure 4.1 Proposed service system information management architecture

4.4.2 Δ E-maintenance components

In this section, part of the service system information management architecture is elaborated, focusing on the e-maintenance part, which connects equipment and clients and enables effective and efficient use of operational equipment data.

In the proposed situation, extension of the current level-1 system architecture with level-2, level-3 and level-4 functions that meet the functional and non-functional requirements is shown. A component model of the proposed situation is depicted in Figure 4.2.

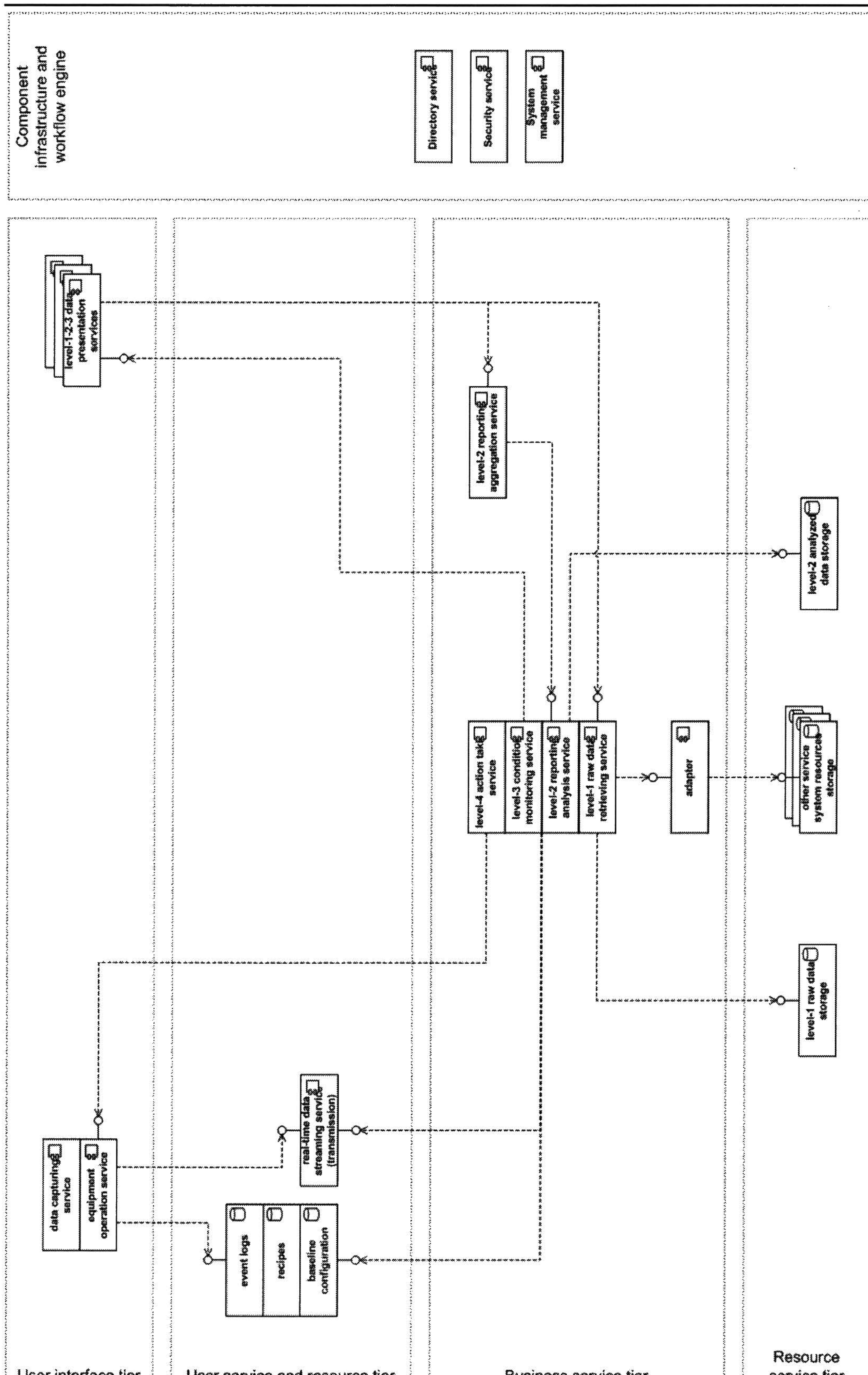

Figure 4.2 Proposed component model

In the current situation, *level-1 data* is accessible, but resides directly on the equipment computer (*event logs, recipes* and *baseline configuration*). This solution does not meet a number of non-functional requirements. First, the solution is not secure. As the equipment computer is directly exposed to an outside network, hackers may not only get access to equipment data, but may also be able to bring equipment down. Furthermore, the equipment computer has limited reliability. It may go down, due to either hardware or software problems, rendering the equipment data inaccessible and therefore useless for troubleshooting purposes. Not only may the data become inaccessible, in case of storage failures data may be lost as well. To solve these issues, data is stored and made accessible outside the equipment. Therefore, level-1 business services and resources are introduced; the *level-1 raw data retrieving service* and the *level-1 raw data storage components*. The level-1 raw data retrieving service gathers equipment data from the real-time data streaming service. This data is stored in combination with recipe and baseline configuration data. The data is then presented on-request at the *level-1 data presentation service*.

The core level-2 reporting function is reporting logic; therefore, a *level-2 reporting analysis service* is proposed. Input data for the reporting analysis is sourced from the real-time data streaming service and the data is combined for different views. To limit the amount of data storage, no raw data is stored. To realize real-time analysis, data manipulation models must be fully defined beforehand, or must be developed real-time. New analysis models cannot be applied to historic raw data, as raw data is only available for a very limited amount of time. As analyzed data must be available on-request, it is stored for a finite amount of time in the *level-2 analyzed data storage*. A service component for *level-2 data presentation* is implemented as well.

For level-3 functions, a *level-3 condition monitoring service* is implemented on top of the level-2 reporting analysis service. The condition monitoring component constantly compares captured data with predefined limiting values. When a predefined value is exceeded, notifications are being sent via the *level-3 data presentation service*. Basically, the conditions are being constantly monitored, so that equipment problems can be anticipated. As problems are diagnosed before they actually take place, human actors can take corrective action in advance. Thus, the level-3 presentation service must have an interface for receiving incoming notification messages.

Level-4 functions are carried out by a *level-4 action taking service*. This component works together with the level-3 component, so that when a predefined condition is met, the level-4 service automatically takes action. The following actions are identified:

- the service taking corrective action itself, correcting the equipment via an interface in the equipment operation service
- the service notifying of a human actor with steps the actor has to take to correct the diagnosed condition; possibly including automatic scheduling of manpower or ordering of parts

Extending level-3 condition monitoring, the level-4 *action taking service* is able to automatically take actions, based on the conditions that are diagnosed by the level-3 component. Actions include changing equipment software parameters and manipulating existing service system data resources, such as *CRM data, service activities data, technical documentation* and logistics data. To enable synergic use of all combined service system resources by the level-4 action taking service, an *adapter* component is proposed. For example, the condition monitoring component can be linked to the logistic ordering system to automatically order spare parts at a given equipment condition.

To provide human users with methods for interaction with the e-maintenance system's data processing functions, *user interfaces* are provided at level-1, level-2 and level-3. As level-4 does not require human action, a level-4 user interface is not required. It should be noted that, because of their real-time nature, level-3 services require an interface to the user interface that enables them to notify the user in real-time.

Although automation provides efficiency and effectiveness benefits, there will always be situations in which humans have to process the data. Examples of such situations are failure of the system, or the inability of the system to execute a specific function. To preserve the option of human data processing, level-1 raw data transport should be kept intact, as well as an on-site equipment interface in case even level-1 raw data transport fails.

Adaptation of the current underlying infrastructure is required as well. To enable full interoperability of the services, the service directory must be able to automatically manage the available services in the system. Therefore the directory must be adapted, but the services as well, as they need to register themselves with the directory. Conceptually, a service wrapper is proposed that enables authentication, registration and discovery of the service on the network. This concept is illustrated in Figure 4.3 (adapted from Whitehead (2002)). Obviously, the system management service must be adapted to reflect the proposed infrastructure changes as well.

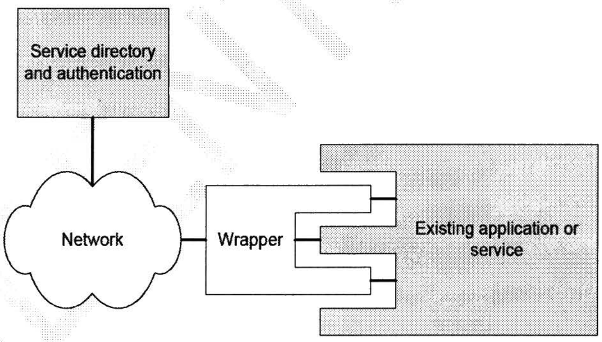

Figure 4.3 Component wrapper interface to existing applications

4.5 Δ Platform Specific Model (Δ PSM)

In this section, deployment of the proposed components is discussed. First, deployment of all service system information management components is briefly described. Then, deployment of the e-maintenance components is discussed in more detail.

4.5.1 Δ Service system information management components deployment

As the focus of this report is on e-maintenance technology, deployment the other service system information management components is not extensively researched. As described in section 3.6.3, Assembléon will implement a new ERP solution for management of the service system information resources. As shown in section 4.4.1, the e-maintenance system should be integrated into the rest of the systems, thus into the new ERP system.

4.5.2 Δ E-maintenance components deployment

In this section, deployment of the proposed components is discussed. A deployment model of the to-be situation can be found in Figure 4.4.

In the current situation, hardware in the form of equipment computers, on-site servers and a global e-maintenance data center is available. This hardware infrastructure is probably sufficient for the near future. The *on-site data collection server* functions as the central processing node for each customer's site. All four proposed levels of data processing are (partly) deployed on the hardware infrastructure.

First, *level-1* functions (access to raw data) are deployed on the on-site server, as this will eliminate issues regarding data unavailability in case of equipment computer failures. Thus, to eliminate possible data loss at equipment, the *level-1 raw equipment data* is replicated on the on-site server, as well as the *level-1 data access service*. To deal with the large amounts of generated data, level-1 raw data is stored for a limited amount of time only, sufficient for troubleshooting.

The next level, level-2, comprises data analysis and reporting. A *level-2 data analysis component* is deployed at the on-site server. This component is implemented as a real-time stream analysis component (see Carney *et al.*, 2002 and Thuraisingham *et al.*, 2005). It does not depend on batch processing of stored raw data, but on real-time analysis of the data stream that is generated by the *real-time data transmission service* as deployed on the *equipment computers*. As the analyzed data has to be available for on-request viewing, *level-2 reporting data storage* is deployed on the on-site server as well. Aggregation of the analyzed data is required, both on production line level and installed base level. Aggregation components are therefore deployed on the on-site data server and the Assembléon data center. As level-2 analyzed data involves considerably smaller amounts of data, storage capacity is not expected to be an (future) issue. Therefore, level-2 data can be stored for a relatively long time.

Depending on the real-time data streaming service as well, the *level-3 condition monitoring service* is deployed on the on-site data server. It is only responsible for real-time analysis and notification, so no data has to be stored for on-request viewing.

The *level-4 action taking service* is deployed on top of the level-3 condition monitoring service, as it uses the same input data. As part of the service's functions require an interface to manipulate equipment parameters, the service must be implemented within the same network as the equipment, as implementation outside of the equipment network would require the equipment to be directly connected to the outside network, imposing a security risk.

To provide users with access to the e-maintenance system's data processing functions, *interfaces* are provided at equipment, the on-site data server and the Assembléon data center. These interfaces provide *level-1, level-2 and level-3* functions, as desired by actors at the particular node.

In the proposed design, all services are connected via an Internet-based infrastructure. The Internet is the most obvious choice, as a high percentage of customers' sites are already connected to the Internet. As broadband Internet is becoming more and more widely available, this percentage will only increase over the years to come. All infrastructure services, such as the security, directory and system management service, are deployed centrally on the data center server. Administration data should be aggregated centrally to prevent redundant data storage and administration. Thus, the underlying infrastructure that enables the interaction between the e-maintenance components is implemented centrally.

As Assembléon's installed base grows, the amount of equipment that supports e-maintenance will grow as well. Furthermore, Assembléon may become independent from Philips. Therefore, in the future, outsourcing the e-maintenance system to a third party hosting provider might be a viable option. To facilitate a relatively easy relocation of the hosting of the services, the data center server must be deployed independent of the Assembléon office network. If it would be deployed inside of the office network, it would depend on this network. Furthermore, central services should be implemented on the highest aggregation level, to facilitate easy administration.

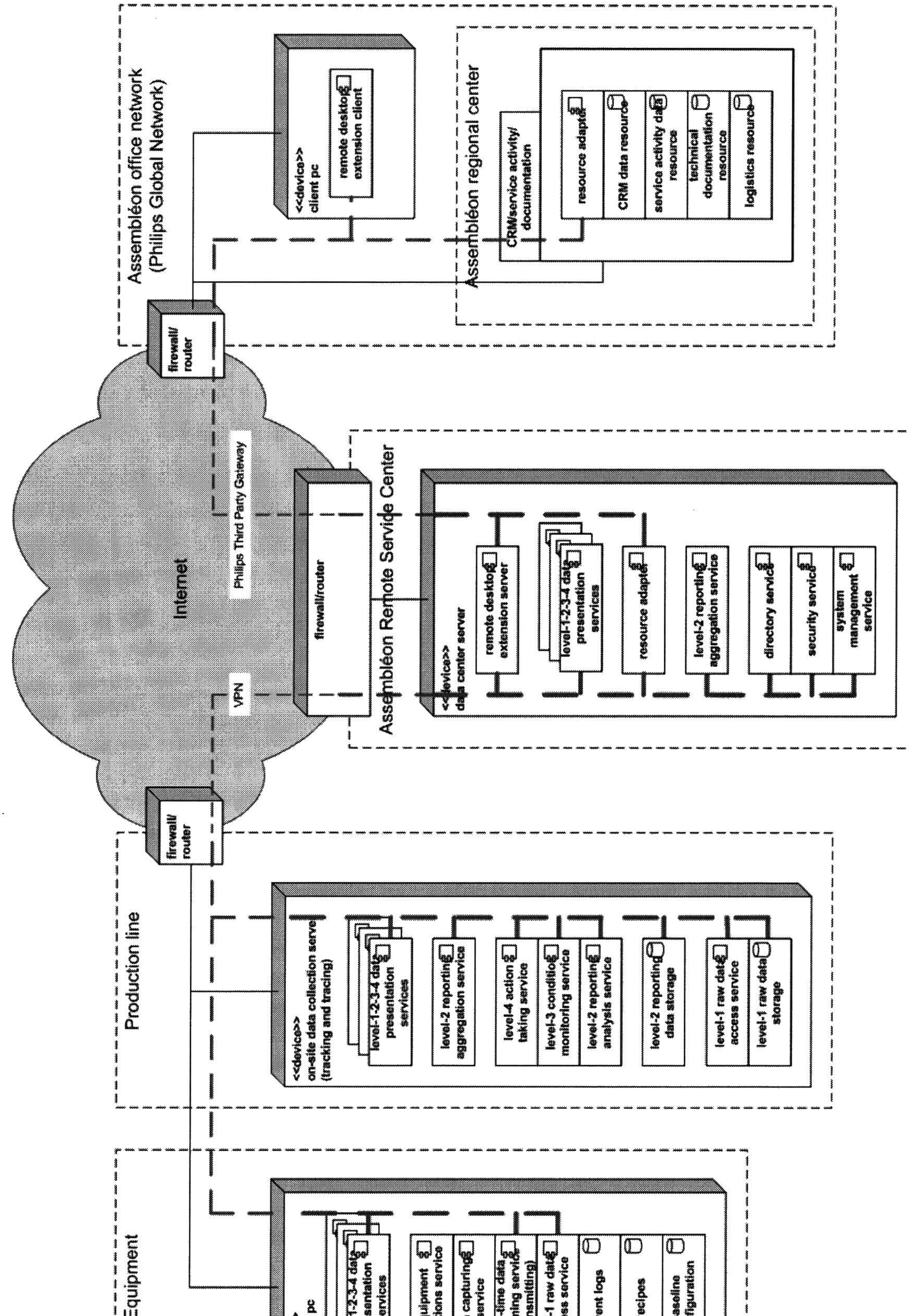

Figure 4.4 Proposed deployment model

4.6 Validation of the proposed changes

In this section, the benefits of the proposed architectural changes are discussed in relation to the problems identified during the problem analysis phase. Furthermore, the architecture is validated by examining a business problem outside of the scope of this project and discussing the changes to the current architecture that are required to solve this problem.

4.6.1 Benefits of the proposed design in relation to problem areas

In this section, the benefits of the proposed design will be discussed. For each level of e-maintenance technology, benefits are described in relation to the problem areas that have been identified in section 3.3.

Strategic benefits

E-maintenance technology does not provide strategic solutions directly, but the proposed change management program does solve strategic problems. First, the service system architecture is defined and maintained, for which the COMET+-based models as presented in this report serve as a starting point. Furthermore, part of the change management system is system performance measurement. In the proposed situation, performance measurement throughout the service system is implemented, linking operational and tactical goals to the strategic goals derived from and defined in the balanced scorecard.

The e-maintenance solution provides tactical and operational solutions, resulting in increased service product differentiation through extension of the portfolio and improved service quality. Furthermore, as operational costs decrease, higher margins are possible.

Tactical benefits

The change management program includes tactical performance measurement, linked to strategic and operational goals. Relationships to customer requirements may be included as well.

The e-maintenance extension of the service system enables solution of several of the identified tactical problems. The introduction of new service products to complement the decreasing spare parts sales is supported. Specifically, the delivery of the performance improvement service product (Machine, process and/or production audits) is enabled by level-1 functionality. As operational equipment data becomes directly available to Assembléon personnel, they are able to analyze equipment performance and report improvement opportunities to the customer. At level-1, analysis still needs to be done manually. Delivery of this service product could be improved greatly by level-2 automatic reporting, as the reporting logic can be defined in detail.

A proactive service delivery approach is enabled by level-3 e-maintenance components. Instead of reacting to customer's request, equipment conditions can be monitored constantly and human actors in the system can be notified that action has to be taken, based on the condition of the equipment. With condition based service delivery, the following drawbacks of reactive maintenance are avoided (Tsang, 1995):

- high costs of restoring equipment under crisis situation

- secondary damage and safety/health hazards inflicted by the failure
- lost production

A proactive approach potentially increases the mean time between failures (MTBF) of equipment, minimizing costly unscheduled downtime and lost production. Operational costs decrease due to the maintenance process becoming more predictable as it is no longer based on escalations. Furthermore, as the use of spare parts and consumables can be predicted more accurately, lower inventory has to be kept, reducing warehousing and stocking costs.

Level-4 functions enable an even more effective and efficient proactive service strategy. Instead of notifying a human and waiting for a reaction, the reaction is automated. Possibilities include, but are not limited to, automatic ordering of spare parts and consumables, automatic improvement of production line performance by adjusting equipment parameters, automatic preventive maintenance and automatic adjustments to equipment in case of equipment failures. Level-4 functions provide many opportunities, but as this service depends on the automation of processes currently carried out by humans, the processes have to be well-defined before feasibility of automation of these processes can be examined. Most processes are currently insufficiently defined, so the possibilities are hard to analyze.

Operational improvements that weaken the limitations of the current service concept on the tactical level include increased service delivery quality and decreased TCOO for current products.

Operational benefits
Level-1 e-maintenance components enable the use of operational equipment data and thus a new service delivery model, relying less on phone support and field support. Furthermore, level-1 data can be used to identify the installed base configuration remotely.

Both improvements enable more efficient and effective delivery of the current service products, resulting in the operational level benefits of lower operational costs and lead time. Specifically, improved delivery of the following service products is enabled:

- *General technical support* can be delivered faster and therefore cheaper as well. Assembléon personnel will be able to answer questions related to equipment faster as they will have direct access to equipment event logs and baseline configuration.
- *Reactive maintenance (break-fix services)* can be delivered faster and cheaper. As equipment baseline configuration and event logs are now directly available, the mean call handling time will be reduced. Furthermore, the number of field service operations (travel costs) will be reduced as the effectiveness of phone support will increase. Assembléon personnel will be able to solve more problems remotely, as they will be able to remotely configure equipment. Finally, less wrong parts will be sent as remote diagnosis will be more accurate, decreasing shipping costs and waiting time for spare parts.
- Like the other two products, *software support* can be delivered faster and cheaper for the same reasons. Furthermore, software upgrades can be delivered remotely, so that no engineer has to carry out software upgrades on-site.

Less human involvement means that the process is executed more efficiently and effectively. Higher efficiency means lower lead time and costs of data analysis and reporting and higher effectiveness means that human errors are eliminated. Thus, where applicable, a level-2 e-maintenance implementation enables a more efficient and effective delivery of service products that are supported by the level-1 system. More specifically, level-2 reporting enables automatic performance measurement on the equipment and customer levels.

Several operational problems are solved by the proposed integration of the e-maintenance components in the service system information management platform. As the MFG/Pro will likely be replaced with a modern ERP implementation like SAP, synergic use of information resources is enabled. Specifically, in the new ERP system a variety of operational problems can be solved. The following requirements are proposed to solve the identified problems:

- *Limited service history data;* a requirement for the new ERP system is to integrate service activity registration and possibly an expert system.
- *Limited installed base configuration registration;* a further requirement for the new ERP system is to enable local registration of the installed based configurations. For optimum results, this registration is linked to the configuration data as present on the equipment, via the e-maintenance components.
- *Operational and tactical performance measurement linked to strategic goals;* the new ERP system should include extensive possibilities for change management and specifically performance measurement.

4.6.2 Limitations of the proposed design

In relation to the identified service system problems, the proposed design has some limitations on the strategic, tactical and operational levels.

Strategic limitations
The proposed solution is not specifically aimed at integration of the service system in the rest of the organization. Due to the limited time available for this project, the service system is treated as a relatively independent entity within the Assembléon organization; the analysis is not a fully integrated approach.

Furthermore, the proposed solution does not specifically address the technical focus of the organization. To accomplish full integration of the service system in the organization, the mindset of complete organization should be changed to regard Assembléon as a provider of equipment and services.

A further limitation is that the proposed solution includes change management and performance measurement, but these activities are not elaborated in detail. The development of a complete set of strategic, tactical and operational performance indicators is recommended for the future.

Finally, the proposed approach to development and implementation of e-maintenance components, including implementation of a strategic change management program requires considerable initial investments. It is expected that these will yield a positive long-term ROI. However, a positive short-term ROI is expected from ad-hoc development. Quantitative analysis of the approach based on initial performance measurement results is required to estimate the long-term ROI.

Tactical limitations
In the proposed solution, new business models and product definitions are required to market new and improved service products enabled by e-maintenance components. In this study, the possibilities have not been explored. The operational problem of the per-hour rate may also be solved by introduction of new business models.

Operational limitations
In the proposed situation, the Work system Operations Model is not elaborated. Process changes and person-level changes are not described. For example, the service delivery processes must be adapted to include the use of e-maintenance tools.

4.6.3 Validation of design in terms of architecture extendibility

The current repository of architectural models forms the foundation for improvement projects. A business problem outside of the scope of this project is used to validate the extendibility of the architecture. In interviews with the problem owner, the project is situated in the project portfolio and the architecture.

The business problem that has been chosen comprehends tracking and tracing of individual parts during their life cycle. Basically, tracking and tracing can be seen as the management of information that defines the life events over the life cycle of an individual part. Currently, two main requirements are identified for the tracking and tracing project:

- Validation of warranty claims for individual parts; in case of a customer claiming warranty, Assembléon wants to be able to check whether or not the customer is indeed entitled to a part replacement under warranty. Furthermore, Assembléon wants to be able to check whether or not warranty can be claimed with the supplier of the part. It should be noted that warranty contracts may differ from customer to customer and from supplier to supplier.
- Tracking of individual parts for recall actions; in the situation that Assembléon wants to recall and swap specific parts, the company wants to be able to precisely track where the specific parts are located, so that not the complete customer base needs to be contacted. As recall actions may constitute only certain series of a part (e.g. in case of a bad production batch), tracking must be available based on individual parts.

Currently, parts are not tracked on an individual basis in Assembléon's current logistics process flow. To track the location of individual parts in this flow, parts must be identifiable by a unique code. Currently, in MFG/Pro parts do possess an item number and a serial number. Both are not unique, but combining the two results in a number that uniquely identifies the part.

Tracking two types of warranty requires Assembléon to administer two sets of dates for each part. First, for customer warranty claims, Assembléon must track the difference between the delivery date and the return data to the customer. Furthermore, for Assembléon claiming warranty from the parts supplier, the difference between the reception date and return date to the supplier must be tracked. Tracking of both pairs of dates is depicted in Figure 4.5. It should be noted that Figure 4.5 only depicts the dates required to fulfill the tracking and tracing requirements as mentioned earlier. For full tracking and tracing capabilities, all changes of stock location in the logistics flow should be registered.

For Assembléon to be able to track the owner of individual parts for recall actions, the unique part id must be linked to the customer information. Furthermore, for warranty tracking, each part must be linked to the service contract conditions that apply to that part.

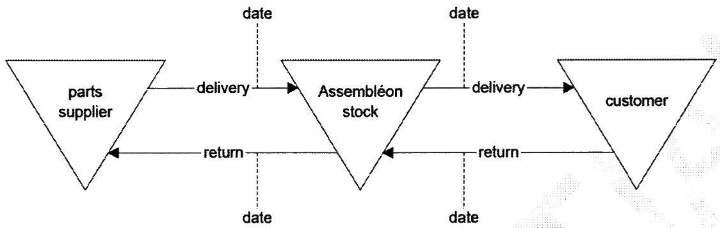

Figure 4.5 Parts logistics tracking and tracing

In the proposed solution, the opportunity of improvement of the logistics flow is identified. As a result, the tracking and tracing problem is included in the project portfolio as a project. For this project, the regulative cycle is executed. As the solution to the problem is likely to be IT-reliant, the regulative cycle is extended with an IT-specific system development methodology such as COMET+, analogous to the execution of the methodology in this report. For the tracking and tracing problem, the execution of the system development methodology will be briefly discussed.

Based on the current service system architecture, the processes and information management system are adapted to fulfill the tracking and tracing requirements. The tracking and tracing requirements are met by manipulating the logistics data and the CRM data in the maintenance information management system. In the business information model, the *parts life events* are depicted. In this class, changes of *locations* are administered, with the corresponding *dates*. For customer locations, a link must be provided between the location attribute in the life events class and information in the *equipment owner class*. This link enables tracking of parts for recall actions. Furthermore, a link is provided between the parts life events and the class that defines the (custom) *service contract* between Assembléon and its customer.

E-maintenance technology also provides an opportunity to contribute to life cycle management of individual parts. With e-maintenance technology, Assembléon can remotely manage the installed base. For e-maintenance technology to be useful for tracking and tracing of individual parts, the e-maintenance system must be aware of unique ids of installed parts and it must be capable of noticing changes of parts ids.

Assembléon keeps consignment stock at various customers' sites. Parts kept in consignment stock are owned by Assembléon and not by the customer. Only when a customer exchanges a part in his equipment with a part from the consignment stock the customer becomes the owner. Although consignment stock is an Assembléon stock location, Assembléon is currently not able to monitor this stock location and must rely on the customer calling that an equipment part has been exchanged for a part from the consignment stock. Thus, the date of the customer calling that he has exchanged a part is the date that the warranty period becomes effective. This method is susceptible to fraud. E-maintenance technology could be used to monitor the exchange of the part in equipment. A level-3 system is able to notify Assembléon that a part has been changed and a level-4 system is able to automatically register the unique part id with Assembléon's ERP system. Another benefit of equipment awareness of unique part ids is to be found with recall actions. Using level-2 remote reporting, a report can be generated of the locations of equipment that parts within a certain series are currently installed in.

In conclusion, tracking and tracing problems fit into the logistics data part of the current architecture and can be solved by including them in the project portfolio in the change management program. Actual development and implementation of tracking and tracing functions within the service system information system is accelerated by the use of a system development methodology analogous to the methodology used in this report, in combination with the proposed architecture repository.

Chapter 5 Implementation of the proposed changes

The changes to the service system architecture as proposed in Chapter 4 provide a high-level overview of the possibilities of e-maintenance technology with the current service system architecture as a starting point. The high-level overview can be used as a conceptual framework for development of service system functions based on e-maintenance technology. Before the proposed functions can actually be developed and implemented, a variety of decisions have to be made. In this chapter, decisions regarding the implementation of the change management program, outsourcing, the system's underlying technical infrastructure and functional services are discussed.

In this chapter, the following research question is answered:

(5) How can the service system changes as proposed in research question (3) be implemented?

5.1 Change management program and project portfolio

The implementation of a strategic change management program is proposed to facilitate the implementation of service system improvements, including the gradual implementation of the proposed e-maintenance components. The components required for implementation of such a program are discussed in section 4.1. In this section, the realization of the project portfolio in relation to the implementation of e-maintenance components is discussed.

5.1.1 Outsourcing

The first decision Assembléon will have to make is whether or not it wants to develop the system itself. Various off-the-shelf e-maintenance solutions are offered on the market, but these will generally lack the benefits of being very flexible and extendable. A ready-made system will generally not be able to fully meet Assembléon's changing requirements. Of course, this does not imply that Assembléon cannot outsource the actual development and hosting of a build-to-order system. Outsourcing may be the preferred option as Assembléon's core competence is not the development of service oriented systems and a finding suitable partner for execution of such a project will provide benefits in terms of lower costs and higher expertise.

5.1.2 Choice of technology

Development and implementation of the proposed e-maintenance components consists of augmentation of functional services to the basic infrastructure. The basic infrastructure is part of the service system information management infrastructure. Before functional services can be developed and implemented, a technology has to be chosen to form the foundation for the service oriented architecture. The introduction of a new ERP system should also be taken into account. Over the years, a number of technologies have been developed (Britton *et al.,* 2004), Web Services being one of the latest. As the proposed design is Internet-based, Web Services provide a suitable technology. However, further research is required to determine the most suitable technology for Assembléon's solution.

5.1.3 Specific functions as projects in the project portfolio

On top of the infrastructure e-maintenance components are implemented for different functions specifically tailored to each actor in the service system. The design as proposed in this report provides a framework for determining priorities for different functions that Assembléon wants to implement. For example, level-1 raw data transport should be implemented before level-2 reporting. However, different actors in the service system require different levels of functions. For each function, a project is executed in the project portfolio. The use of the shared architecture repository enables accelerated development. Appendix XVIII provides a set of questions that need to be answered to determine the specific requirements for each function.

Special attention should be paid to establishing business processes for administration and maintenance of the e-maintenance components. To do so, responsibilities and processes should be defined and assigned to actors in Assembléon's organization.

5.1.4 Return On Investment (ROI)

Generally, improvement projects should yield a positive Return On Investment (ROI). However, the gradual implementation of long-term strategic program has many future consequences which cannot be financially quantified beforehand. The implementation of the change management program enables more accurate estimation of the ROI of long-term strategic projects for development and implementation of e-maintenance components.

5.2 Impact on customers' work systems

Deployment of an e-maintenance system is not limited to Assembléon's organization, as the proposed architecture extends beyond Assembléon's own organization. Both hardware and software must be installed at customers' sites, requiring acceptance by the customer. Although customers are not asked to radically change their own architectures, the customer must be convinced of the advantages of implementation of the system. Thus, the service marketing subsystem must take this factor into account to effectively market the e-maintenance concept and its derived service products.

5.3 Impact on person-scale work system

As actors are an integral part of the service system, architectural changes on the organization scale have a direct impact on the person-scale. Therefore, changes in the person-scale architecture have to be taken into account as well. For actors that reside directly in the affected parts of the service system, tasks and processes may change. To fully utilize the new functions of the system, it is important that actors both accept the new system functions and know how to operate them.

To effectively implement organization-scale changes, the resulting person-scale changes must be properly supported. The following should be taken into account:

- *Involvement in requirements specification;* future users that are involved in the development process will feel more committed and comfortable with the system. User acceptation is increased. Whitten *et al.* (2007) provide several methods for user involvement during system requirements specification. In this project, stakeholders in the service system have been involved in the definition of the service system architecture and the e-maintenance extension requirements. In the interviews that have been conducted with current and future users, generally no lack of commitment and acceptance was found. However, one should still make sure that for specific functions users are sufficiently committed.

- *Provide training;* users should be trained sufficiently in using the new system functions, so that they are actually able to reach the intended goals. Training should not be limited to system users, but to system support personnel as well.
- *Provide technical support;* system users should be able to get help in case of system problems. Again, to do so, responsibilities and processes should be defined and assigned to actors in Assembléon's organization.

Chapter 6 Conclusions and recommendations

In this chapter, the conclusions of the research project will be presented. Furthermore, recommendations for future activities based on research conclusions and limitations are discussed.

6.1 Conclusions

In this research project a model-based approach is used, relying on the availability of a repository of models of the architecture of the system. At the start of the project, no complete definition of the service system architecture was available. Therefore, the current service system was analyzed, resulting in a basic repository of architectural models. The repository serves as a foundation for future system improvements in general and in this case, e-maintenance technology specifically.

Ideally, improvement of a system is facilitated by a change management program. Performance of the system is measured and improved if unsatisfactory. A structural change management program is currently absent in the service system, hindering the detection and quantification of improvement opportunities and leaving considerable room for improvement.

While analyzing the service system, a variety of strategic, tactical and operational problems that negatively influence the performance of Assembléon's service system have been identified. A considerable amount of these problems is rooted into the fact that operational equipment data is not efficiently available to the service system. A design for application of e-maintenance technology in the service system is proposed to solve part of these problems. In the proposed design, several key features can be distinguished:

- To deal with changing requirements, the design is open and flexible. Four levels of functionality are distinguished that can be implemented gradually.
- The different levels of functionality in the design provide a framework for further development of actual e-maintenance functions.
- The development of specific functions is facilitated by a change management program. For each specific e-maintenance function, a project is added to a portfolio of improvement projects.
- For flexibility, the proposed design is based on a flexible service-oriented architecture.
- The e-maintenance services are supported by an infrastructure. A suitable technology must be chosen to implement this infrastructure.
- Assembléon's current hardware infrastructure provides a suitable platform for implementation of e-maintenance technology.
- To enable outsourced hosting, the e-maintenance system should be implemented independently from the Philips office network.
- The on-site data servers that will be installed in the near future serve as distributed operational equipment data repositories.
- Operational equipment data is replicated on the on-site server to prevent data loss.
- Possible storage capacity issues are solved by real-time level-2 analysis.

- Possible bandwidth issues are solved by on-site analysis and on-request data transport.
- Administration of the e-maintenance system is simplified by an infrastructure with a central e-maintenance server.
- Manual data processing should be kept as an alternative in case of failure of automatic data processing.

Although no quantitative analysis has been carried out, it is expected that implementation of specific e-maintenance functions enables more efficient and effective delivery of the current service products, as well as the introduction of new service products.

The application of e-maintenance technology in the service system is a long-term strategic project. For full utilization of the e-maintenance improvement opportunities, implementation of the change management program and development of an e-maintenance service infrastructure is required. Both are costly; therefore the ROI should be determined on the long term. On the short term, the ROI may be negative.

6.2 Recommendations

Based on the conclusions, a set of strategic, tactical and operational recommendations will be given specifically for the Assembléon service system.

Strategic recommendations
To efficiently and effectively detect, quantify and execute performance improvement, the implementation of a change management program is required. Assigning the following responsibilities to service system actors is recommended:

- Maintenance of the architectural repository of the models that represent the current state of the system. The models developed in this report provide a starting point.
- Establishing interrelated strategic, tactical and operational goals in the service system.
- Monitoring of the system's performance relative to the goals.
- Management of the portfolio of improvement projects to improve unsatisfactory performance.
- Execution of the projects in the project portfolio based on the regulative cycle.

In the research project, the service system has been analyzed as relatively independent system that interacts with other systems in the Assembléon organization. Of course, this is a simplification. To effectively use service products for the company's competitive advantage, it is recommended that all processes in the organization are adapted to deliver a balanced pick-and-place product, consisting of equipment and complementary services.

Tactical recommendations
E-maintenance technology provides many opportunities to improve the service system. It is recommended to continue the current program of activities for developing and implementing e-maintenance functions, based on the proposed change management program. Due to the strategic nature of the application of e-maintenance technology, it

is recommended to evaluate the long-term ROI for e-maintenance projects, rather than on the short-term ROI.

Marketing of new possibilities enabled by e-maintenance technology has not been researched. Application of e-maintenance technology may require a change in business models for the different service products. It is recommended that the service marketing system tailors the service portfolio to customers' demands to optimize the profitability of the extended service portfolio.

Operational recommendations
Continuation of the development of e-maintenance functions will result in a set of tools that enable more efficient and effective delivery of the service products. To ensure effective and efficient use of the tools, it is recommended that future users are involved in specification of the requirements, to ensure user commitment and acceptance of the tools. Furthermore, providing the users with training and technical support is essential.

E-maintenance technology is not the only improvement opportunity that has been identified. Part of the improvement project portfolio is the future implementation of a new ERP system. For this project, the following requirements for the new ERP system are recommended:

- Provide functionality for detailed registration of service activities.
- Enable local registration of the installed based configurations, possibly linked to the configuration data as present on the equipment.
- Include extensive possibilities for change management and performance measurement.

References

Alter, S. (2003). 18 Reasons why IT-reliant work systems should replace the "the IT artifact" as the core subject matter of the IS field. *Communications of the Association for Information Systems, 12,* 366-395.

Bangemann, T., Rebeuf, X. Reboul, D., Schulze, A., Szymanski, J., Thomesse, J.-P., Thron, M., Zerhouni, N. (2006). PROTEUS – Creating distributed maintenance systems through an integration platform. *Computers in Industry, 57,* 539-551.

Berre, A.-J., Elvesæter, B., Nordmoen, B., Oldevik, J., Sims, O.,Sluman, C., Solberg, A., Tyndale-Biscoe, S., Wood, B., Aagedal, J. Ø. (2006). *COMET – Component and model-based development methodology.* Retrieved July 28, 2006, from COMET website : http://modelbased.net/comet/index.html.

Bowen, T. P., Wigle, G. B. and Tsai, J. T. (1985). Specification of software quality attributes. *Report RADC-TR-85-37.* Rome Air Development Center : Griffiss Air Force Base.

Britton, C. and Bye P. (2004). *IT Architectures and Middleware (2nd ed.).* London : Addison-Wesley.

Carney, D., Cetintemel, U., Cherniack, M., Convey, C., Lee, S., Seidman, G., Stonebraker, M., Tatbul, M. and Zdonik, S. (2002). Monitoring streams – A new class of data management applications, *Proceedings of the 28th VLDB Conference,* 2002.

ISMI (2005). *e-Diagnostics Guidebook.* Retrieved September 14, 2006 from SEMATECH website : http://ismi.sematech.org/emanufacturing/ediagguide.htm

Gits, C. W. (1992). Design of maintenance concepts. *International Journal of Production Economics, 24,* 217-226.

Goossenaerts, J. B. M. (2006a). *A Society Wide Architectural Framework and its Research Challenges.* Presentation, retrieved January 9, 2007, from TU/e, Department of Technology Management, Section Information Systems website : http://is.tm.tue.nl/staff/jgoossenaerts/4PublicPdf/2006_SWAF_YNU.pdf

Goossenaerts, J. B. M. (2006b). *Making COMET Enterprise Architecture Aware (and multi-scale).* Unpublished paper. Eindhoven University of Technology.

Haksever, C., Render, B., Russell, R. S. and Murdick, R. G. (2000). *Service management and operations* (2nd ed.). Upper Saddle River : Prentice Hall.

Heskett, J. L. (1986). *Managing in the service economy.* Boston : Harvard Business School Press.

Hoe, N. S. (2005). *Free/Open Source Software Open Standards.* Retrieved November 3, 2006, from International Open Source Network (IOSN) website : http://www.iosn.net/open-standards/foss-open-standards-primer/

Hung, M-H., Cheng, F.-T. and Yeh, S.-C. (2005). Development of a web-services-based e-Diagnostics framework for semiconductor manufacturing industry. *IEEE Transactions on semiconductor manufacturing, 18,* 122-135.

IPC (2006). *Generic Requirements for Electronics Manufacturing Shop-Floor Equipment Communication Messages (CAMX).* Retrieved October 26, 2006, from IPC website : http://webstds.ipc.org/2541/2541pub.pdf

Komonen, K. (2002). A cost model of industrial maintenance for profitability analysis and benchmarking. *International Journal of Production Economics, 79,* 15-31.

Konopka, J. M. (1995). Capacity utilization bottleneck efficiency system – CUBES. *IEEE Transactions on Components, Packaging, and Manufacturing Technology, Part A, 18 (3),* 484-191.

Locy, M. (2001). The impact of E-diagnostics – One year later. *Proceedings of 2001 IEEE International Semiconductor Manufacturing Symposium.* Oct. 8-10, 2001, 435-438.

Peters, T. J. (1988). *Thriving on chaos.* New York : Knopf.

Pintelon, L. M. and Gelders, L. F. (1992). Maintenance management decision making. *European Journal of Operational Research, 58,* 301-317.

Pintelon, L. M. and Gelders, L. F. (2002). A framework for maintenance concept development. *International Journal of Production Economics, 77,* 299-313.

Qiao, F., Schlange, H., Meier, H. and Massberg, W. (2005). Internet-based remote access for a manufacturing-oriented teleservice. *International Journal of Advanced Manufacturing Technology,* Published online: 20 December 2005.

Spiess, M. (1998). Teleservice. *Service-management, 6,* 1-28.

Thuraisingham, B., Khan, L., Clifton, C., Maurer, J. and Ceruti, M. (2005). Dependable real-time data mining. *Proceedings of the Eight IEEE International Symposium on Object-Oriented Real-time Distributed Computing (ISORC '05),* 2005.

Tsang, A. H. C. (1995). Condition-based maintenance : tools and decision making. *Journal of Quality in Maintenance Engineering, 1 (3),* 3-17.

Van Aken, J. E. van, Bij, J. D. v.d. and Berends, J. J. (2003). *Bedrijfskundige Methodologie.* Eindhoven : Eindhoven University of Technology.

Van Strien, P. J. (1997). Towards a Methodology of Psychological Practice, the Regulative Cycle. *Theory and Psychology, 7 (5),* 683-700.

Whitehead, K. (2002). *Component-based development – Principles and planning for Business Systems.* Amsterdam : Addison-Wesley.

Whitten, J. L., Bentley, L. D. and Dittman, K. C. (2007). *Systems analysis and design methods* (7^{th} ed.). London : McGraw-Hill.

Zeithaml, V.A. (2000). Service quality, profitability, and the economic worth of customers : what we know and what we need to learn. *Journal of the academy of marketing science, 28,* 67-85.

Appendix I E-maintenance functional requirements

As this thesis focuses on the possible benefits of e-maintenance technology, specific reference requirements for the e-maintenance part of the IT system that supports the service system are presented.

Based on functional requirements for failure-based and condition-based maintenance, the International Sematech Manufacturing Initiative has proposed guidelines and a guidebook (ISMI, 2005) for application of e-maintenance technology, and, more specifically, e-diagnostics. Although developed for the semiconductor manufacturing industry, these guidelines provide a suitable framework for development of any e-diagnostics system.

For this thesis, the ISMI framework is adapted, resulting in the model proposed in Figure I.1. In this model, four levels of data processing automation are distinguished, based on four data processing steps; transport, analysis, diagnosis and action. The starting point is a situation in which no system is in use, thus all data processing is done manually. When data is transported automatically, the system is called a level-1 system. A level-2 system also includes automated analysis of the transported data, but it does not draw conclusions. Whereas a level-2 system does present data in an understandable way, a level-3 system also draws conclusions and may advice the user of actions to take. The essential difference between level-2 and level-3 is that a level-3 system compares the actual data with a predefined set of data. The highest level system, level-4, is fully automated. It is able to analyze a given situation, develop a solution in case of a problem, and take the required action to solve the problem without user involvement.

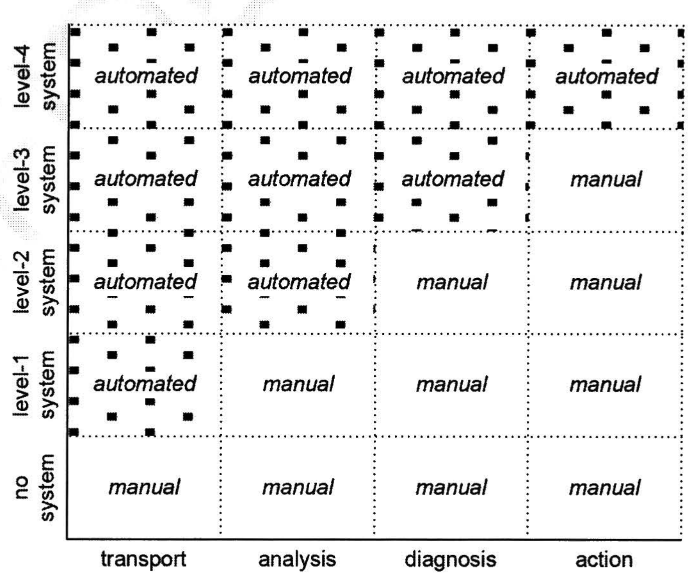

Figure I.1 Data processing system automation levels

Before a human activity is automated, it must be clearly defined. Process automation requires the processes to be defined very precisely. If the activities carried out in the processes are not clearly defined, it is impossible to automatically carry out the activities.

Appendix II Research approach Orientation Phase

The goal of this research phase is to identify improvement opportunities in the corrective maintenance process. This is done by analyzing the current corrective maintenance process in the European, mapping these to the American region (best practice) and examining the possible improvements remote services can bring to these processes.

A planning for the orientation phase of the research is displayed in Table II.1.

Table II.1 Initial research planning

Phase	Weeks	Phase name	Tasks	Deliverables
I	1-4 (8-11)	Scope	• Hold orientation interviews (interviews) • Study maintenance literature (literature) • Study internal quality documentation (documents) • Identify business model Customers Support (interviews) • Identify perceived problem(s) and real problem(s) (interview)	• Top level business process • Organizational structure • Financial performance • Market situation • Key specs machine • Machine life events • Performance indicators • Business model Customer Support • Problem tree
II	5-6 (12-13)	Research design	• Create research design, including planning (interviews, literature)	• Research design problem analysis phase and planning
III	7-10 (14-17)	Mapping	Machine life events • Create machine life events model (interviews, documents)	• Machine life events model • List of machine events triggering action
			Triggered processes • Identify escalation processes (interviews, documents) • Identify planned processes (interviews, documents) • Identify CRM system (interviews, documents)	• Escalation processes model RCE • Differences with escalation processes model RCA • CRM system identification
			Performance indicators • Identify applicable performance indicators (literature) • Identify performance indicators used by Assembléon and its customers (interviews, documents, literature)	• Set of applicable performance indicators
			Remote services • Identify remote services	• Remote service

			possibilities (literature) • Identify remote services capabilities of customers and Assembléon (interviews, documents) • Identify current remote services applications Assembléon (interviews, documents)	capabilities and opportunities
IV	10-13 (17-20)	Problem analysis & Improvement opportunities	Directive • Identify performance targets (benchmarking similar processes and identifying customer desires) (interviews, literature)	• Benchmark similar processes (case study, company visit) • Customer desires
			Problems • Identify problems in after-sales service processes, preventing targets from being reached (interviews, literature)	• Current performance and performance mechanisms in current processes (RCA) (qualitatively) • Problems keeping processes from reaching targets
			Opportunities • Identify improvement opportunities in current processes created by remote services (interviews, literature)	• Process improvement opportunities and expected performance increase
V	13-14 (20-21)	Planning Design & Implemen-tation	• Preparation intermediate presentation • Create solution design and implementation research plan	• Intermediate presentation • Choice of improvement opportunity • Solution design and implementation research plan

Appendix III FAST methodology

Figure III.1 depicts the combination of the FAST methodology (Whitten *et al.*, 2004) with the regulative cycle methodology (Strien, 1975).

The phases in the FAST methodology are:

1. Scope definition
2. Problem analysis
3. Requirements analysis
4. Logical design
5. Decision analysis
6. Physical design and integration
7. Construction and testing
8. Installation and delivery

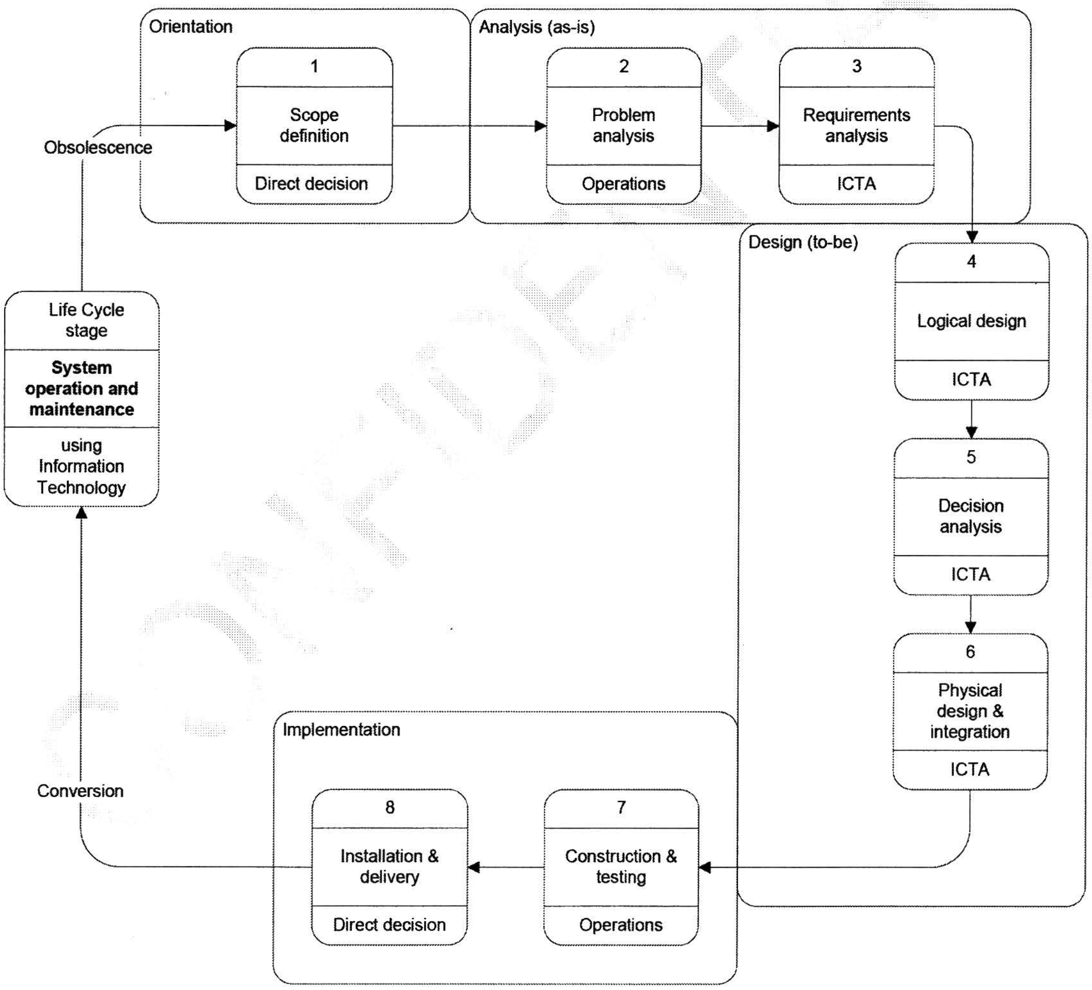

Figure III.1 FAST methodology combined with regulative cycle

Appendix IV COMET+ deliverables

During system development all models and documentation are stored in a repository. In order to fill a repository, deliverables have to be defined. The COMET system development methodology (Berre *et al.*, 2006) provides deliverables for a use-case driven, model-focused approach, suitable for development of medium size IT-reliant work systems. The deliverables of the COMET methodology can be directly linked to the three levels of system development in the 3-V model, which is displayed in Figure 2.7. The colors of the table's cells correspond to the levels in the 3-V model.

IV.1 COMET+ deliverables linked to multi-scale 3-V model levels

3-V level		Society Scale (Consolidation by Institution)	Enterprise/Business Scale[1] (Consolidation by Organisation)	Person/Equipment/Tool Scale (= Ens) (Consolidation by Internalization)
			Value and risk model (VARM)	
Direct decision	1	Mission Statement	Organization Mission Statement	Ambition Model
	2	Domain Statement	Organization Context statement	Ens Context statement
	3	Market Indicator Register	Organization Indicator Register	Ens Indicator Register
	4	Market Value & Risk Register	Organization Value & Risk Register	Ens Value & Risk Register
			Worksystem operations model (WOM)	
Operations project	1	Principal Model	Community Model	Role Model
	2	Market Asset Model	Organization Asset Model	Ens Asset Model
	3	Market Resource Model	Organization Resource Model	Ens Resource Model
	4	Interaction Refinement Model	Work Refinement Model	Behaviour Model
			Cumulative Requirements model (CRM)	
ICT project	1	Principal Data Model	Relation Data Model	Relation Data Model
	2	Market Asset Data Model	Organization Asset Data Model	Ens Asset Data Model
	3	Market Resource Data Model	Organization Resource Data Model	Ens Resource Data Model
	4	Interaction Specification	Work Refinement Specification	Behaviour Specification
	5	Security & Enforcement Model	Non-functional Requirements	Non-functional Requirements
	6		Reference architectural analysis	
			Cumulative Component model (CCM)	
	1	Market Component Structure	Organization Component Structure	Ens Component structure
	2		Data Model to Component Data Types Map	
	3		Component Interface and Information Model	
	4		Component Behaviour Specification	
			Platform specific model (PSM)	
	1		Platform profile model	
	2		Component implementation model	
	3		Deployment model	

[1] COMET metamodels and examples focus at this scale, but often merge the "project charter" content elements. In this table row the project charter content elements are not included.

IV.2 Explanation of the repository content elements (VARM and WOM)

Repository Content Element	Shorthand	Description
Mission Statement	**SRM.VARM.MS**	A description of the conditions the public agent wants to achieve and sustain for the society's members.
Organization Mission Statement	**ORM.VARM.OMS**	A description of the continuous service flow the Organization wants to offer to its customers, in exchange for their attention or money. Compliance with Society-enacted institutions is a constraint for OMS.
Ambition Model	**ERM.VARM.AM**	A description of the general ambitions of a person. Compliance with Society-enacted institutions is a constraint for AM.
Domain Statement	**SRM.VARM.DS**	The identification of the different kinds of principals and objects that will be involved in or affected by the services that the public agents will enact in order to fulfil their missions.
Organization Context Statement	**ORM.VARM.ECS**	The identification of the different kinds of principals and objects that the Organization will engage with in order to fulfil its missions.
Person Context Statement	**ERM.VARM.PCS**	The identification of the different kinds and instances of society members that the person engages with in order to achieve its ambitions.
Market Indicator Register	**SRM.VARM.MIR**	A register with the names, definitions and specifications of the indicators that the public agents use to verify the extend of achievement regarding the conditions they want to achieve and sustain for the society's members.
Organization Indicator Register	**ORM.VARM.OIR**	A register with the names, definitions and specifications of the indicators that the Organization uses to verify the extend of achievement regarding the service and product flow the Organization wants to offer to the market, and regarding the Organization's compliance with the society's enacted institutions.
Person Indicator Register	**ERM.VARM.EIR**	A register with the names, definitions and specifications of the indicators that the person uses to verify the extend of achieving his/her ambitions, and regarding the person's compliance with the society's enacted institutions.
Market Value & Risk Register	**SRM.VARM.MVRR**	A register with the identified sources of values and risks, their indicators, references to their (past) measurements and future expectations. These values and risks (vulnerabilities and threats) continuously influence the chances of achieving the conditions public agents want to sustain for the society's members. The sources can be natural (temperature, water, wind, earthquakes,..) and social (perverse missions and ambitions or careless behaviour of principals.)
Organization Value & Risk Register	**ORM.VARM.OVR R**	A register with the identified sources of values and risks, their indicators, references to their (past) measurements and future expectations. These values and risks influence the chances of achieving the service and product flow the Organization wants to offer to the market, as well as its compliance with the society's enacted institutions.
Ens Value & Risk Register	**SRM.VARM.EVRR**	A register with the identified sources of values and risks that influence a person/equipment/tool's ability and chances to achieve its ambitions, as well as the compliance of the person's behaviour with the society's enacted institutions.
Principal Model	**SRM.WOM.PM**	A model that includes all the principals that are recognized by the society's institutions, either in the role of public or civil agents.
Community Model	**ORM.WOM.CM**	A model that includes all the principals that are recognized by the Organization's work processes and their refinements (as specified in **ORM.WOM.WRM**. It must be aligned with **SRM.WOM.PM,** but typically it will include specialization classes to differentiate principals in relation to **ORM.VARM.OMS.**
Role Model	**ERM.WOM.RM**	A model that includes all the principals that the person engages with during his/her behaviour (as specified in **SRM.WOM.BM**. It must be aligned with **ERM.WOM.PM,** but typically it will include role models with respect to **SRM.WOM.IRM** and their specialization by Organization principals with whom the person interacts (as defined in **ORM.WOM.WRM** of those Organizations).

Market Asset Model	**SRM.WOM.MAM**	A model of all the assets that are recognized by the society's public agents as contributing to the conditions the public agent wants to achieve and sustain for its member principals. It will include land, rivers, sea, forests, roads, harbours, airports, utilities, the assets owned by the principals, etc.
Organization Asset Model	**ORM.WOM.OAM**	A model of all the assets that the Organization controls in order to sustain the continuous service flow it wants to offer to its customers, in exchange for their attention or money. It will include facilities, brands, distribution channels, equipment, intellectual property rights, etc.
Ens Asset Model	**ERM.WOM.EAM**	A model of all the assets that the person owns in order to achieve his or her ambitions.
Market Resource Model	**SRM.WOM.MRM**	A model of all the resources that are created by the society's public agents to support the enactment of the institutions that are considered necessary to fullfil the society's mission. It will include administrative records, organisational structures, acts, etc. In contrast with Assets, Resources can more easily be modified (in principle, and for capable principals).
Organization Resource Model	**ORM.WOM.ORM**	A model of all the resources that the Organization creates, acquires and maintains to realize the flow of products and services identified in its mission statement. It will cover the information flows, organisational structures, worker-roles, etc.
Ens Resource Model	**ERM.WOM.ERM**	A model of all the resources that the person uses to protect and sustain his/her assets and use them in achieving ambitions.
Interaction Refinement Model	**SRM.WOM.IRM**	A model of all the principal interactions that the society's public agents have specified to ensure that society SOM and SD are consistent with **SRM.VARM.MS** and they recognize the values and risks identified in **SRM.VARM.MVRR** . This model offers reference models to which the models of principals (as specified in **ORM.WOM.WRM** and **ERM.WOM.BM**) should be compliant.
Work Refinement Model	**ORM.WOM.WRM**	A model of all the Organization processes and **SRM.WOM.IRM** interaction specializations that the Organization has specified to fulfil its missions (**ORM.VARM.OMS**), pursue its values while avoiding the risks (**ORM.VARM.MVRR**). As far as interactions and the use of restricted assets and resources is concerned, the models must be compliant with **SRM.WOM.IRM**.
Behaviour Model	**ERM.WOM.BM**	A model of all the person processes and **SRM.WOM.IRM** interaction specializations that the person has selected to achieve his/her ambitions (**ORM.VARM.AM**), pursue its values while avoiding the risks (**ERM.VARM.MVRR**). As far as interactions and the use of restricted assets and resources is concerned, the models must be compliant with **SRM.WOM.IRM**.

Appendix V Value proposition differentiating factors

Product differentiation is essential for Assembléon to be able to generate sustainable profits. The possibilities for differentiating on both the equipment and service part are different. For the equipment part, technologies have matured and it is becoming very hard to differentiate on output. Furthermore, equipment quality is a prerequisite to compete, not a competitive advantage. Costs control is already on an acceptable level; room for improvement is limited.

For services, product differentiation is still possible. Assembléon as well as its competitors mainly use traditional, outdated service methods that leave room for the introduction of new services, as well as process improvements that lower costs and increase performance of current services. Table V.1 shows the value proposition and possibilities to improve the differentiation for both the equipment and services part of the offering. For the value proposition, a distinction is made between output and cost factors in the value proposition.

Table V.1 Elements of product offering and differentiation possibilities

value proposition		value proposition description	possibilities for differentiation
equipment	output	offer equipment that is designed to perform at a given specification (output rate and flexibility)	differentiation hard; quality is prerequisite and technology is available to competitors
	cost	minimize total cost of ownership; lower development and production costs enable lower price	processes optimized; less room for lowering costs
services	output	eliminate all influences that cause sub-specification equipment performance over lifetime	differentiation possible; Assembléon and competitors mainly use traditional methods
	cost	minimize total cost of ownership; lower service process costs enable lower price	service processes outdated; opportunities for lowering costs

Appendix VI Equipment processing speed and equipment states

Konopka (1995) proposes a model in which various equipment states are combined with various equipment processing speeds (Figure VI.1). In essence, the goal of a maintenance service system is to ensure that the amount of productive time in combination with the effective tool speed matches the desired amount of output of the customer over the productive lifetime of the equipment, at the lowest possible costs.

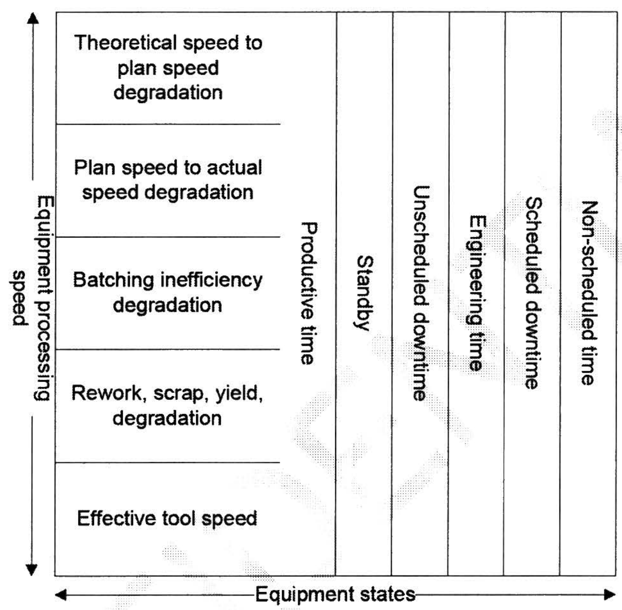

Figure VI.1 Equipment processing speed and equipment states

Appendix VII Work system Operations Model (WOM) patterns

The Work system Operations Model is container for several models that describe the system's processes, resources and actors. The operations model details the way in which the goals as defined in the VARM are accomplished.

Haksever *et al.* (2000) propose a service system model on which a generic service system Work system Operations model can be based. Heskett (1986) proposes a set of strategic service vision elements that can be integrated into the operations model. Tsang *et al.* (1999) propose a general model for maintenance operations. To create a maintenance service system pattern, the three models have been integrated (*Figure VII.1*).

In the resulting model, several subsystems can be distinguished, depicted as rectangles with rounded corners; *service system governance, service marketing*, *service operations management, service delivery, logistics management* and *equipment development*. The subsystems contain their own processes, interacting with each other through resources in the service system. Within the service delivery system, two main activities can be distinguished: *service activity administration and scheduling* and *service activity execution.* Integrating concepts between the systems are depicted as rectangles with straight corners. It should be noted that the model cannot be read as a process model. Within the system, processes are continuously running and interacting with each other.

The system's governance system develops the *company mission, vision and strategy*, using *market intelligence*. Deduced from the company mission, vision and strategy is a *mission and a vision* for the service system. Once established, the service mission and vision serve as input for service marketing and service operations management to develop the service strategy, which serves as a basis for the *service portfolio* and *maintenance policy and maintenance concept.*

Measuring customer satisfaction and finding out customer requirements is an important task for the service marketing system, as the financial value of existing customers is generally regarded higher than the financial value of new customers (Zeithaml, 2000). Peters (1988) proposes that selling costs for existing customers are on average 20% lower than selling costs for new customers.

The service portfolio is the mix of service products that is designed to satisfy the customer's needs. It is developed by the marketing and operations management system together, as the operations management system must be able to deliver the service portfolio that satisfies customer's needs. Market intelligence and the service mission and vision serve as input.

The operations management system is responsible for converting the service portfolio into a service delivery system by developing an operating strategy, describing how the service portfolio is delivered to the customer by the service delivery system. Furthermore, the operations management system develops a maintenance concept from a certain maintenance policy. Gits (1992) identifies three basic maintenance policies on which a maintenance concept can be based:

- *Failure-based maintenance;* maintenance activities are initiated in the event of equipment failure.
- *Use-based maintenance;* maintenance activities are initiated on expiration of a specific period of equipment use.
- *Condition-based maintenance;* maintenance activities are initiated on attainment of a specific equipment condition.

In the service delivery system the service products from the service portfolio are delivered. The input for the service delivery is *customer equipment that performs unsatisfactory*, whereas the output is *equipment with enhanced performance.* In case of input, the customer request is administered, using *Customer Relationship Management (CRM) data*, and a service activity is planned in the *service activity schedule.* Also, the service activity schedule is filled with use-based maintenance tasks in case the maintenance concept is based on use-based maintenance. Then, the service activity is executed. Several resources might be used during service activity execution; *operational equipment data*, *spare parts*, *technical documentation* and the *history of service activities*. Also, on completion of the service activity, CRM data is used for invoicing, and the service activity is evaluated and reported, resulting in an updated service activity history.
The equipment development system is not only responsible for the development of equipment but also for maintenance of the accompanying documentation. Furthermore, results from the service activities, as described in the service activity history, are analyzed resulting in improved equipment and documentation.

The operations management system is responsible for managing the service delivery system. It must also constantly monitor the *delivery system operational performance*, to be able to track performance of the system relative to the targets set in the operating strategy.

Finally, logistics management is responsible for management of spare parts inventory, including procurement of the parts.

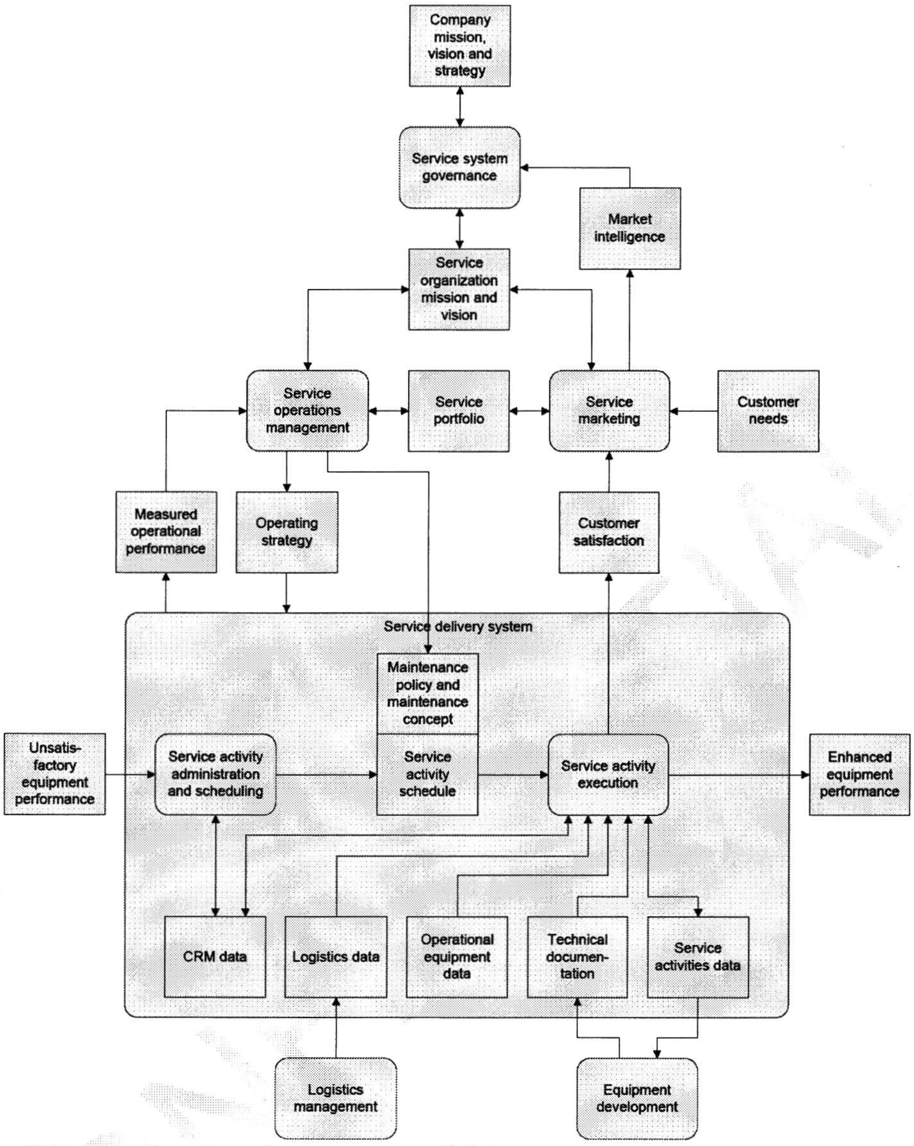

Figure VII.1 Work system Operations Model for a maintenance service system

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Appendix VIII Service system actors

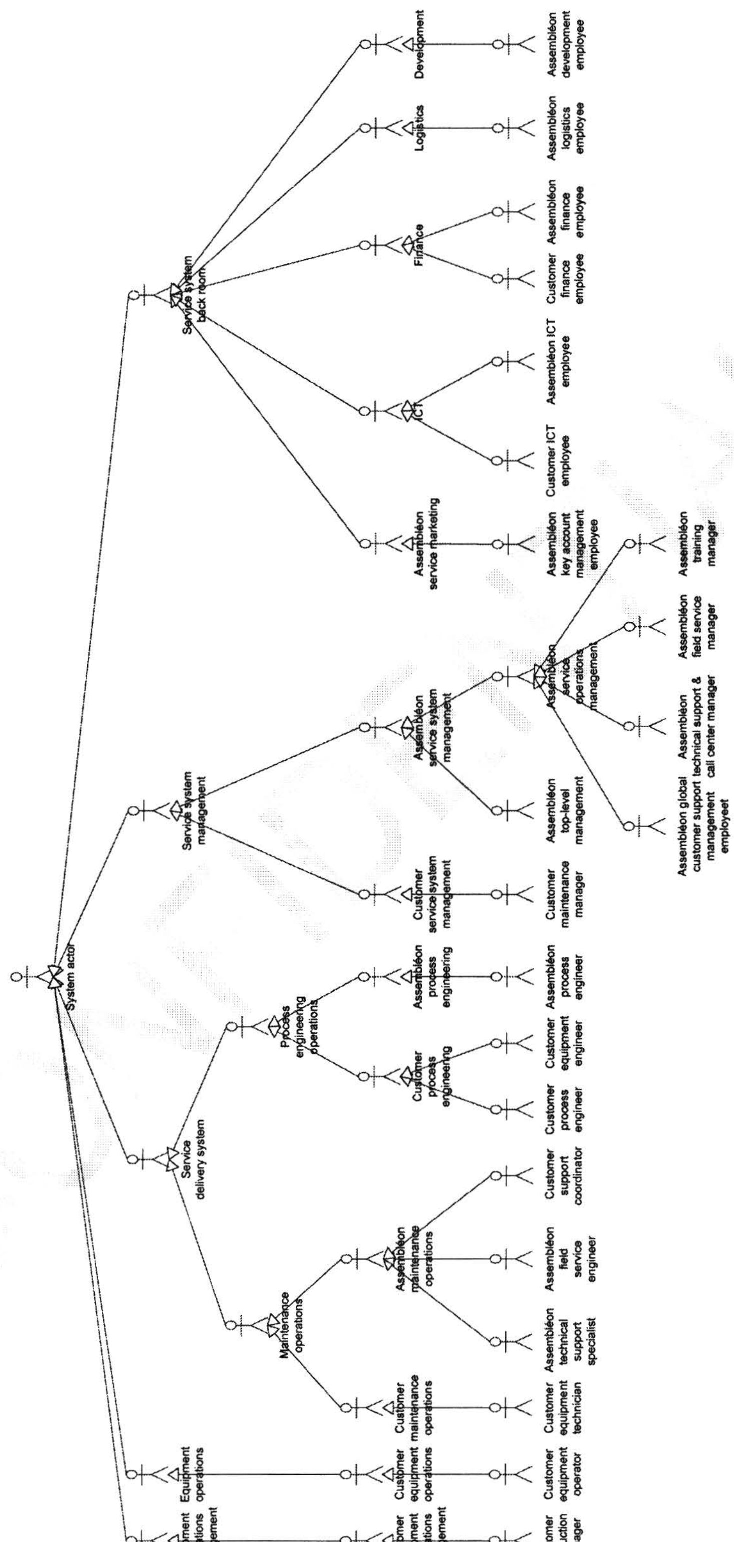


Figure VIII.1 Service system actors model

Appendix IX Business information model

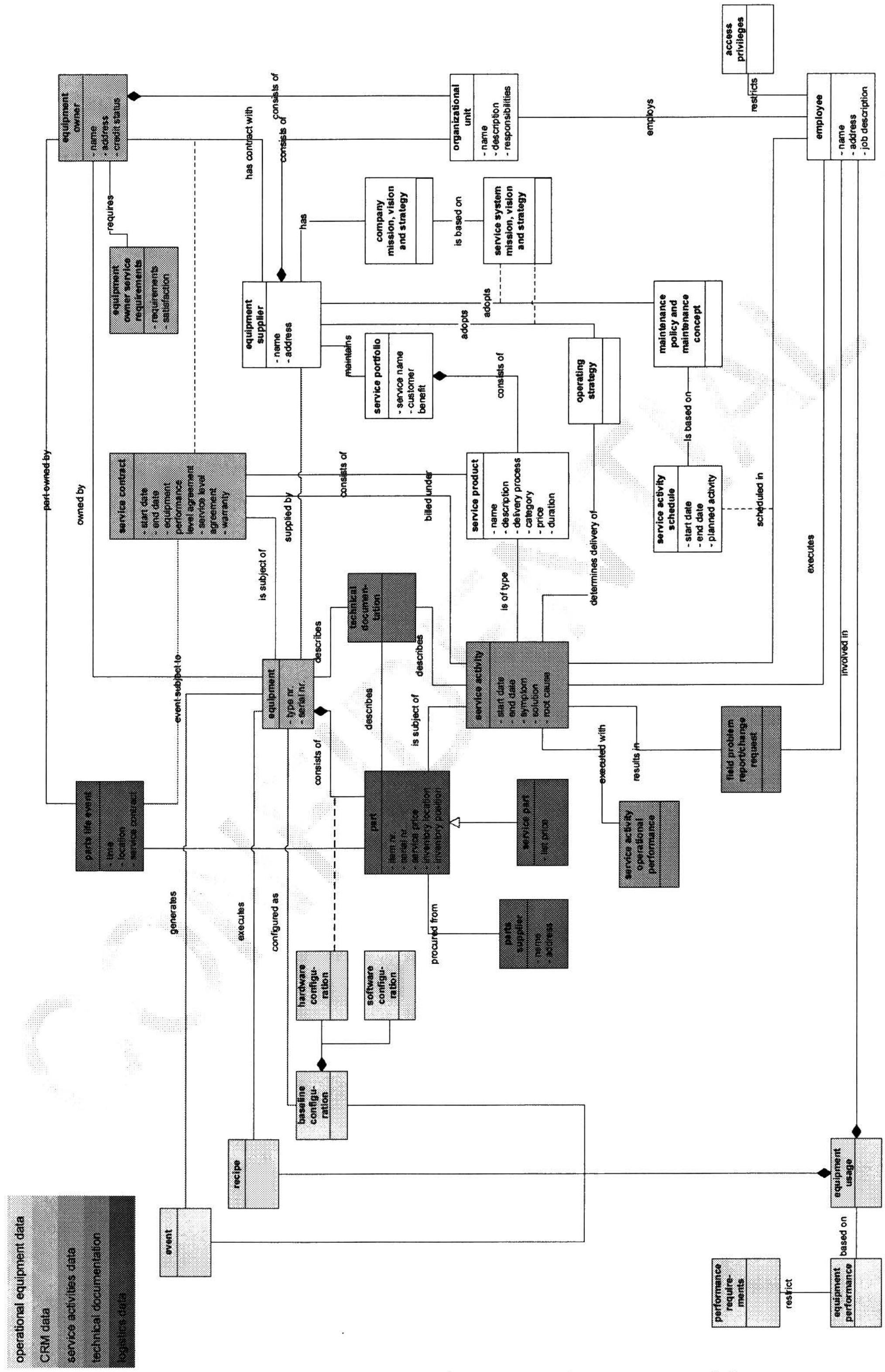


Figure IX.1 Service system business information model

Appendix X Service system product portfolio

Table X.1 Assembléon service system product portfolio

Service category	Name of service	Service description
Logistics	Spare parts and consumables	Assembléon provides customers with spare parts and consumables after the equipment has been installed on-site.
Training	Training	Assembléon provides customers with various training courses, such as operator, user and maintenance personnel training.
Performance improvement	Machine, process and/or production audits	Assembléon personnel carries out audits, indicating what actions are needed for machine output optimization.
Installation	New equipment installations	After equipment has been ordered by a customer, it is installed and tested at the customer's site by Assembléon personnel.
	Ramp-up support	Ramp-up support is delivered after equipment has been installed Assembléon helps customers reach their optimal output levels as quickly as possible.
Technical support and maintenance	Accuracy certification	Assembléon personnel measure any deviations from the required degree of equipment efficiency and adjust the equipment accordingly.
	Preventive maintenance	Assembléon personnel carry out preventive maintenance as specified in a service contract. Preventive maintenance includes inspection, cleaning and lubrication of equipment.
	Reactive maintenance (break-fix services)	Assembléon provides customers with reactive maintenance services, in case equipment has broken down.
	General technical support	Assembléon provides customers with access to general technical support.
	Software support	Assembléon offers customers software tools to run the equipment. Software product support is provided by the Customer Support department.
	Technical Service Information updates	Technical Service Information updates are used to inform customers on product modifications and upgrades.

Appendix XI Data processing activities

The reference e-maintenance component model (Figure XI.1) is based upon the six data processing functions that Alter (2003) describes; capturing (1), transmitting (2, 6), storing (4, 8), retrieving (3, 7), manipulating (5) and displaying (9) of data.

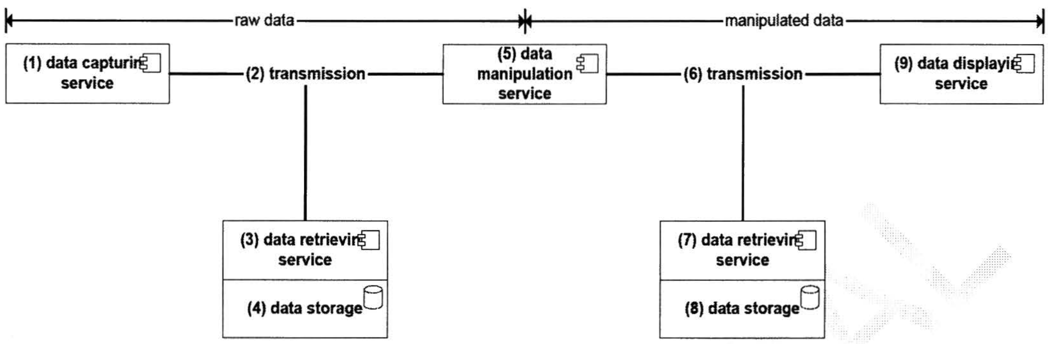


Figure XI.1 E-maintenance data processing functions

Appendix XII Current e-maintenance components model

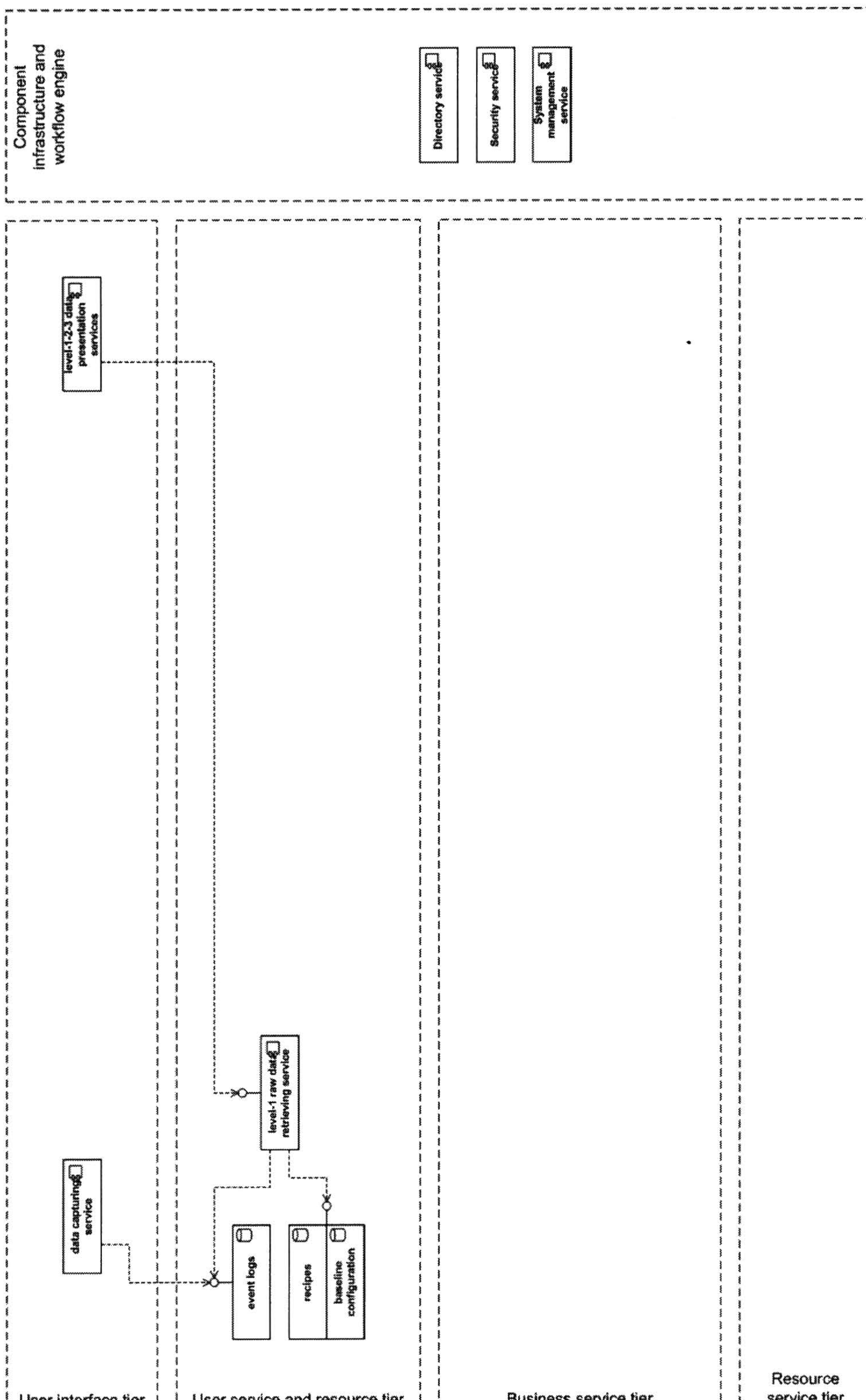


Figure XII.1 Current e-maintenance component structure

Appendix XIII Current e-maintenance components deployment

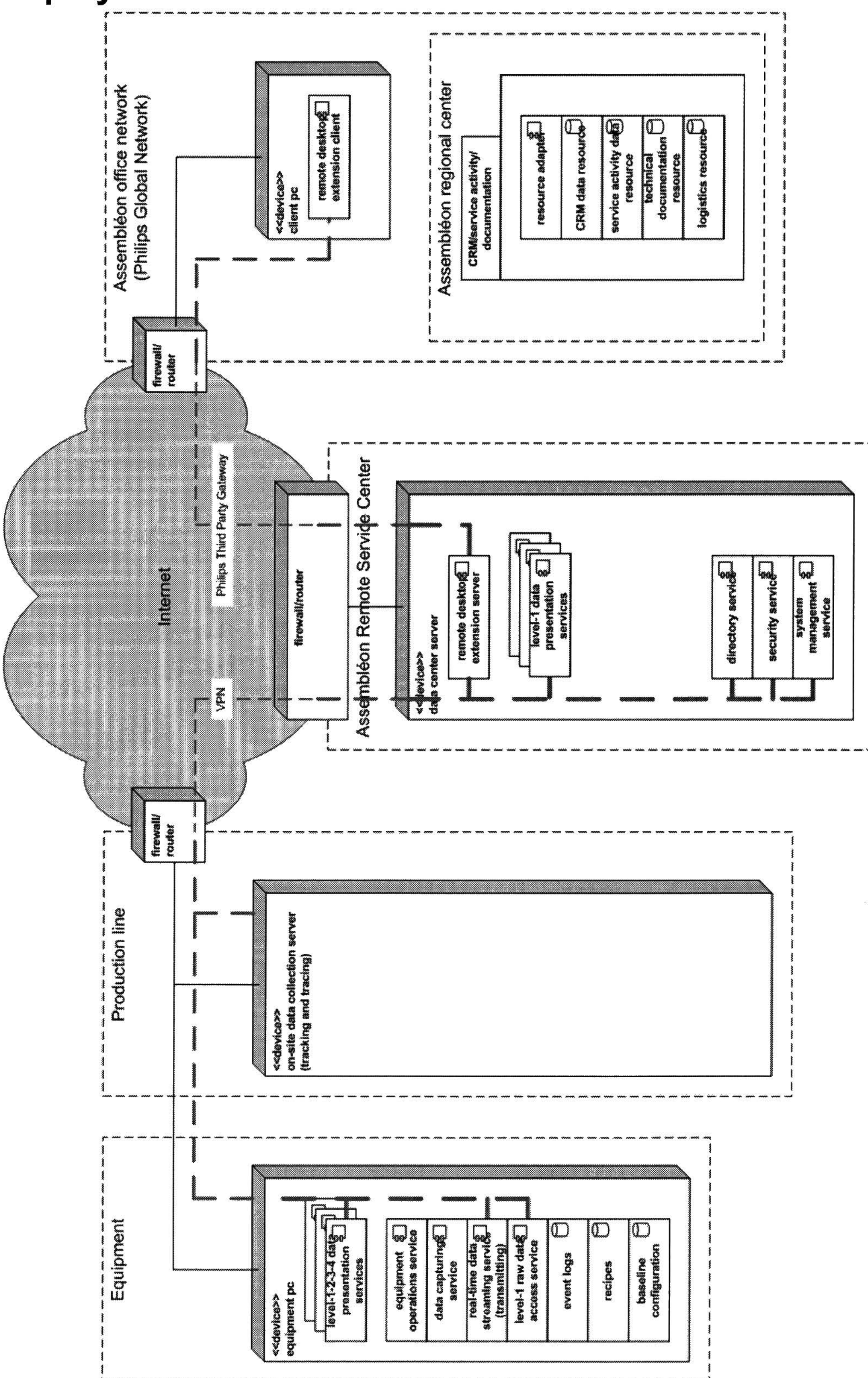


Figure XIII.1 Current e-maintenance component deployment structure

Appendix XIV Semi-structured interview

From: http://www.fao.org/docrep/x5307e/x5307e08.htm

Tool description

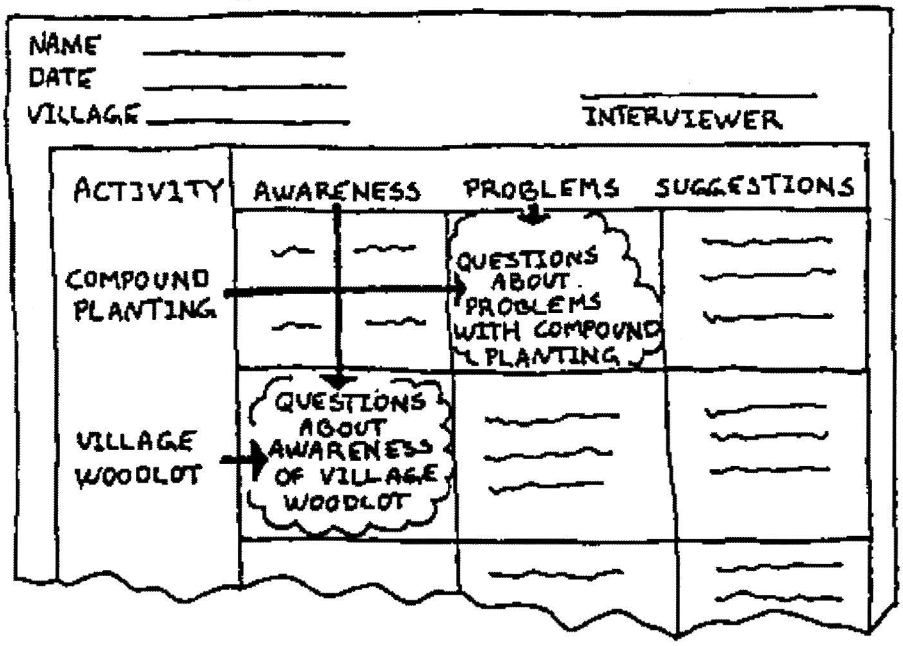
Semi-structured interviews are conducted with a fairly open framework which allow for focused, conversational, two-way communication. They can be used both to give and receive information.

Unlike the questionnaire framework, where detailed questions are formulating ahead of time, semi structured interviewing starts with more general questions or topics. Relevant topics (such as cookstoves) are initially identified and the possible relationship between these topics and the issues such as availability, expense, effectiveness become the basis for more specific questions which do not need to be prepared in advance.

Not all questions are designed and phrased ahead of time. The majority of questions are created during the interview, allowing both the interviewer and the person being interviewed the flexibility to probe for details or discuss issues.

Semi-structured interviewing is guided only in the sense that some form of interview guide, such as the matrix described below is prepared beforehand, and provides a framework for the interview.

Tool description



Purpose of the tool

• Obtain specific quantitative and qualitative information from a sample of the population
• Obtain general information relevant to specific issues, (ie: to probe for what is not known)
• Gain a range of insights on specific issues

Major benefits

Less intrusive to those being interviewed as the semi-structured interview encourages two-way communication. Those being interviewed can ask questions of the interviewer. In this way it can also function as an extension tool.

Confirms what is already known but also provides the opportunity for learning. Often the information obtained from semi-structured interviews will provide not just answers, but the reasons for the answers.

When individuals are interviewed they may more easily discuss sensitive issues.

Help field staff become acquainted with community members. Outsiders may be better at interviewing because they are perceived as more objective.

Using both individual and group interviews can optimize the strengths of both.

Using the tool

1. Design (facilitator and/or interview team) an interview framework such as the matrix example. Include topics or questions for discussion.

2. Establish the sample size and method of sampling.

3. Interviewers can conduct a number of practice interviews with each other and/or with a few community members, to become familiar with the questions, and get feedback on their two-way communication skills.

4. Record only brief notes during the interview. Immediately following the interview elaborate upon the notes.

5. Analyze the information at the end of each day of interviewing. This can be done with the interview team or group.

6. Discuss the overall results of the analysis with community members so that they can challenge the perceptions of the interview team. This can make the process even more participatory.

Precautions in Using the tool

A lot of extra information may surface during interviews. Team meetings can help identify similarities in responses.

Assure that, in a personal interview, the person being interviewed understands and trusts that the responses will be confidential.

It may take some practice for the interviewer to find the balance between open-ended and focused interviewing.

In a semi-structured group interview people may interrupt one another or "help one another out," or not take turns. They may get off the topic completely.

Interviewers need some skills. The most common problem with interviewers is asking leading questions. Other problems are: failure to listen closely; repeating questions that have already been asked; failure to probe when necessary; failure to judge the answers; and asking vague or insensitive questions.

Appendix XV First contact solution rate of machine down calls

RCA - EMTDOWN Totals, With "Phone Fix" Percentages (via Technical Support) By Month

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
# of EMTDOWN Calls - 2005	22	24	21	26	24	18	25	22	15	42	17	22	23
# of EMTDOWN Calls Fixed by Phone - 2005	16	17	17	22	20	15	20	19	12	33	14	15	18
# of EMTDOWN Calls Fixed by CSE's - 2005	6	7	4	4	4	3	5	3	3	9	3	7	5
Phone Fix Percentage - 2005	73%	71%	81%	85%	83%	83%	80%	86%	80%	79%	82%	68%	79%

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Avg.
# of EMTDOWN Calls - 2004	16	14	57	21	16	24	22	18	21	30	23	24	24
# of EMTDOWN Calls Fixed by Phone - 2004	12	10	43	14	10	17	16	15	16	21	18	19	18
# of EMTDOWN Calls Fixed by CSE's - 2004	4	4	14	7	6	7	6	3	5	9	5	5	6
Phone Fix Percentage - 2004	75%	71%	75%	67%	63%	71%	73%	83%	76%	70%	78%	79%	73%

Total of calls w/percentage logged as "EMTDOWN," by year

Year	# Calls	EMTDOWN	
2005	5456	220	4.03%
2004	4637	212	4.57%

Figure XV.1 First contact solution rate of machine down calls

Appendix XVI Hierarchical system of maintenance performance indicators

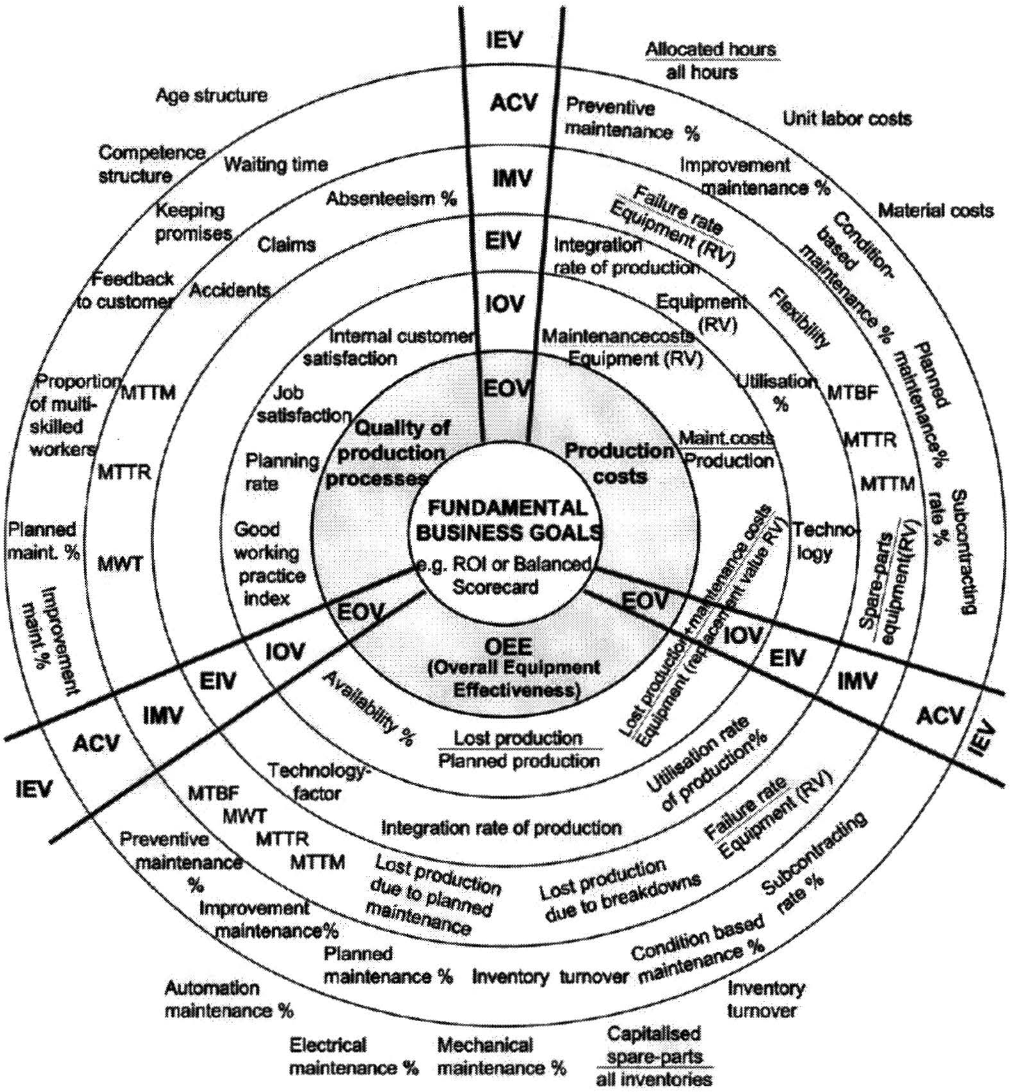


Figure XVI.1 Hierarchical system of key figures for industrial maintenance

Komonen (2000) presents a hierarchical system of performance indicators (Figure XVI.1) that can be used to measure and indicate performance of industrial maintenance systems. The identified performance indicators can be classified in a hierarchical manner:

- *External objective variables (EOV)* are business-oriented key figures such as return-on-investments, overall equipment effectiveness and equipment life cycle costs.
- *Internal objective variables (IOV)* are metrics for the effectiveness of maintenance operations, such as equipment availability, the sum of lost production and maintenance costs, and maintenance costs as a % of estimated plant replacement value (RV).

- *Exogeneous independent variables (EOV)* are indicators that help higher-level management to interpret variables and to evaluate the current state of affairs.
- *Intermediate internal objective variables (IMV)* are performance indicators that provide intermediate information on the main objective.
- *Action variables of the maintenance function (ACV)* are tools for maintenance managers that support the attainment of certain objectives. Examples are preventive maintenance, outsourcing and operator maintenance.
- *Internal explanatory variables (IEV)* give additional information, for example about the cost and organization structure.

Appendix XVII Use cases to-be situation

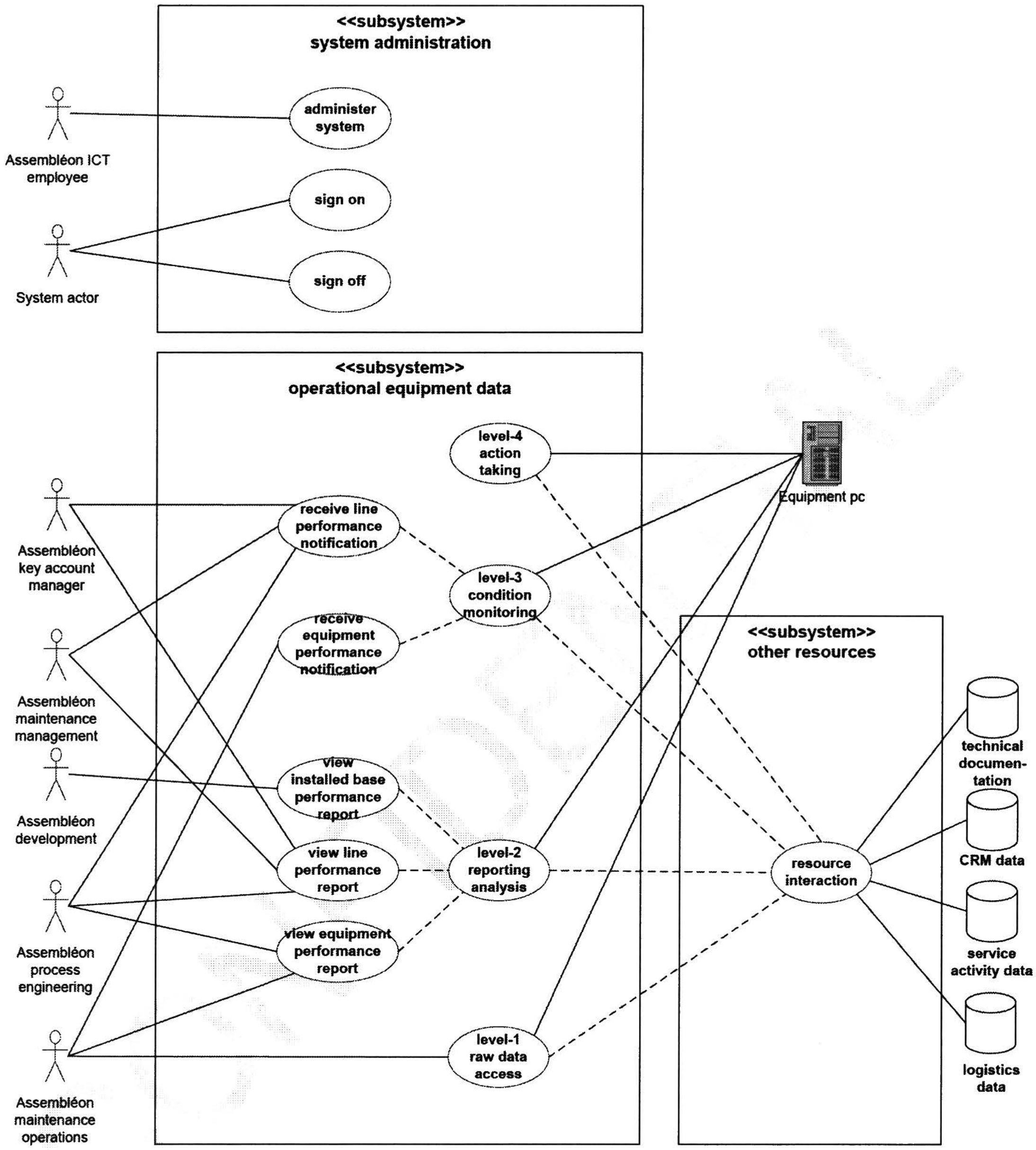


Figure XVII.1 Use cases to-be situation

Appendix XVIII Requirements specification

Table XVIII.1 Determination of specific requirements for desired functions

Model from repository	Functional questions
1) Actors models	a) What Assembléon and customer actors require the desired e-maintenance function?
	b) What level of automation is required?
2) Business information model	a) What business information is required?
	b) What classes and attributes are required?
3) Generic data processing model	a) For the required business information attributes to be available, must the data capturing service be extended?
	b) Must raw data be stored, before it is manipulated? (real-time/batch analysis)
	c) What data manipulation is required?
	d) Must data manipulation data be stored? (real-time/batch presentation)
	e) What services are required for data presentation? Is automatic action required?
4) Component model	a) What software components have to be added to the current architecture, based on the requirements following from 3)?
5) Deployment model	a) What level of data aggregation is required?
	b) On what hardware nodes are the added components deployed?